Facility Location for a Closed-Loop Distribution Network: a Hybrid Approach

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Purpose - The aim of the study is to find a sustainable facility location solution for a closed loop distribution network in the uncertain environment created by of high levels of product returns from online retailing coupled with growing pressure to reduce carbon emissions.

Design/methodology/approach - A case study approach attempts to optimize the distribution centre location decision for single and double hub scenarios. A hybrid approach combining centre of gravity and mixed integer programming is established for the un-capacitated multiple allocation facility location problem. Empirical data from a major national UK retail distributor network is used to validate the model.

Findings - The paper develops a contemporary model that can take into account multiple factors (e.g. operational and transportation costs and supply chain risks) while improving performance on environmental sustainability.

Practical implications - Based on varying product return rates, Supply Chain Managers can decide whether to choose a single or a double hub solution to meet their needs. The study recommends a two hub facility location approach to mitigate emergent supply chain risks and disruptions.

Originality/value - A two-stage hybrid approach outlines a unique technique to generate candidate locations under 21st century conditions for new distribution centers.

Keywords: Facility Location Problem, Mathematical Modelling, Centre of Gravity, Reverse Logistics, Product Returns, Closed-loop Supply Chains, Online retail.

1. Introduction

The increased cost of distribution and reverse logistics activities are making the location decision of where to site storage and service facilities a strategic decision (Pishvaee et al., 2010). Supply chain management must answer the Facility Location Problem (FLP) in order to serve customers' requirements efficiently with reduced delivery cost and time (Harris et al., 2014). Location decisions are determined by several factors such as geographical restrictions, financial constraints and capacity issues related to storage and distribution. Increasingly in online retail, organizations must offer fast and cost effective forward and return services; and therefore product returns are emerging as an additional factor in the location decision. Most Distribution Centres (DCs) or warehouses are located at a convenient location with proximity to a production plant or transportation infrastructure (Nilsson and Smirnov, 2016). Due to constant changes in supply chain network design, facility location decisions need to be reviewed over time (Melo et al., 2009). It has been observed that facilities are often not re-located even when the scale and scope of the operations has grown exponentially (weterings, 2014).

With the new focus on the costs of distribution and the implications of reverse logistics, the main concern for Supply Chain (SC) Managers is to optimise the locations of their service and storage facilities. The FLP decision is locating a set of facilities in order to achieve the lowest costs and simultaneously satisfy customer demand under certain constraints (Hekmatfar and Pilshvaee, 2009). It is possible to reduce the transportation and delivery cost from the warehouse to customer simply by improving the distribution network. This can be achieved by adjusting the transportation modes and scheduling techniques. However, increasing government regulations to reduce carbon emission (Kotzab et al., 2011; Singh et al, 2015) are also forcing organizations to re-address the issue of FLP. This new pressure for carbon emission reduction means that traditional optimization models that only take limited factors or unidirectional flow into consideration are less salient. This increased complexity of managing forward and reverse logistics demands the integration of sustainability considerations in Closed Loop Supply Chain (CLSC) networks. There is extant work on the forward FLP decision (e.g. Amin and Zhang, 2013) and on understanding the requirements for sustainable facility location (Chen et al., 2010) using multiple case studies. However this study addresses a current gap by focusing on reverse flow considerations and therefore will make a contribution to the area of decision making on sustainable facility location.

Extant literature provides several definitions of sustainability (e.g. Ahi and Searcy, 2013) and for a closed loop supply chain (e.g. Souza, 2013). We define a sustainable facility location as an environmentally conscious, cost effective location decision focussed on providing efficient customer service. The proposed definition compliments the *triple bottom line* proposed by Carter and Rogers (2008) by taking into account the environmental, social and economic dimensions of sustainability. Therefore in this study a sustainable facility location takes into account environmental awareness, cost effectiveness and service level issues.

E-commerce is the fastest growing retail market in the Europe and North America with online sales growth of 20% annually (Centre for Retail Research, 2016). The retail sector has been observed to react dynamically in response to changes in the economy (Larsson, 2014). The explosive growth of online retailing and E-commerce has led to a new problem dimension in FLP decision making; the sheer volume of customer returns. U.K. retail analysts estimate that online returns range from 25% to 50% depending on the commodity (Information week, 2013). Today's customer centric return policies are driving this return rate and fuelling demand for enhanced reverse logistics activities (Jack et al., 2010; Alumur et al., 2012). A well-structured CLSC is necessary to cope with the collection and recovery of uncertain product returns generated through online transactions. Hence the aim of the study is to develop a sustainable facility location for a closed loop supply chain in an uncertain E-commerce environment.

The objectives of the research are two-fold. First, to establish whether increasing product returns made through E-commerce significantly influence the FLP decision. And, if the answer to that question is positive, to develop a robust FLP model to accommodate this uncertainty in forward and reverse logistics flow due to increased E-commerce activity. The research attempts to optimize the facility location decision using a hybrid method approach by combining a centre of gravity approach with mixed integer linear programming modelling. The hybrid model represents a relatively novel approach to solving the FLP for increasing product returns compounded by regulatory demand for minimization of CO_2 emission.

