Improving the operational efficiency and reducing transport-related carbon emissions of food distribution hubs: a short, non-technical overview

Research Report

Improving the operational efficiency and reducing transport-related carbon emissions of food distribution hubs: a short, non-technical overview

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Abstract

The challenges faced by small-scale food producers, such as low profits and limited bargaining power, can be mitigated through local and regional food hubs. These hubs not only contribute to local economic development but also gather products from producers and distribute them to consumers. However, the logistics involved in food hubs can be expensive, particularly for small volume journeys, which can result in carbon emissions that surpass those of supermarket supply chains. This study aims to enhance the efficiency of food hub logistics by decreasing transport costs and carbon emissions. To address the "producer-to-hub-to-customer" problem, an optimisation model was developed using real-world data from a local food hub that serves over 150 producers in the North East of England. This short report provides a non-technical overview of optimisation model and the main findings. Computational experiments were conducted to assess the impact of producer cooperation on transport and fuel costs, as well as carbon emissions. This research provided valuable insights, including the benefits of switching to electric vehicles in terms of costs and carbon emissions.

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Executive summary

Food hubs provide a viable solution to the logistical challenges faced by Short Food Supply Chains (SFSCs). By consolidating goods from various local and regional producers and fulfilling consumer orders placed on the internet, they can achieve the intended socio-economic benefits of SFSCs while benefiting from economies of scale in transportation. This, in turn, reduces logistics costs and environmental footprint for suppliers while increasing convenience and reducing consumer travel. However, the extent to which a food hub can reduce operational and environmental costs depends on several factors, such as coordinating aggregation from producers to the hub, the nature of vehicles used, and coordinating logistics.

Our research focuses on improving the operational and environmental efficiency of food hubs by minimising transport costs and carbon emissions. We have developed a model based on real-world data from a food hub that serves over 150 producers in North East England. Our empirical results show that horizontal collaboration in logistics between producers play a key role in improving vehicle utilisation which, in turn, can significantly reduce carbon emissions by up to 16%. Additionally, by switching to electric vehicles, transport costs can be reduced by 31.5%, helping to optimise operational costs and reduce environmental impacts. From a managerial perspective, these findings provide useful empirical evidence for improving logistics strategies. Importantly, data visualisation software and tools can play an important role in better understanding performance metrics and optimising logistics solutions.

Introduction

Small-scale food suppliers face major challenges in meeting consumer demands and fulfilling last-mile delivery (Majewski et al., 2020; Malak-Rawlikowska et al., 2019; Todorovic et al., 2018). However, food hubs can be a game-changer in the industry by combining products from local and regional producers and delivering them to consumers (Curry, 2022; Guzman & Reynolds, 2019). This not only helps the economy but also benefits the environment. Nevertheless, the process can be expensive due to small volume journeys and increased emissions (Drut et al., 2021; Li et al., 2022; Majewski et al., 2020; Oglethorpe, 2009). Coordinating supply chains across scattered farms, consumers, and rural-urban transport networks is complex, especially when trying to meet delivery requirements while maintaining quality, freshness, and cost efficiency (Mohammed & Wang, 2017). To mitigate these issues, food hubs must focus on coordinating both product and delivery aggregation, utilising vehicles efficiently (in terms of fuel use and journey routes), and thus minimising empty journeys, costs, and carbon emissions. Although these challenges are well known to practitioners, they have not received sustained attention in operations research. The research aims to address this challenge by improving the operational efficiency in logistics, minimising transport costs and carbon emissions in the producer-to-hub-to-customer distribution process, and optimising logistics solutions. This short report provides a non-technical overview of the work undertaken.

Problem description

Food and Drink North East (FADNE) is a community interest company that supports the food, drink, and hospitality sectors in the North East of England. In the wake of the Covid-19 pandemic that hit the UK in spring 2020, many high-margin market channels, such as farmers' markets, cafes, and restaurants, were forced to close, consequently affecting the income of many small-scale producers. To tackle this crisis, FADNE set up "Local Heroes", a regional food hub that offered an internet-based ordering portal and home delivery service for customer orders. The hub, which operated for a 12-month period from the end of March 2020 until physical shops and farmers' markets 'returned to normal' in 2021, featured over 150 different producers from the North East, selling perishable seafood, meat, and dairy products that require refrigerated and temperature-controlled logistics, as well as long-life items like jams, confectionery, beer, and spirits. The suppliers who sold through the hub were located across the region, ranging from remote rural locations to more semi-urban areas. Consumers were similarly widely dispersed, but the hub only provided free, low-carbon, delivery within a five-mile radius from its headquarters in Newcastle upon Tyne, the largest city in the region with a population of approximately 300,000.

