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Sustainability Challenges of Last Mile Logistics and Transition from Offline to Online Grocery Retailing in Sparsely Populated Areas

Abstract

Purpose – This paper focuses on the last mile logistics (LML) operations in fulfilling online grocery orders and the related sustainability considerations in sparsely populated areas like Australia. It aims to examine how online groceries in sparsely populated areas can benefit from the online business. Specifically, this study seeks to investigate whether a centralized order fulfilment approach is better than the existing approach which fulfils online orders from local grocery stores.

Design/methodology/approach – A multi-method approach is employed to conduct a high level of cost and emission analysis between the existing and the proposed approaches to illustrate the ratios between the two approaches in terms of cost and carbon emissions. Mathematical models are developed with support from the literature. The model is empirically validated with a case study of grocery distribution in the city of Gold Coast, Australia.

Findings – It finds that the centralized order fulfillment approach in sparsely populated areas can achieve the LML sustainability with low cost, high efficiency and less double handling. Meanwhile, the separation of in-store and online retailing processes improves the in-store shopping experience and online shopping visibility, jointly improves customer satisfaction, consequently achieve positive effect on long-term sustainability. Additionally, the possibility of automating order picking and dispatching at a central place can make the processes more efficient and help build more sustainable grocery retailing supply chains by using more environmentally friendly systems.

Originality/value – This paper offers analytical and empirical insights into the sustainability of multi-channel grocery retailing supply chains. The high-level model developed is the first to incorporate the concept of online shopping adoption rates, and can serve as a decision-making tool for practitioners to improve supply chain sustainability in LML.

Keywords: Sustainable supply chain management; Multi-channel distribution; Grocery retailing; Last mile logistics; transfer from offline to online retailing.

Paper type: research article

1. Introduction

Compared with traditional businesses, online models have many advantages, such as price, convenience, and recreational benefits (Arora and Aggarwal, 2018). The Internet and digital communication technologies, together with fast delivery (Kaur et al., 2020; Taher, 2021), have made more and more businesses to transit from offline to online to meet customers' requirements (Aryani et al., 2021). Data shows that global e-commerce sales are expected to hit $5.5 trillion in 2022 and around 76% of U.S. adults shop online (Cloudwards.net, 2023). One of these businesses is grocery retailing, and e-grocery platforms have emerged to fulfill customer orders (Wu et al., 2023). However, such transitions mainly occur in high population density areas because of the economy of scale. Many grocery retailers in low population density areas are simply using their local retail stores to fulfill their online orders, which might not be the best practice. This study aims to examine how grocery retailers in low population density areas can better manage their online order fulfillment. Specifically, this study seeks to investigate whether a centralized approach is more suitable for grocery retailers who operate in low population density areas.

Prior work has found that the transition to online models needs to consider many factors, such as the rate of internet access, consumers' age (Lissitsa and Kol, 2016), information quality, user interface quality, security perceptions (Park and Kim, 2003), and the geographical factors

(Brand et al., 2020; Shi et al., 2019). Most extant papers focus on high population density areas studying the challenges and opportunities (Liguori & Winkler, 2020), advantages, models (Zhou et al., 2007), factors to affect behaviors (Lu et al., 2011), and customer loyalty (Rafiq & Fulford, 2005).

However, there is scant research to study the transition to online shopping in sparsely populated areas like Australia where the transition may face economic, social, and environmental challenges. For example, households in lower population density areas were less likely to order goods online (Saphores & Xu, 2020) because of the less delivery convenience (Duarte et al., 2018) and complex infrastructural variables (Javadi et al., 2012). The higher delivering cost including the high last mile logistics (LML) cost, and longer delivering time can impede the online shopping as well. Further, the increased average travel distances can cause delay and extra packaging (Gonzalez et al., 2023). This may cause challenges for short shelf life or perishable food products which require timely and quality LML service (Kärkkäinen, 2003).

Therefore, it is significant to investigate how grocery retailers can manage their online order fulfillment cost-effectively and sustainably in sparsely populated areas. Our paper aims to fill in the research gap by answering the following two research questions.

RQ1. Is a centralized online grocery fulfillment approach better than fulfillment directly from local grocery stores in sparsely populated areas like Australia?