The remainder of this paper is structured as follows. In the next section supporting literature on the facility location problem and reverse logistics is reviewed. Section 3 outlines the research design and presents the data collection and analysis techniques. Section 4 describes the problem statement and the formulation of the model using a hybrid approach to solve the

facility location problem. Following a descriptive analysis of the simulation results in section 5, findings are drawn out in section 6. The key insights, managerial implications and possible avenues for the future research are discussed in the final section.

2. The Facility Location Problem

The structure of a physical distribution network is aligned with the flow of material between different locations with intermediate switching points being used for the most cost and time efficient transportation (Çetiner et al., 2010). Such a transportation network is referred as a *hub and spoke system*. In such a system, the nodes, i.e. the points of origin and destination are connected via one central or multiple regional hubs, called switching points. Spokes represent the direct links between hubs and nodes. Hubs are built to provide switching, transhipment and sorting operations in order to smooth the product flow and gain benefit from economies of scale (Sheffi, 2013). A hub and spoke system significantly reduces the number of transportation linkages by consolidating the collection process, line haul journey and final delivery to customers journey (Yaman, 2011). Following the emergence of 'Third Party Logistics Providers' (3PLs'), operations research is re-addressing the hub location decisions in supply chain networks (Arabzad et al., 2015). The recent trend of building collaborations and alliances through SC strategies (e.g. VMI, Agility, etc.) makes the strategic location of hubs a crucial decision in the firm's long term planning. Important decision factors such as operational cost, demand, distance and availability (or feasibility) of locations influence the efficiency and effectiveness of the whole supply chain network (Creazza et al., 2012; Hadas and Laor, 2013).

Aspects and dimensions of sustainability are increasingly important for FLP decisions (Chen et al., 2014) yet research that combines FLP and sustainability perspective is still rare. Recent research on reverse logistics and waste management in FLP by Dekker et al. (2012) and Van der Wiel et al. (2012) reflects the growing interest in the field. The Hub Location Problem (HLP) is an extension to the conventional FLP (Farahani et al., 2013); with the assumption that there is no direct shipment between spoke nodes (Alumur et al., 2012). The location routing problem is another approach, which integrates FLP and vehicle routing with the aid of modern optimization techniques (Prodhon and Prins, 2014).

Location decision making plays a crucial role in the retail logistics sector; demonstrated by several studies that have achieved seminal status (e.g. Clark et al., 1997; Hernandez and Bennison, 2000). Location decision approaches have stressed the adoption of objective

assessment techniques (Reynolds and Wood, 2010); and several quantitative research methods can solve complex facility location problems. Multiple factors such as market requirements, competition, power, economies of scale, international regulations, government incentives, taxes and trade barriers have been considered. Farahani et al. (2012) conducted a comprehensive review of facility location models, solutions and applications. Facility locations are typically classified into static and dynamic problems depending on space and time issues respectively. An et al. (2014) proposes a two-stage robust optimization model for a facility location exposed to disruptions. Multi-objective optimization models can be used for making a facility location sustainable by combining economic, service and environmental considerations (Xifeng et al., 2013). Also extant literature reports on the multi-commodity, multi-plant, un-capacitated facility location problem using Mixed Integer Linear Programming (MILP), heuristics, and genetic algorithm. MILP is found to be the preferred research method for FLP decisions within CLSC network design (Devika et al., 2014). Gelareh and Nickel (2011) generated an advanced MILP simulation approach to solve large databases. Cardoso et al. (2013) use a MILP optimization approach for a CLSC network under uncertain demand. Similarly, Taghipourian et al. (2012) presents a fuzzy integer liner programming approach in order to solve a dynamic virtual hub location problem. More recently, Gelareh et al. (2015) optimized a multi-period hub location problem for leased facilities using a meta-heuristic solution algorithm. All of these approaches expand the domain of FLP decision making.

3. Reverse Logistics and Product Returns

In the academic literature Reverse Logistics (RL) is also referred to as reversed logistics, return logistics, retro logistics and reverse distribution. Reuse, repair, recycle, remanufacture, refurbish and cannibalizations are different kinds of reverse logistics activities (Rogers et al., 2012). Product returns can be divided in three categories: manufacturing returns, distribution returns and customer returns (Souza, 2013). CLSCs incorporate RL activities to reduce resource consumption and waste (Kim et al., 2014). Economic features, government regulations and customer pressure are three influences on RL (Melo et al., 2009). Several developed nations have put in place strict regulations and policies on products and services that impact society and the environment (Xu et al., 2013; Gunasekaran and Spalanzani, 2012). Although government regulations and policies differ across nations (Mollenkopf et al., 2010); all SC networks face pressure from ever rising environmental standards. Where environmental standards are most rigorously applied, government legislation forces a manufacturer to take on

an extended responsibility for any social and environmental issues associated with their product. The 'Extended producer responsibility' concept has evolved out of government interventions, RL, sustainability and interaction between manufacturers (Sheu and Gao, 2014; Piers et al., 2015). Customer's environmental consciousness is becoming another driving force for RL (Kumar and Putnam, 2008). In addition to government legislation, growing consumer awareness of high levels of carbon emissions in the atmosphere has encouraged firms to publically appear to comply with the government imposed legislations and to be associated with 'green' practices and products (Guarnieri et al., 2015). The size of the firm also dictates the implementation of reverse flow operations (Min and Galle, 2001). Large-sized organizations have a significantly higher rate of returns than small or medium-sized organizations. Where a business is virtual, RL is critical, as online businesses encounter higher product returns than traditional brick-and-mortar businesses (Ramanathan, 2011). It is evident that a robust CLSC network is necessary for handling such increased product returns.