This research considers the distribution problem from producers to the hub, and respectively from the hub to customers. It addresses empirically several crucial questions such as:

- how to effectively handle fluctuations in customer demand?
- what strategies can be employed to address fuel price increases regarding fuel vehicles?

- what is the impact on carbon emissions and cost components when adopting electric vehicles for delivery?
- what is the impact on carbon emissions and costs when using direct delivery from producers to customers?

Research design and methodology

FADNE's Local Heroes logistics network incorporates three main supply chain actors: producers, the hub, and customers. Producers are conceptualised into three categories based on their willingness to collaborate, coordinating logistics efforts and using common vehicles for shipment. The first category comprises producers who are willing to work with each other using the hub's transport. The second category consists of producers who work in tandem using one producer's vehicle. The third category contains producers who do not wish to coordinate logistics and use their own individual vehicles to deliver to the hub. Figure 1 visually illustrates these three logistics distribution options, with lines in red denoting empty vehicle travels. Different producer groups are formed based on their location and willingness to coordinate. Customers are also grouped into geographical zones based on their location, with product delivery occurring via the hub.

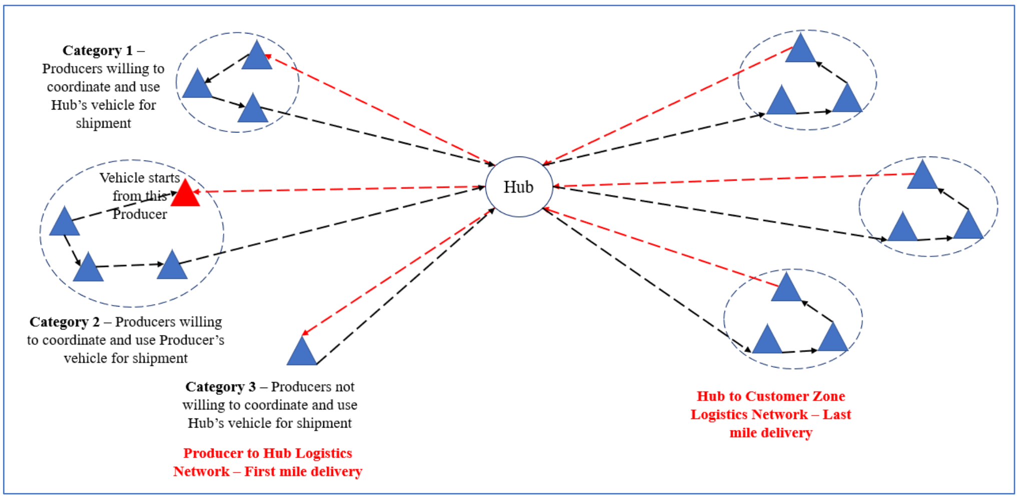

Figure 1 **Visual illustration of the producer to hub to customer zone distribution network**

This study focuses on optimising the logistics network for the delivery of food products, which involves the shipment of goods from producer groups to a hub and then to customer zones. Our research explores the possibility of shipping products directly from producer groups to customer zones (refer to Figure 2) to minimise vehicle trips and unutilised vehicle volume, while also considering the weight and volume of the products. Furthermore, it aims to improve the environmental performance of logistics by reducing fuel consumption and carbon emissions from the vehicles used in the distribution network. The study conducts a thorough analysis of different vehicle types, including electric and fuel-efficient vehicles, to fully comprehend their impact on economic and environmental factors.

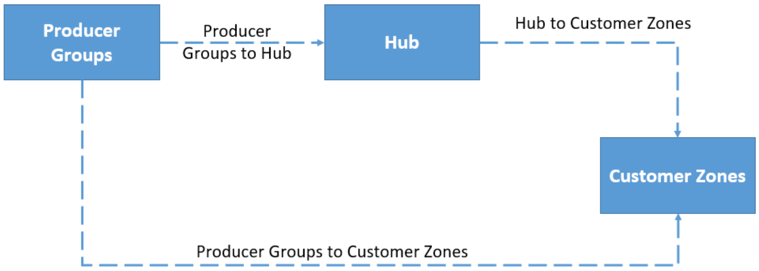

Figure 2 Logistics network considering Producer Groups, Hub and Customer Zones

We have developed an optimisation model that helps meet customer demand while minimising transportation and fuel costs. Figure 3 shows the model's framework, which includes an objective function and constraints. The model uses several input data parameters to generate outcomes. Our goal is to minimise transportation costs, inventory holding costs, fuel costs, penalty costs for unmet demand, and unused vehicle volume. We also consider carbon emissions by factoring in fuel vehicle emissions restrictions. The model suggests switching to electric vehicles to reduce carbon emissions and includes charging costs in its calculations.