RQ2. What are the key parameters that affect the decision to adopt an online grocery order fulfillment approach, especially in sparsely populated areas like Australia?

To seek the answers, we apply a multi-method approach in this study to examine how online grocery orders should be fulfilled for online grocery retailing in sparsely populated areas. The study enriches the literature by extending online grocery shopping to sparsely populated areas.

Practically, our research results can provide significant and pertinent guidance and reference to grocery retailers who are providing or aiming at providing online grocery services.

The remainder of the paper is organized as follows. Section 2 reviews the literature in e-commerce and online grocery retailing, LML, and sustainability challenges to transit from offline to online retailing. Section 3 describes the research methodology and Section 4 displays the processes, issues, and proposals. Section 5 discusses the research findings, theoretical and practical contributions and implications. Finally, Section 6 concludes our research, discusses the study limitations, and suggests directions for future research.

2. Literature review

2.1 E-commerce and online grocery retailing

Thanks to efficient and effective transportation technology and digital technologies (such as internet, smartphones, cloud computing, online payment, artificial intelligence) (Wang et al, 2020; Wang et al., 2021), e-commerce has bridged consumers and retailers in the last two decades (Al Mashalah et al., 2022; Pahawa et al., 2022). The COVID-19 pandemic further sped up the adoption of online shopping worldwide. In certain countries like the United States, e-commerce grew 44% in 2020, nearly triple that of 2019 (Ali, 2021). E-commerce has become a trend, especially in retail sector which will account for 50% of the e-commerce growth (Al Mashalah et al., 2022).

E-commerce has been promoting and facilitating the transformation of traditional retailing to online. E-commerce and online shopping offer multi-faceted advantages such as increased speed and responsiveness (Baršauskas et al., 2008), better customer segmentation (Agatz et al., 2008), and bringing products and services to consumers in a convenient, cost-efficient manner (Mangiaracina et al., 2015; Pahwa & Jaller, 2022). E-commerce can also improve supply chain management decision making by providing real-time information, transparency and thus enabling rapid collaboration between online retailers, LML service providers, and customers (Doherty and Ellis-Chadwick, 2010). The success of Alibaba and Amazon shows that e-commerce and big retail platforms contribute positively to each other's growth and development. Consequently, through E-commerce, online grocery retailing stores, termed as 'e-grocers' (Edwards et al., 2010), can overcome the geographical limitations, open 24/7 all year, provide time-saving and convenient service for customers (Taher, 2021).

Rapid development of technologies (e.g., orders and payment through smartphones) has contributed to the uptake of online shopping, which has simultaneously reshaped consumer behavior and supply chains (Hagberg et al., 2017b). The Internet provides the ability to link customers to stores from their homes and helps integrate supply chain operations such as marketing, sales and logistics (Boyer & Hult, 2005). However, e-retailing has its disadvantages. For example, it cannot provide the same level of customer experience and social commerce with the physical stores (Hablibas et al., 2023), causing higher return rate (Griffis et al., 2012) and affecting customer satisfaction. As the Internet has become omnipresent and popularity of online shopping has grown, traditional bricks-and-mortar retailers face pressure to adapt and provide customers with the opportunity to make purchases where, when and how they want via multiple channels (Hübner et al., 2016a, b).

However, multi-channel distribution systems bring a new set of challenges. Boundaries between distribution channels can start to disappear as "*information exchange, joint operations, logistics and inventories across channels enable conflation of the fulfillment process*" (Hübner et al., 2016b, p. 564). Therefore, there is a research gap to seek the trade-off between process integration and separation across multiple channels when considering e-commerce operations in their supply chain designs (Agatz et al., 2008). Table 1 below summarizes the advantages and disadvantages of e-commerce online shopping.