Poor quality of products, liberal return policies and the ease of online transactions are some of the common grounds for product returns (Souza, 2012). A good customer experience with returning a product improves customer perception of the seller and the likelihood of re-using that seller (Prahinski and Kocabasoglu, 2006). Walsh et. al (2016) found a strong relationship between an online retailer's reputation and product returns. They observed a 14.6% return rate from respondents shopping at eight online retailers. Product returns cost US firms up to $100bn annually in RL activities (Blanchard, 2007). In a contemporary survey conducted by Petersen and Kumar (2015), 70% of customers returned their products for apparel retail and 75% for general merchandise retailing. Return rates could be as high as 50% in the retail sector, whilst customers may respond positively to firms that have good returns processes, this is still a trade-off between customer satisfaction and profitability (Martinez, 2009). Such reports on online returns make RL and facility location related decisions of strategic importance.

4. Research Methodology

The research adopts a quantitative approach to the facility location decision for a closed-loop distribution network. Table I outlines a general comparison of different optimization models that can be used to solve the FLP. Each method has specific characteristics associated with it that aid the choice of an appropriate methodology, based on objectives and constraints. We use a mixed infinite-set approach to calculate a series of alternative locations. Linear programming

is applied for optimizing the result in terms of costs by using the *Centre of Gravity* approach. Centre of Gravity (COG) is an infinite set approach that uses the weighted mean centre function to minimise transportation costs in FLP.

Table I. Comparison of common optimisation methods

Method	*Characteristics*
Linear Programming	Limited resources; single objective
Analytical Hierarchy Process	Combines qualitative and quantitative methods; used to process hierarchy factors
Fuzzy Clustering Method	Suitable for vague and approximate situations
P-Median Problem	Limited to one facility location problem; takes the average distance
Centre of gravity	Infinite set approach, simple and expansible

Past research has considered dynamic supply and customer demand volumes. Several quantitative models have been studied within the context of an RL network (e.g. Fleischmann et al., 2001; Salema et al., 2007). However, there are limited FLP optimization studies that consider customer demand flows in both forward and backward directions. As stated earlier, the objectives of the research are to first find whether increasing product returns significantly influence the strategic decision of FLP. Then, building on a positive answer to the first question, to develop a robust model to accommodate forward and reverse flow uncertainty in the CLSC network. In the proposed model, two different kinds of optimization methods are integrated for solving the facility location problem. COG is implemented to find out the possible options for the distribution centre locations, producing an input to the second stage. Mixed integer linear programming will perform the final selection addressing single and group option scenarios. The COG and MILP approaches blend well together, because geometrically COG is a linear programming problem (Dantzig and Thapa, 2006). First the assumptions of the model are described and explained for clarity. Later, the COG model is modified to suit reverse flow considerations. A MILP model is developed and tested following a systematic approach to propose an optimal facility location.

4.1. Data collection process

Empirical and secondary data was collected from Argos, a large nationwide retailer and distributor of UK consumer goods. Shipment data (shipment volume, points of origin and

destinations) was collected from an Argos distribution centre to model the problem. The secondary data collected included volume in terms of weight and the location of the different warehouses. However, due to commercial sensitivity, certain data could not be made available to the researchers, and so for example, the unit costs for infrastructure, administrative and transport costs for each distribution centre are assumed to be average for modelling purposes.

4.2. Data analysis process

The hybrid approach adopted in the research methodology is discussed in this section. A simulation model was constructed using the software Xcode, which is a programming platform under the environment of a MacOS X operating system. The modelling code was programmed using C++ as the main programming language. The simulation for different scenarios was tested individually. Convergence criteria for each scenario was met when the simulation run was successful. Due to the use of a commercial simulation platform, it is difficult to identify the exact number of runs performed before reaching the convergence criteria; however, a failed test indicates reasons for the failure.

The COG model resulted in five possible facility locations. The MILP model then determined the optimal solution for two conditions, including both one hub and two hub locations for the DC. The multi-objective function for the MILP model conducts sensitivity analysis by simulating the optimal locations with different return ratios. In order to simulate different scenarios, the stochastic return rates (i.e. the reverse material flows) were randomly generated following a normal distribution. The return rates generated are later presented in Table VIII and fed into the simulation platform.

4.3. Base data description

This section presents the secondary data used for the analysis. The company needs to centralize its inventory and optimize its distribution structure for its supply chain network taking into account both forward and reverse logistics. The new network structure must deal with both distributing products to all customers (demand points A, B and C) and collecting returning goods using the collection center back to the manufacturers (supply points D, E and F). Table II presents the consolidated data that describes the problem, including a total of six supply and demand points and the associated shipment volumes per year. Multiple supply and demand points (A, B, C, D, E and F) in the current structure of the case company provides a realistic scenario for optimizing the location based on their distribution network in the UK.