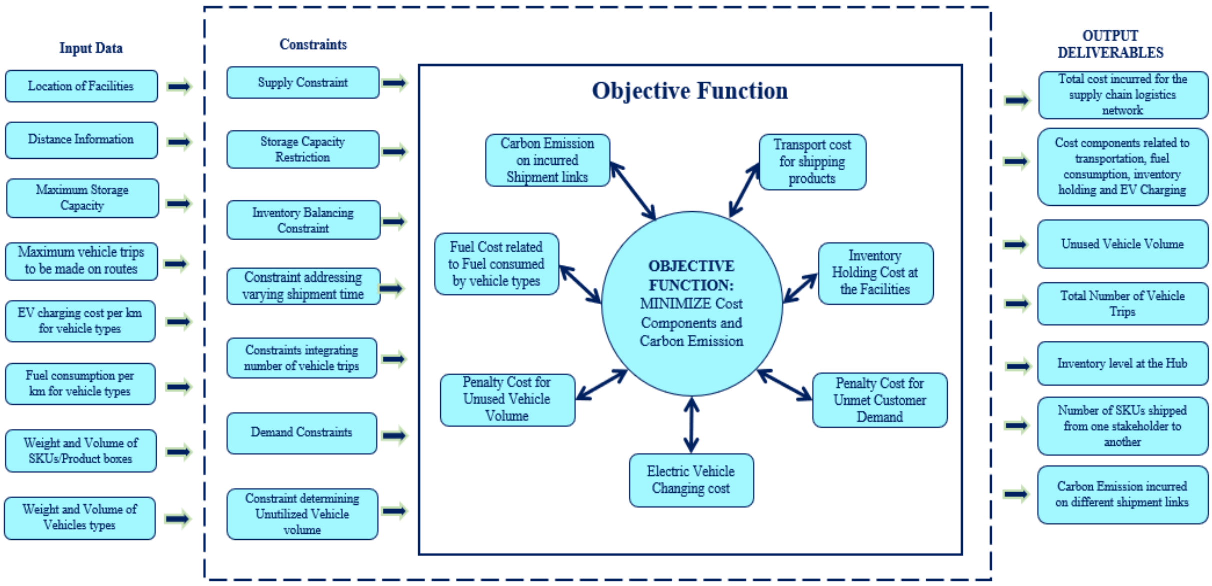

Figure 3 Framework of the Optimisation Model

Our analysis is based on real-world data from FADNE's Local Heroes, covering 24 producer groups and 160 customer zones. The large problem instance for the operations research-based optimisation model consists of 1.08 million decision variables and 1.32 million constraints. This highlights the level of computational complexity handled by the proposed optimisation model. Useful primary data from FADNE include key food hub metrics such as total item costs, orders fulfilled, demand served, and quantities sold.

Summary of key results

Power BI computational experiments

Different computational experiments were performed to solve the optimisation model while considering the real-world example of the Local Heroes food hub. Using Power BI software, we were able to analyse and better visualise detailed sales, cost, and distribution data to gain valuable insights on a monthly and weekly basis.

Figures 4(a) and 4(b) provide visual illustration of the analysis performed on Local Heroes' sales data using Microsoft Power BI to gather some useful insights related to the number of orders met and total quantities sold each month. Furthermore, figures 5(a) and 5(b) present some insights about the customers served and total item cost incurred each month. It can be seen that the number of orders met and customers served in June is quite high. This might be because of the summer holidays. December seems to be second most productive month for Local Heroes, given that the number of orders met, total quantities sold, and customers served are particularly steep this month, particularly due to the Christmas season.

Useful insights are obtained after analysing the data, highlighting that there is clear spike in the number of orders met on the months of June, July and December. Similarly, the number of quantities sold in June, July and December are quite high. Figures 6(a) and 6(b) depict the visual descriptions of Local Heroes' weekly sales data with regard demand quantity met and number of customers served each week.