Table 1. Advantages and disadvantages of online shopping

streamline and automate process flows, increases speed, responsiveness and reduces turnaround times.	Moraru, 2008; Baršauskas et al., 2008
bring products and services to consumers in a convenient, cost efficient manner	Mangiaracina et al., 2015; Taher, 2021； Pahwa and Jaller, 2022
providing real-time information, transparency and thus enabling rapid collaboration between online retailers, LML service providers, and customers	Doherty and Ellis-Chadwick, 2010; Boyer and Hult, 2005,
overcome the geographical limitations, open 24/7 all year	Cairns, 2005; Taher, 2021
reshape consumer behavior and supply chains	Hagberg et al., 2017b
significant reduction in energy consumption and carbon emission	Tehrani et al., 2009
high return rate, low customer experience, social commerce,	Halibas et al, 2023

2.2 Last mile logistics (LML)

Since the quality and cost of last mile logistics (LML) delivery service is highly related to the population density (Beckers et al., 2018; Morganti et al., 2014; Zhou et al., 2014), Al Mashalah et al. (2022) defined three phases of an e-commerce logistics activities. Phase I involves from sourcing goods to major national distribution centers (DCs) and Phase II involves order sorting, picking and packing in order fulfilment centers. Phase III, the last mile logistics (LML), involves activities from the order penetration point to the consumer’s preferred destination point (Lim et al., 2018). LML is a resource-consuming process requiring seamless coordination among stakeholders including e-platform, e-retailers/consigner, courier, and customers.

Previous research has often investigated the energy and cost efficiency of transport from a ‘last mile’ logistics perspective (e.g., Brown and Guiffrida, 2014; Edwards et al., 2010). This is because the ‘last mile’—from retailer to consumer homes or vice versa—is the most time consuming, costly and highest polluting segment of the supply chain (Brown and Guiffrida, 2014; Hagberg et al., 2017a). Van Loon et al. (2015) noted that consumer travel behavior, choice of order fulfillment method, basket size and frequency of failed deliveries are critical factors in determining the sustainability of e-commerce.

To obtain more accurate information and provide a decision framework which can be used for managerial insight, some studies have conducted break-even analyses to calculate a cut-off point for 'last mile' deliveries (e.g., Brown and Guiffrida, 2014). The cut-off point is the distance between consumer homes and retail stores where the total energy consumption and passenger/freight transport cost is equal for both the traditional and online distribution channels (Pålsson et al., 2017). A few studies focused on the home delivery of groceries compared to traditional in-store shopping. One survey conducted in Finland showed that greenhouse gas emissions generated from grocery shopping could be reduced by up to 87% depending on the home delivery model. When a consumer car to and from grocery retailers was substituted for van home delivery in the UK, Cairns (2005) found that vehicle kilometers could be reduced by up to 70%. However, how different online grocery order fulfillment approaches would impact costs and emissions remains to be an underexplored area.

2.3 LML sustainability challenges to transit from physical store to online retailing

It has been a trend to transit from traditional retailers to online ones, but the transition has to face sustainability challenges. Elkington (1997) firstly proposed the triple bottom line as a sustainability framework to examine a business' social, environment, and economic impact. Two critical challenges of sustainable supply chain management are cost-management and eco-efficiency (Burritt et al., 2011).

Historically, e-retailers have struggled to be profitable due to extra costs associated with order picking and home delivery, in addition to overestimating the size of the online grocery market (Wollenburg et al., 2018). Delivery fees are often charged, which vary depending on a variety of factors (e.g., location, basket size, delivery window), and are usually incurred by the customer (Van Loon et al., 2015). However, e-retailers can also benefit from the logistics distribution industry especially when LML can achieve the economies of scale in highly populated areas. In sparsely populated areas, the LML operations need to be meticulously controlled to ensure viable online service offerings.

LML is related to resource-consuming processes, leading to avoidable inefficiencies including low asset utilization and repeated trips, thus increasing delivering carbon emissions, traffic, and operational cost (Aktas et al., 2021). Ignat and Chankov (2020) addressed that the environmental and social impacts of LML can influence e-retailing customers and vice versa. Table 2 summarizes the challenges to transit to online retailing.