Table II. Data coordinates of supply and demand points

Supply and Demand Point	Coordinate		Average volume per year (,000)
	Longitude	Latitude	
Barton (A)	1.21W	52.88N	39,000
Mossend (B)	4.00W	55.81N	12,000
Heywood (C)	2.22W	53.59N	21,000
Castleford (D)	1.36W	53.72N	17,000
Corby (E)	0.70W	52.49N	39,000
Bridgewater (F)	3.00W	51.13N	17,000

The unit costs for handling operations in the DC for warehousing and collection purposes, as well as the transportation costs for forward and reverse flows between each of the supply and demand points are presented in Table III. All the costs are individually calculated based on the average cost structure between the existing location sites of Argos within the UK.

Table III. Unit costs for facility operations

| Facility	Average unit costs
Warehouse	15
Collection Center	10
Transportation	7

5. Problem statement and model formulation

We develop a single objective function, focusing on minimizing costs for both forward and reverse material flows in a closed loop supply chain. This section proposes the framework and the settings required in order to develop and formulate the hybrid model. DC activities are becoming increasingly complex taking on a broad range of additional activities such as after-sales replacement, returns, and other handling activities. DCs are also referred to as Collection Centers (CCs), when their purpose is to handle and process returned goods. Based on the above understanding, we distinguish between the following two types of material flows in our model:

1. Forward Flow: Manufacturer → DC → Retailer
2. Reverse Flow: Retailer → Collection center (CC) → Manufacturer

The proposed model is based on a three level supply chain as illustrated in Figure 1. The distribution center incorporates two different roles namely warehousing and collection center.

Goods in the forward material flows go through the warehouse, while reverse flow goods pass through the collection center in the DC.
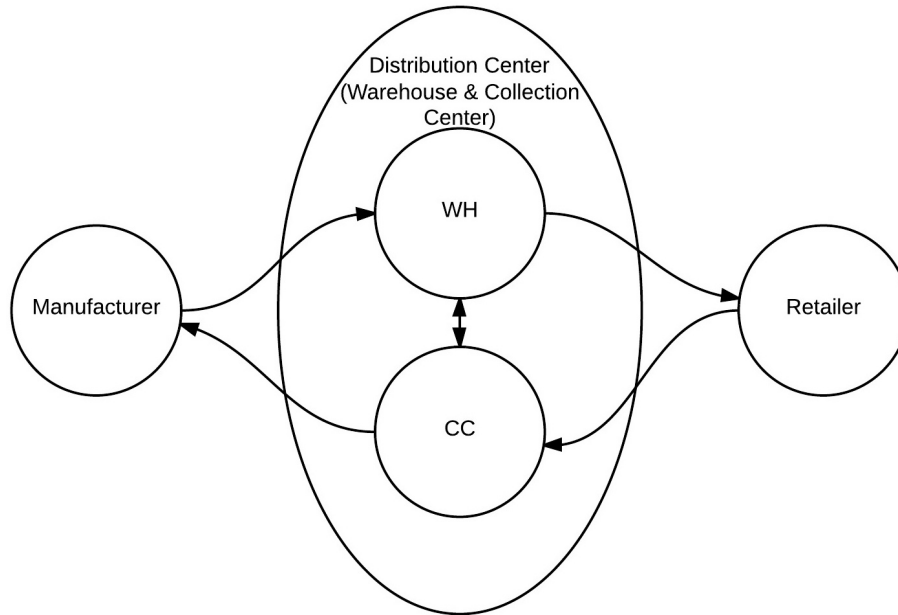
Figure 1. Three level supply chain material flow

Figure 1 illustrates a CLSC with the simplification that the end customer forms a part of the retailer level. A typical CLSC should include forward and reverse materials flow from raw material suppliers to final customers and vice versa. However, some CLSCs incorporate extra functions such as repair and maintenance (Hazen et al., 2012). The simplified model does not consider such extra functions and is expected to provide appropriate insights without increasing the complexity of the FLP problem. As we distinguish between forward and reverse material flow, we also distinguish between handling costs in the distribution center for warehousing (forward flow) and collection (reverse flow).

5.1. Declaration of variables and parameters

In order to formulate the model, we consider the following notation as outlined in the Table IV. Including the use of the previous notations, the mathematical formulation for both the COG and MILP model is described in the following sub-sections.