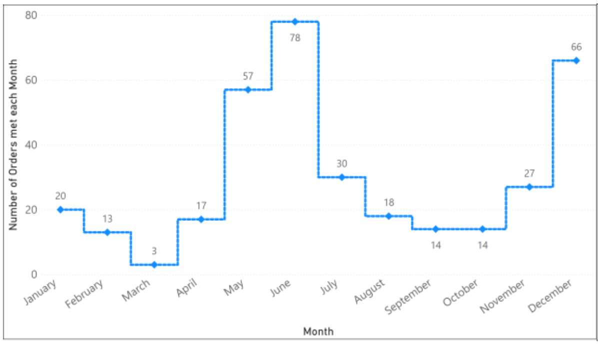

Fig 4(a)

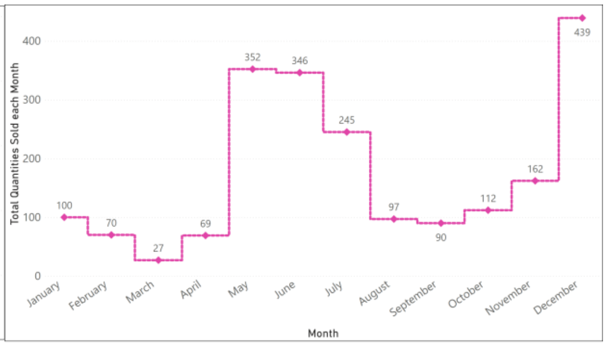

Fig 4(b)

Figures 4(a) and 4(b): Number of orders met and quantities sold each month

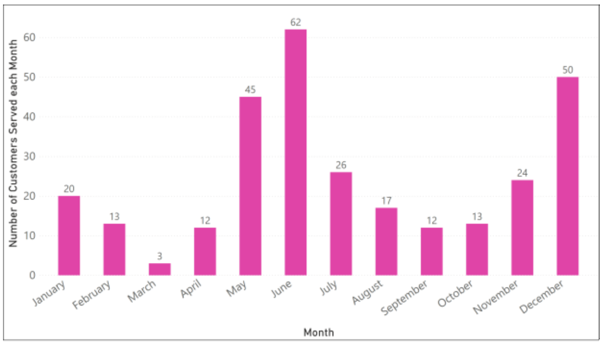

Fig 5(a)

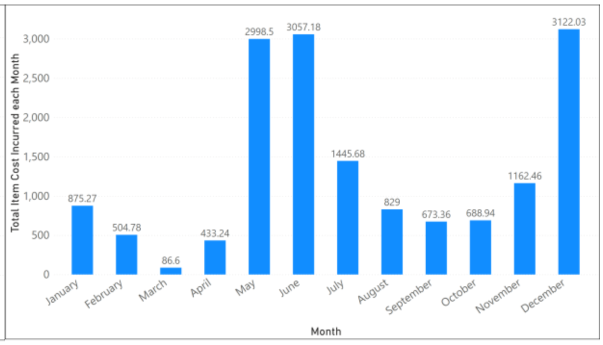

Fig 5(b)

Figures 5(a) and 5(b): Number of customers served and total item cost incurred each month

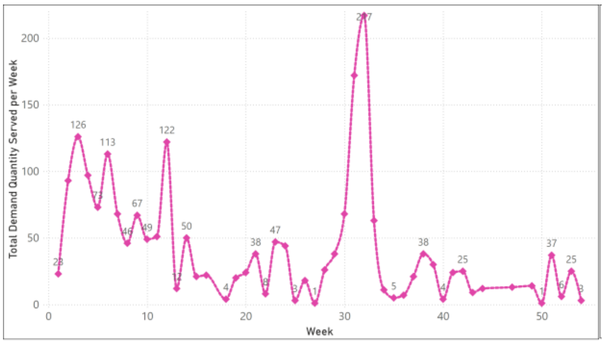

Fig 6(a)

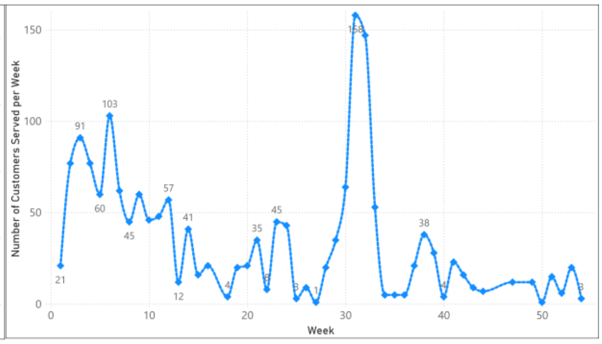

Fig 6(b)