Table 2. LML challenges to transit to online retailing

resource-consuming process requiring seamless coordination among stakeholders; low asset utilization;	Aktas et al., 2021; Mohri et al., 2024
most time consuming, costly; repeated trips and increasing operational costs	Brown and Guiffrida, 2014; Hagberg et al., 2017a; Mohri et al., 2024
consumer travel behavior, choice of order fulfillment method, basket size and frequency of failed deliveries	Van Loon et al., 2015
increasing vehicle carbon emissions, pollution, traffic, and social impacts	Aktas et al., 2021; Brown and Guiffrida, 2014; Ha et al., 2023; Hagberg et al., 2017a; Ignat & Chankov, 2020

Ha et al. (2023) stated that the sustainability concept can be incorporated into all levels of LML, but the current literature landscape mainly concentrates on the operational level. Thus, Campisi et al. (2023) suggested environmentally friendly and small vehicles should be introduced. Some scholars found that e-grocery retailing has transitioned into an omnichannel operating modes and argued the decoupling the LML from the core grocery retail service (Aktas et al., 2021). But most works focus on the LML service in dense areas with lenient temporal constraints because it allows for demand consolidation and thus low-cost low-emission distribution (Pahwa & Jaller, 2022). Although some researchers mention the e-retailers delivering in sparsely populated environments with stringent temporal constraints, the authors suggested the use of low-volume low-pollution vehicles from smaller consolidation facilities close to the market to provide expedited deliveries at fairly low costs and emissions (Pahwa & Jaller, 2022).

Since the "last mile" in sparsely populated areas can be much longer than that in more densely populated areas, Australia needs to face more severe LML cost management and environmental challenge. Because of the characteristics of the built and regulatory environment, the transport network impedance is regarded as the potential hindrance to LML, including the road segments to connect key industrial hubs or activity centers (Ewedairo et al., 2018). All these can cause not only delay in delivery of goods, leading to higher cost per order, but also the emission and congestion, being less environmentally friendly per order (Peppel and Stefan, 2022). Furthermore, the packaging becomes more critical to maintain higher customer service (Pålsson and Sandberg, 2022) in the longer "last mile", requiring higher packaging quality causing higher cost in packaging, delivering, and environmental sustainability per order. The distribution activities of fresh products such as food, fruit and vegetable, and milk can cause additional vehicle-km and tons of carbon emission per year in the last food mile to sustain customer base and geographical coverage (Aljohani and Thompson, 2018).

3. Research methodology

3.1 Discovery procedure and case study contextualization

This paper adopts a multi-method approach. Srivastava (2007) suggested that complex logistics and supply chain problems might need various tools and techniques to facilitate their formulation, approximation, analysis, and solution. The use of multiple research paradigms or methods of analysis to gain multiple perspectives about the same phenomenon is known as the process of triangulation (Boyer and Swink, 2008; Singhal and Singhal, 2012). Triangulation facilitates validation through cross-verifying multiple sources (i.e., data, methods, researchers), which leads to a convergence of information that will likely compensate for inherent limitations of any single method or perspective (Carter et al., 2008).

Previous research regarding the transition from in-store shopping to online shopping has utilized a life cycle analysis (LCA) (e.g., Weber et al., 2010) or a calculation model (e.g., Brown and Guiffrida, 2014). This aligns well with the general approach in Lee and Wu (2014) and Wu et al. (2015) which explored two cases of freight distribution supply chains. A pivotal method in this general approach is the process mapping/modeling exercise to understand the supply chain processes.

In the context of this paper, the supply chain processes focus on the last mile distribution of grocery goods from distribution center (DC) to retail stores, and from there to end customers. The key reason for this focus is due to the characteristics of grocery retailing supply network structures in Australia. Typically, supermarket products are sourced from various key suppliers and are transported to either a national slow-moving DC or a regional fast-moving DC depending on the nature of the products. This part of the supply network utilizes heavy trucks or freight trains through long hauls. At DCs, freight is deconsolidated and either held as inventory (safety stock) or transported to local retailing stores for consumption.

With a proper understanding of the supply chain processes, we utilize both qualitative and quantitative approaches to explore the problem at hand. From a qualitative perspective, the advantages and disadvantages of the existing approach and proposed approaches are analyzed. Quantitatively, we conduct a high level of cost and emission analysis between the existing and the proposed approaches to illustrate the differences in terms of cost and carbon emissions.