Table IV. Variables for the model

Variable	Description
i	Serial number of demand or supply points
j	Serial number of DC candidates
n	Total volume of demand and supply points
m	Total volume of DC candidates
X_j	Longitude of DC candidate j
Y_j	Latitude of DC candidate j
X_i	Longitude of supply point i
Y_i	Latitude of supply point i
wf_i	Total weight of forward flow
wb_i	Total weight of backward flow
λ_{ij}	Stochastic variable as a proportion of forward flow
V_{ij}^f	Total volume of forward flow between i and j
V_{ij}^r	Total volume of reverse flow between i and j
C^f	Unit costs for handling in DC for forward material flow
C^r	Unit costs for handling in DC for reverse material flow
C^t	Transport costs per unit per kilometre
d_{ij}	Distance between points i and j
α	Parameter to convert calculated distance into real distance on road
Z_i	Equals to 1 if DC is considered, otherwise it equals to 0
S_{ij}	Equals to 1 if demand at node I is served by j, otherwise it equals to 0

5.2. Centre of gravity model

The COG method is used for the FLP decisions to find the weighted centres for an infinite number of demand points. It is expected that transportation costs would be minimised, if the facility were located at the weighted centre of those points. The original function of COG is outlined in equation (1) and (2).

$$x = \sum x_j w_j / \sum w_j \tag{1}$$

$$y = \sum y_j w_j / \sum w_j \tag{2}$$

In the above functions, x and y are the coordinates of the potential facility. w_j is the weight of the demand point j. This method only takes forward material flows into consideration. Therefore, a variable λ_{ij} which is set as a random proportion of forward flows is inserted in the original COG function to capture reverse flow. The modified function is shown in the following equations (3) and (4).

$$X_j = \frac{\sum_{i=1}^{n} x_i(w_i + w_i\lambda_{ij})}{\sum_{i=1}^{n}(w_i + w_i\lambda_{ij})} \tag{3}$$

$$Y_j = \frac{\sum_{i=1}^{n} y_i(w_i + w_i\lambda_{ij})}{\sum_{i=1}^{n}(w_i + w_i\lambda_{ij})} \tag{4}$$

Weight $w_{ij}\lambda_{ij}$ represents the reverse material flow between distribution centre j and demand point i. Moreover, λ_{ij} is a stochastic variable as mentioned in the variables notation, which means that each return rate between two points is randomly manipulated, although realistically the return rate follows the normal distribution with a mean of 30 % product returns (see section 6.2. for the results of the randomly generated return rates).

5.3. Mixed integer programming model

MILP is used as a filtering algorithm to identify the potential candidates for a distribution centre in a CLSC. Our modified COG model simulates five possible facility locations that serve as the input for the MILP model. The objective is to find the optimized location for a distribution center by minimizing all associated costs and distances for transportation and material handling. Equation 13 presents the final MILP model for solving the minimum cost objective. There are two major types of costs in our model; operational (handling) costs and transportation costs, which are defined as follows.

- Operational costs:

$$C_{facility} = \sum_{j=1}^{m}\sum_{i=1}^{n} V_{ij}^{f} C^{f} + V_{ij}^{r} C^{r} \tag{5}$$

- Transportation costs:

$$C_{transportation} = \sum_{j=1}^{m}\sum_{i=1}^{n}(V_{ij}^{f} + V_{ij}^{r})d_{ij} C^{r} \tag{6}$$

Seven constraints are included in the proposed MILP model and are discussed below:

(1) Z_j is a variable to decide if DC candidate j is considered in the particular turn of the simulation. If yes, then Z_j equals to one, otherwise equals to zero.

$$Z_j = \{0,1\} \tag{7}$$

(2) Another constraint of Z_j is that after each turn of simulation, the sum of Z_j must be less than or equal to 2. This constraint takes into account the condition that one candidate or two candidates can appear at the same time.

$$\sum_{j=1}^{m} Z_j \leq 2 \tag{8}$$

(3) The function of variable S_{ij} is similar to Z_j and includes the decision whether a direct link between i and j is feasible or not.

$$S_{ij} = \{0,1\} \tag{9}$$

(4) Another constraint for S_{ij} is that its sum should be equal to n, which is the total number of supply and demand points.

$$\sum_{i=1}^{n} S_{ij} = n \tag{10}$$

(5) The difference between the actual distance on a road and that of a straight line drawn between two demand or supply nodes is considered in the following distance calculation function. This calculation allows us to get a close approximation to the actual distance on a road map. This function is also known as *Haversine formula*. The model does not consider external variables such as speed limits and congestion on the roads, as such factors would have little impact on the distance calculation function. d_{ij} represents the distance between demand and supply point i and j. $latA$ and $longA$ is the coordinate of DC j whereas $latB$ and $longB$ is the coordinate of DC i. a is a parameter that converts the assumed direct distance into actual distance on the road.

$$d_{ij} = a\cos(\sin(latA)\sin(latB) + \cos(latA)\cos(latB)\cos(longB - longA))6371a$$

(6) Another constraint is a dynamic selection process for choosing the shorter route between two points, when there are two candidates appearing at the same time (see Figure 2).

$$d_{ij} = \left\{ \min(d_{ik}, d_{il}) \,\middle|\, i, k, l \in Z^+ \right\} \tag{11}$$