Figures 6(a) and 6(b): Total demand quantity met and number of customers served each week

Optimisation model using IBM CPLEX

The proposed optimisation model (refer to figure 3) was solved using IBM CPLEX optimisation software. The computational experiments are performed considering multiple scenarios with different scales of operations and vehicles. This was designed to understand how logistics costs and structure respond to changes in demand. Our empirical model was estimated to minimise carbon emissions and fuel consumption on shipment links while also optimising operational efficiency by reducing vehicle trips and unused vehicle volume. Different empirical experiments were performed to observe how cooperation between producers affects transport and fuel costs, as well as carbon emissions. In addition, due to the backdrop of steep rises in petrol and diesel costs, we analysed the impact of fuel price variations and demand fluctuations on cost components and carbon emissions.

Our analysis indicates the benefits of direct shipping between producers and customers, and so how avoiding transportation of products through the hub, can contribute to reductions in carbon emissions and economic costs. Specifically, the analysis indicates that switching to direct connections between products and customers can cut down emissions by 12-16% per customer order. They also reduce the total cost per customer order by 12-15% and the number of vehicle trips to each customer zone.

This approach can assist logistics managers in improving cost-efficiency and environmental sustainability. It can significantly reduce the carbon footprint of local food systems and thus enhance operational efficiency in the distribution network, making it an ideal solution for managers facing cost and environmental pressures.

Further analysis indicates the presence of substantial economies of scale in local food distribution networks. Specifically, our experiments demonstrate that a 75% increase in demand can result in a substantial 301% decrease in average cost components, such as fuel and total costs. However, local food hubs as a business model are vulnerable to changes in fuel costs - a 50% surge in fuel prices can lead to an alarming 80% increase in fuel costs for producers to customers with direct shipping links. When using fuel-based vehicles (e.g., petrol and diesel vehicles), fuel costs account for around 50.2% of total logistics costs. Our study identifies the benefits of using of electric vehicles (EVs) for all shipments in distribution networks – results indicate that introduction of EVs can reduce transport and total costs by an impressive 31.5% and 59.1%, respectively. By adopting electric vehicles in the logistics industry, carbon emissions and costs can be significantly cut, particularly in urban areas where there are dense networks of customers who live close together.

Our optimisation model can handle disruptions in shipment links and counter unexpected events while focussing on mitigating economic and environmental costs, with only a slight increase in average fuel costs and carbon emissions per customer order. This is important for a distribution network's resilience as delays often occur.

Conclusions and managerial implications

SFSCs and, specifically, regional food hubs can support the growth of small-scale food producers, both economically and socially. They can also have positive environmental impacts on communities (Doernberg et al., 2022; Malak-Rawlikowska et al., 2019). However, it's not always easy to manage these supply chains efficiently. Logistics can be a challenge, and this can lead to increased costs and carbon emissions, which can undercut the appeal of such networks to companies and potential customers alike (Majewski et al., 2020; Malak-Rawlikowska et al., 2019). Our research aims to address these challenges by suggesting strategies to reduce logistics costs when shipping products from producers to customers through hubs. This study provides empirical evidence on the benefits of horizontal collaboration between producers, which in turn can contribute to achieve more sustainable food systems. With many small-scale food producers struggling with coordinating logistics themselves (Majewski et al., 2020), clustering producers based on their location and willingness to collaborate, and forming producer groups/ networks, can be an effective strategy. Similarly, grouping customers according to their location, forming customer zones, will create a distribution network which minimises economic and environmental factors when shipping products.

Our optimisation model aimed to decrease costs related to inventory holding, transportation, and fuel consumption, while reducing carbon emissions, unused vehicle volume, and the number of vehicle trips. In this paper we provide a short non-technical summary of findings, with more detailed analysis available from the authors on request. Our findings provide valuable insights for food supply chain practitioners and food hub managers. Operational modelling and optimising techniques can be effective in reducing transport, inventory, and fuel costs while contributing to a cleaner environment. Using

Power BI and data visualisation software can also help optimise solutions and better understand performance metrics.

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