As mentioned earlier, we focus on the grocery retailing industry in Australia. There are four main grocery retailers in Australia, namely Woolworths, Coles, Aldi, and Metcash (IGA) (Statista Research Department, 2023a). Among them, Woolworths was the largest grocery retailer by market share (37%) and sales (over 45 billion Australian dollars) as of 2022 (Statista Research Department, 2023a). An online search in August 2023 by the authors confirmed that Woolworths, Coles and IGA are all offering online shopping with the exception of Aldi, which is still operating in a brick-and-mortar style. Volume wise, online spending of grocery and liquor accounts for 15.6% of the total online spending across Australia as of March 2023 (Statista Research Department, 2023b). In online grocery retailing, it is observed that online orders are often processed at local stores close to where the orders are to be delivered. In this sense, this approach falls into the bricks-and-clicks model described in Laudon and Traver (2007). Online grocery retailing offers a substantial opportunity, if implemented correctly, given the highly concentrated market structure of the grocery retailing industry in Australia.

3.2 Modeling assumptions

Mathematical calculation models are then formulated to quantify transport costs, which can be viewed as a proxy for CO_2 emissions. Mathematical models can also serve as the basis for sensitivity analysis to compensate for the inaccuracies of available data and parameters. As a result, decision makers can observe the system dynamics when the model parameters and variables change.

We build a general mathematical model to consider parameters such as service area, population density, average household size, etc., to compare the differences between different approaches for online order fulfillment. Subsequently, we select Gold Coast, Australia as the case to conduct our quantitative analysis and validate the model. Upon model validation, the mathematical model is further extended through sensitivity analyses to observe how the parameters, such as population densities and online order adoption rates, would change the model behavior.

Gold Coast is a coastal city in the South East Queensland, Australia. The urban area of Gold Coast is concentrated along the coast sprawling almost 60 kilometers, with a population over 600,000 (ABS, 2021b). Figure 1 shows the area of Gold Coast (left) and its population density grid (right). It can be observed that the overall population density on the Gold Coast is not very high, and most of the population density grids are in the “less than 500” or “500 to less than 2000” (per square kilometer) categories.

Figure 1: The area of Gold Coast and its population density grid (source: left: *https://profile.id.com.au/gold-coast/home*; right: *https://storymaps.arcgis.com/stories/e2eac66d11984d0e86e6d795b0ca0eec*)