Figure 2 illustrates a schematic plot for two DC options. The solid line from DP1 to DC1 is shorter than the dotted line from DP1 to DC2. Hence, all material flows will go through the solid line rather than the dotted line. This selective feature is also reflected in the simulation model and realised through a comparison of choosing the shortest route for each point.
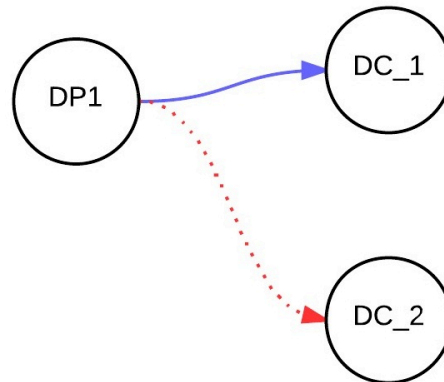
Figure 2. Plot for the automatic selection of the shortest route

(7) The proportion of reverse material flows in relation to forward material flows is represented in the following constraint function. The variable $\lambda_{ij} V_{ij}^f$ has already been included into the modified COG function above.

$$\text{Vr}_{ij} = \lambda_{ij} V_{ij}^f \tag{12}$$

The complete model of MILP is presented below in equation 13. The simulation model solves this objective function by finding the minimum overall costs and distances.

$$\text{Min R} = \sum_{j=1}^{m} \sum_{i=1}^{n} \left((V_{ij}^f C^f + V_{ij}^r C^r) Z_j \right) + \sum_{j=1}^{m} \sum_{i=1}^{n} ((V_{ij}^f + V_{ij}^r) d_{ij} C^t S_{ij}) \tag{13}$$

Subject to:

$Z_j = \{0,1\}$

$$\sum_{j=1}^{m} Z_j \leq 2$$

$S_{ij} = \{0,1\}$

$$\sum_{i=1}^{n} S_{ij} = n$$

$d_{ij} = \alpha \cos(\sin(latA)\sin(latB) + \cos(latA)\cos(latB)\cos(longB - longA))6371\alpha$

$$d_{ij} = \left\{ minimum(d_{ij}, d_{il}) \middle| k, l = \{1,2,3,4, \dots, m\}, i = \{1,2,3, \dots, n\} \right\}$$

$$V_{ij}^r = \lambda_{ij} V_{ij}^f$$

6. Model solution and simulation results

Using the base data of locations and demand and supply volumes, Table V shows the group of candidates calculated by our modified COG model.

Table V. Results of all possible candidates calculated by COG

Candidates Number	Coordinate	
	Longitude	Latitude
1	1.60664W	52.881N
2	1.61488W	52.965N
3	1.62606W	53.0664N
4	1.68863W	53.1288N
5	1.60911W	53.0201N

As mentioned in the constraints of our model formulation, we consider two solution conditions for the facility location. Table VI presents a matrix including the combination of different possible candidates that are included in different options for the simulation using the MILP model. For example, option 1 considers candidate number 1 and 2, whereas option 2 considers candidates number 1 and 3, and so on.

Table VI. Number of possible options corresponding to candidates

Candidates	1	2	3	4	5
1	X	Option 1	Option 2	Option 3	Option 4
2		X	Option 5	Option 6	Option 7
3			X	Option 8	Option 9
4				X	Option 10
5					X

6.1. Model Solution for both one hub and two hub conditions

By minimizing the costs and distances for all the options, the MILP model simulates the minimum cost function resulting in an optimal facility location (Table VII) for both scenarios- one DC and two DCs. The Optimization is solved using Cplex solver and the results are presented in the form of tables and figures for further analysis.

Table VII: Results of the final DC selection

Condition	Option / Candidates no.		Coordinates		Operation Volume (Unit)	Cost (£)
			Longitude	Latitude		
One DC	1		1.60664	52.881	218,290	1,468,447,416
Two DCs	4	1	1.60664	52.881	157,220	1,504,719,616
		5	1.60911	53.0201	80,610	

The results presented in Table VII indicate that the model solution supports one hub condition, resulting in candidate number 1 as the preferred facility location with the lowest overall costs. However, this solution implies higher overall volumes for handling and collection per DC (218,290 units) compared to the solution under a two hub condition (157,220 units and 80,610 units). This may not be an ideal solution for organizations looking to avoid the risk of disruptions in a supply network. With increased man-made and natural disruptions currently being experienced in global supply chains a two hub solution can mitigate disruption risk by transferring it to another hub. Hence, a two hub solution is currently more realistic as it provides options over how volume can be allocated but at the expense of slightly higher overall costs.

6.2. Records of return rate

The simulation program recorded the return rates between the supply and demand points and the five DC candidates. Table VIII presents the randomly generated proportions of reverse material flows as a percentage of the forward material flow. This analysis was conducted in order to understand the variation in location decision for changing return rates, as returns are often influenced by factors such as seasonality, marketing initiatives and quality related issues.

Table VIII. Return rates between supply/demand points and DCs

	A	B	C	D	E	F
1	0.35	0.01	0.5	0.42	0.76	0.72
2	0.61	0.2	0.89	0.56	0.75	0.54

3	0.87	0.59	0.81	0.38	0.61	0.15
4	0.49	0.75	0.79	0.17	0.47	0.01
5	0.95	0.72	0.26	0.97	0.77	0.52

6.3. Model solution for forward flows only

By averaging the simulation run results from all the scenarios, we found that the results significantly vary when considering reverse flow. Table IX indicates the optimal location of the distribution centres for two separate scenarios-forward flow and closed-loop flow.

Table IX. Comparison of optimal facility location including and excluding reverse flow

Condition for consideration in model	Coordinate of optimised location	
	Longitude	Latitude
Forward flow	1.720W	53.049N
Forward + Reverse flow	1.607W	52.880N

7. Analysis of results

7.1. Analysis of mixed method simulation model

Figure 3 visualizes locations of supply and demand points for Argos on a geographic map of the UK. The diamond symbols represent the retailers (i.e. demand points), and the square symbols represent manufacturers (i.e. supply points). The circles represent the possible candidate locations for the DC identified from the modified COG method. The model solution for a facility location under a one hub condition is highlighted with an asterisk symbol in Figure 3.

The longest distance between the five candidates is around 49 kilometers. This shows that there is a significant difference between the possible facility locations when taking into account reverse flow. These possible location candidates appear aligned in a straight line in Figure 3. There are two possible explanations for this phenomenon: (1) Geographically, the United Kingdom is a narrow country, which means that the possible options for facility locations will shift along a vertical centre of gravity axis. (2) The shift in the position is due to reverse material flow and caused by different return rates for each link. Therefore, no matter how much the proportion of return rates change, all of the possible options will appear around a vertical line as in the figure 3. This assumption will now be further tested and evaluated in the next section.
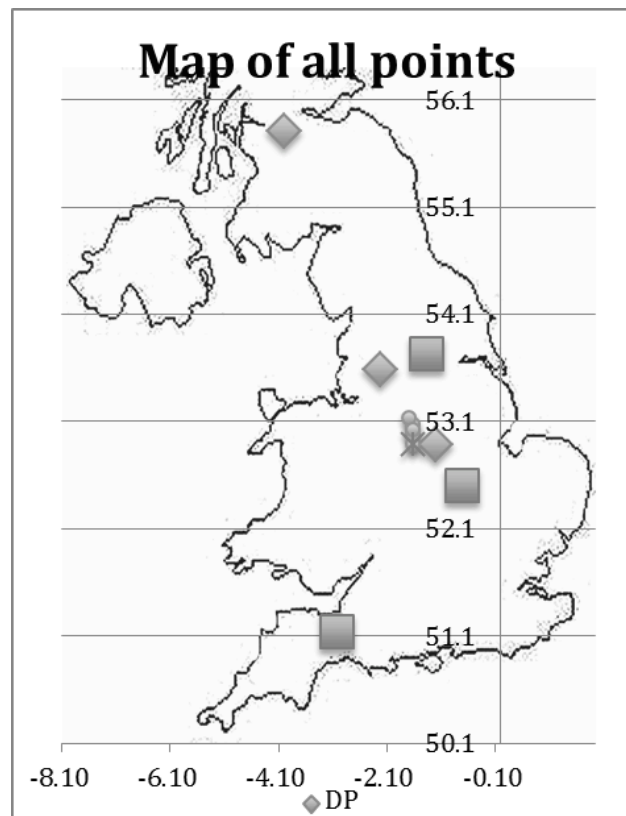
Figure 3. Visualisation of supply/demand points and potential DC facility locations

7.2. Comparison of the model solution for two flow conditions

With regard to any supply chain strategy, operating multiple distribution centers decentralizes inventory and minimizes the risks of disruption and errors. Hence, it is sensible to evaluate the option of setting up two DCs simultaneously for these strategic reasons. Our proposed objective function allows simulating this condition and can therefore be applied to the situation where two DCs are considered. The simulation results in Table VIII show option 4 as the most optimized facility locations (in a two DC condition) with candidate number one and candidate number five. We believe that both the facility locations might have different operational capacities and utilization restrictions, which results in a multiple allocation problem of allocating suppliers and customers to one or both DCs. The results however show that the model is able to simulate dynamic matching for each supply and demand point and allocate them to the closest DC. The distance between the two distribution centers is 49.26 kilometers which is a relatively a small distance but with significant benefits over a one hub solution. A two hub DC solution will help in mitigating unexpected demand/supply risks arising from within the network bringing benefits over a single DC solution. Also it can be anticipated that the close

proximity of the two hub DCs would also enable better management of the forward and reverse flow of products.