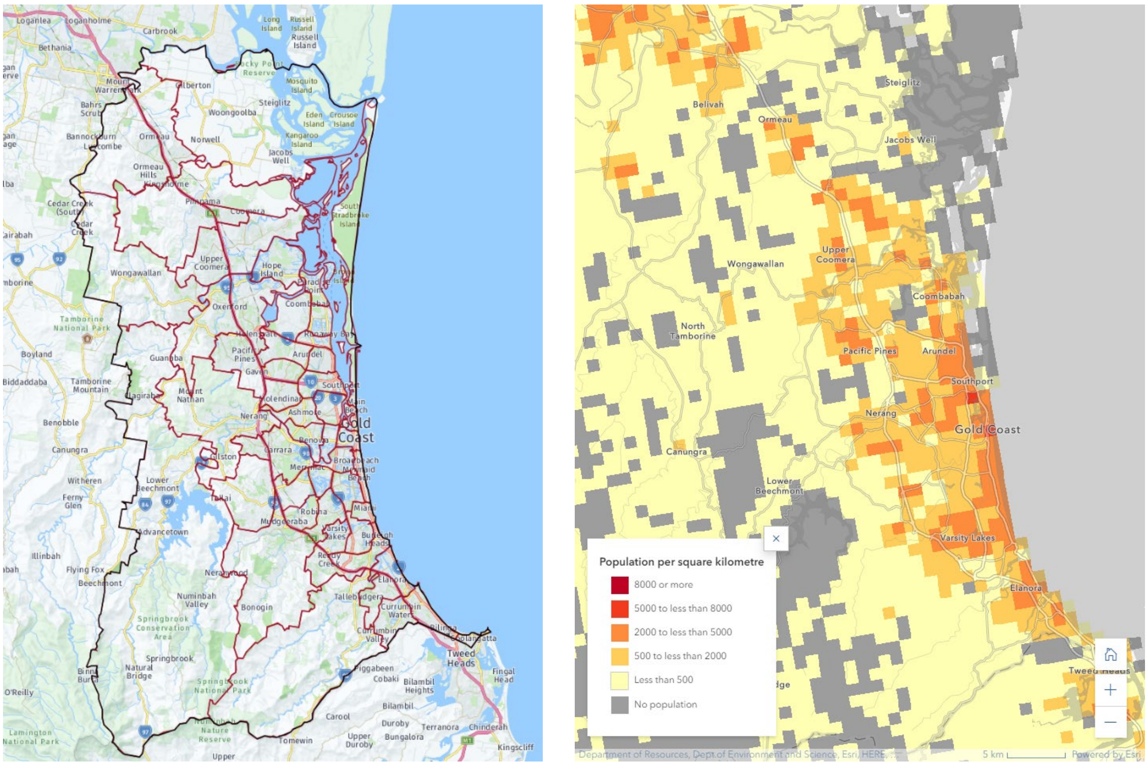


Table 3, which lists the population density for statistical areas across Gold Coast, further confirms this observation. The suburbs that have relatively higher population density are clustered along the coastal area and are bound by a major highway – the M1.

Table 3: Gold Coast estimated resident population density as of 2021 (persons/km^2)

Statistical Areas Level 2 (SA2)	Density	Statistical Areas Level 2 (SA2)	Density
Arundel	1,175	Mermaid Beach – Broadbeach	4,549
Ashmore	1,794	Mermaid Waters	1,844
Benowa	1,507	Merrimac	909
Biggera Waters	3,403	Miami	2,561
Broadbeach Waters	1,595	Molendinar	876
Bundall	1,196	Mudgeeraba – Bonogin	300
Burleigh Heads	1,091	Nerang – Mount Nathan	352
Burleigh Waters	2,222	Ormeau – Yatala	334
Carrara	945	Oxenford – Maudsland	682
Clear Island Waters	973	Pacific Pines – Gaven	1,192
Coolangatta	3,613	Palm Beach	2,658
Coombabah	925	Paradise Point – Hollywell	1,807
Coomera	845	Parkwood	1,446
Currumbin – Tugun	1,604	Pimpama	610
Currumbin Valley – Tallebudgera	69	Reedy Creek – Andrews	1,143
Currumbin Waters	985	Robina	1,784
Elanora	1,465	Runaway Bay	1,743
Guanaba – Springbrook	15	Southport – North	2,205
Helensvale	940	Southport – South	2,870
Highland Park	1,896	Surfers Paradise	4,956
Hope Island	257	Upper Coomera – Willow Vale	300
Jacobs Well – Alberton	29	Varsity Lakes	2,812
Labrador	3,979	Worongary – Tallai	335
Main Beach	1,205		
Total Gold Coast City	**483**		

(Source: Reproduced from https://www.goldcoast.qld.gov.au/files/sharedassets/public/v/1/pdfs/brochures-amp-factsheets/estimated-resident-population-gold-coast-2021.pdf)

With the above background in mind, we make the following assumptions to facilitate our modeling:

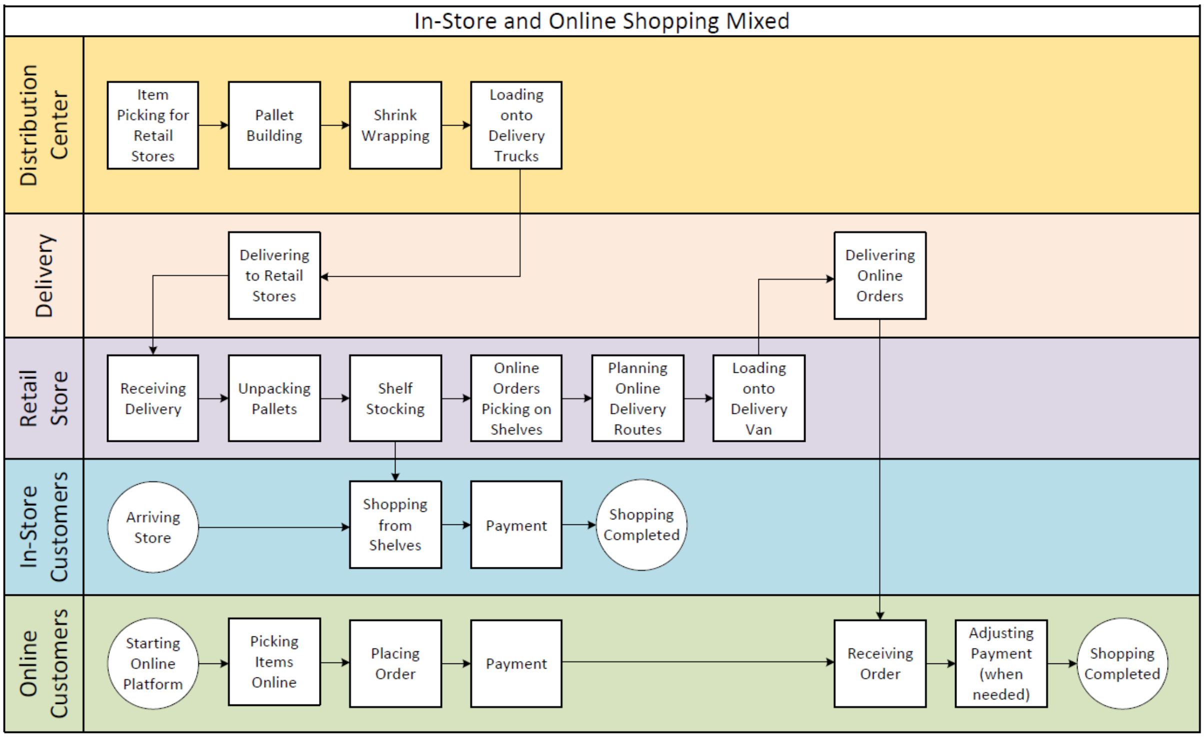
1. Delivery success rate: we assume delivery is successful for first-time home deliveries (Pålsson et al., 2017). Despite previous research acknowledging this as a potential limitation, it is a reasonable assumption in this context, given that deliveries are scheduled in consultation with the customer for a specified time slot.
2. Population distribution and online shopping adoption rate: we assume that the population is uniformly distributed across the considered area and the demand for online grocery services is uniformly distributed. We acknowledge that there are grids/suburbs that have higher population density. However, given these grids/suburbs tend to have a concentration of apartments with supermarkets nearby, it is reasonable to assume that the demand for online grocery services is lower than other areas.
3. Last mile distribution and online order fulfillment: for existing last mile operations, we assume that there is a central DC which replenishes supermarkets. Selected supermarkets, each of which is assigned a service area, are to be used to fulfill online orders from their corresponding service areas. We assume the service areas are in general of square shapes, to reflect the layouts of most cities. The service areas are therefore determined by the length of their sides.
4. Order frequency: we assume each household will visit the supermarket once a week, either in-store or online, and the visits are evenly distributed across the week. Consequently, we will focus on one day's delivery tasks for the modeling exercise.
5. Delivery costs and emissions: delivery vans will be used for online order deliveries. This will still be the case if these orders need to be dispatched from the DC, rather than from the supermarkets. In other words, the delivery vans are homogeneous. As such, delivery cost can be treated as a proxy for CO_2 emissions.

4. Processes, issues and proposals

4.1 Processes used for existing online orders

In Australia, online services for grocery shopping started as early as 1990s but the service areas and forms were rather limited (Australian Food Timeline, n.d.). It was around 2010 that both Woolworths and Coles rolled out online grocery services to major cities across Australia (Australian Food Timeline, n.d.). Inevitably, the initial online grocery sales were low and thus many online orders were fulfilled through local supermarkets. Despite the uptake rate of online grocery shopping increased over the years, and the fact that the COVID-19 pandemic boosted online grocery shopping, the fulfillment of many online orders remains the same, as shown in Figure 2.

Figure 2: Existing processes for in-store and online grocery shopping.