7.3. Comparison of the model solution for forward only and combined (forward and reverse) material flows

The results for the simulation model under the two hub condition of including and excluding reverse material flow (Table IX) are presented in Figure 4. An asterisk symbol represents the optimized location for forward and reverse flows and a cross symbol marks the optimized location while only taking into account forward flows.
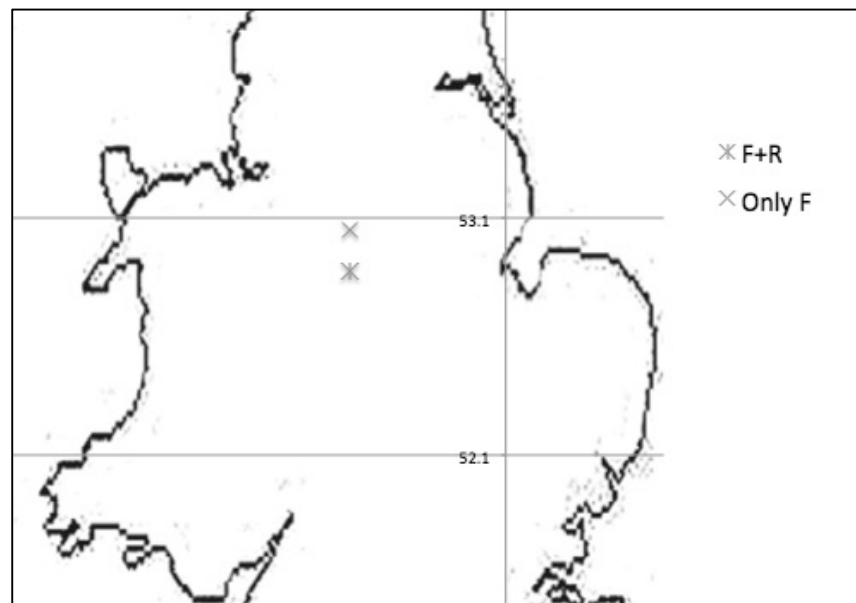
Figure 4. Visualisation of optimised DC location including and excluding reverse flows

The distance between these two locations considering two separate scenarios is approximately 43 kilometres. This suggests that there is a remarkable difference between the two optimized facility locations when taking into account combined flows. Furthermore, such consideration for the DC location decision can lead to several other improvements within internal operations. Transportation costs covering both forward and reverse logistics decrease due to the closer location of facilities for the individual supply and demand points. Optimized location change also promotes vehicle efficiency at a time when companies are being challenged by consumers and legislators to improve on issues of empty running vehicles and CO_2 emission to meet sustainability agendas. Since the sample points selected are within the

UK, the shift in the optimal location is not significant. However, it is possible that examining our research objective in other European countries or the American continent would generate significant changes in the location decision when taking into account reverse flow in the CLSC network.

8. Conclusion

It is evident that online shopping is generating increasing product returns and hence significantly influencing the strategic decision of facility location. The study has proposed an approach to optimize the facilities location decision making problem by considering forward as well as reverses logistics flow. The paper develops a contemporary model that can take into account multiple factors while making the appropriate decision for performance on sustainability. Sustainable facility location modelling is important to understand the trade-off between the pillars of sustainability (Xifeng et al., 2013). The sustainable facility location is environmentally conscious as it minimizes the total distance covered in a CLSC network, thus supporting reductions in carbon emission. In addition, that the total costs of operations and transportation are reduced shows that the solution is cost effective. Furthermore, as the model can incorporate variable return rates, it can provide improved levels of customer service. The research utilises a mixed-method modelling approach by combining the COG and MILP approaches to the problem. The main advantage of the proposed hybrid model is its flexibility through incorporating different return rates in the reverse logistics scenario to replicate a real world returns scenario. The study contributes to the modelling and the practices of FLP by combining two established analytical techniques to construct an optimal solution. The research validates the critical need to take into account reverse flow in the uncertain and competitive environments of retail distribution. RL will have a growing influence on profitability (Peterson and Kumar, 2015) through product return policies. Specifically, the research offers an avenue whereby flexible return policies supported with robust closed loop supply chain networks could enhance the profitability of the organization.

Multiple assumptions such as capacity constraints, availability or feasibility of locations as well as unit cost structures limit the practicality of the proposed optimization approach. We believe that reducing uncertainty in the data would create several improvements to the model. For example, the return rate is set as a random parameter in the proposed model due to a lack of empirical data on customer returns behaviour. In particular, online businesses with

significant statistical data on product returns could generate accurate estimations of return rates and further enhance FLP decision making. Furthermore, it has to be acknowledged that in practice pre-existing facilities locations will be favoured largely as they are often perceived as hub locations. In practice the facilities allocation decision also depends on the infrastructural, geographic or political circumstances rather than linear programming optimization (Horner and O'Kelly, 2001). For example, the proposed model does not consider external factors such as speed limits and traffic congestion on roads, regional customer demand, etc. The hybrid model is not tested for its robustness by comparing results with other conventional modelling approaches. These are some of the limitations of the research.

Increasingly the growth of online retailing and associated high product return rates will significantly influence locating the facility in a CLSC network. This study offers SC Managers some guidance on the wider implications of increased reverse logistics. The study also guides SC Managers on adapting appropriate mitigation strategies, if facility location change is not an immediate option. The study provides a structured approach for single hub and two hub location decision making in a fast moving E-commerce environment. Based on varying product return rates, SC Managers can decide whether to choose a single or a double hub solution to meet their needs. The research recommends a two hub facility location approach to mitigate emergent supply chain risks and disruptions. The research also reconfirms that reverse logistics affects the company's operations at both strategic and tactical levels.

There are several possible avenues for future research. First, the proposed model uses only current demand flows and could be extended by adopting fluctuating or dynamic demand flows. Second, product types could be categorised and considered as individual units to be distributed and stored, which could then be related to the capacity constraints of the warehouse. Regardless of possible alternatives to the research approach discussed here the FLP model proposed is a step forward in improving sustainability performance in supply chain distribution networks.

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