As it can be seen from Figure 2, goods for both in-store and online grocery shopping are firstly delivered to local retail stores. From where the goods are received, sorted, and stocked onto shelves. In-store customers then go to the store and pick their items from the shelves. At the same time, the online grocery orders are picked from local retail store shelves as well. In this sense, the online orders are fulfilled via a mode of "I shop in-store on behalf of you for your online orders." Once the goods for an online order are picked, they are delivered to customers. Any items that are not fulfilled will be refunded to the customer. While this approach can be an effective makeshift when online service volume was low, there are several issues that could impact the last mile logistics and customer experience:

1. Double handling: the existing approach picks customer orders from local retail store shelves. This means that the goods for online orders are firstly stocked onto store shelves and then picked for delivery. In order to avoid this double handling, online order picking will need to happen at the back of the retail store, which is often impractical or impossible due to the limited space available at local retail stores.
2. Lack of visibility: as a result of double handling, online customers are essentially competing with in-store customers for goods. This makes it difficult for the local stores to forecast demand accurately and replenish the shelves on time. Consequently, out of stock could happen for both online and in-store customers. Ideally, when a customer places an online order, the inventory level should be able to tell whether the product is in stock or not and offer alternative products if it is out of stock. However, the existing approach could not offer such information.
3. Handling of out of stock: when an out of stock event happens, in-store customers could try to find alternative products. However, online customers are often left with limited choices. Common practices of handling out of stock include using alternative brands, similar products, or choosing not to fulfill the product. This could significantly impact on the desire of customers to shop online as there is less predictability of product availability. A refund is also needed when the product is not fulfilled. Furthermore, missing critical items means that the customer will need to submit another online order,

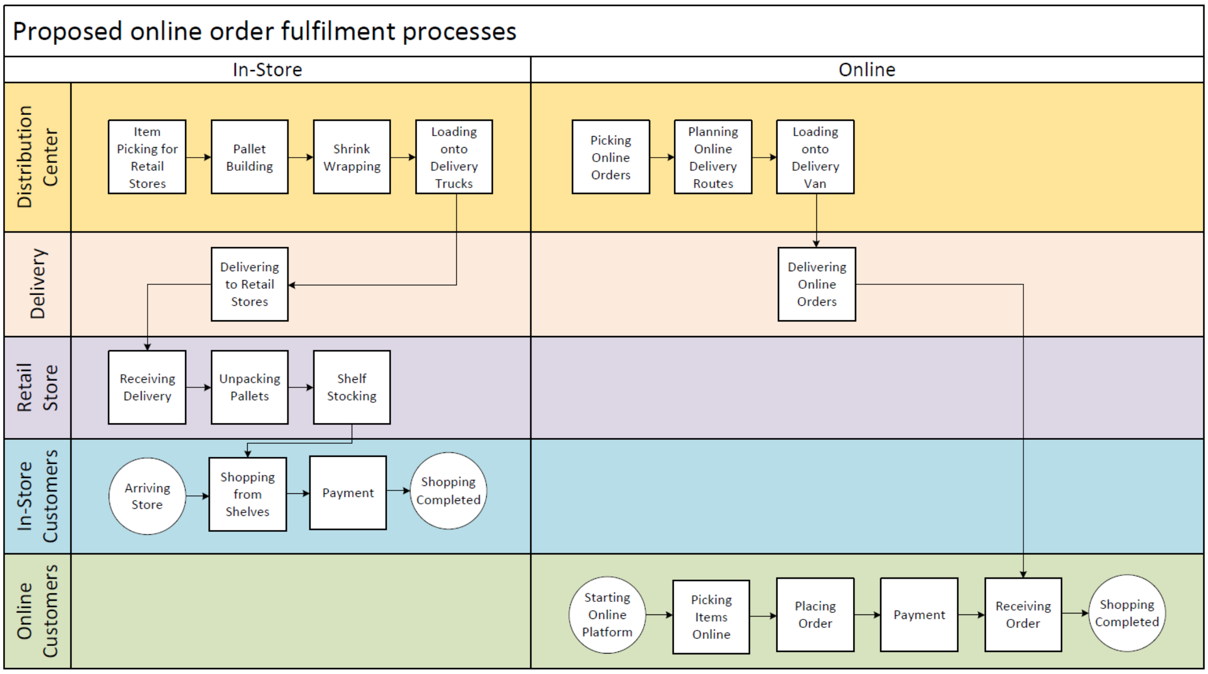
or visit a retail store physically, which further reduces the desirability and uptake of online grocery shopping.

4. Dedicated delivery van(s) and staff: in order to deliver online grocery orders, assigned supermarkets will need to maintain a dedicated team of staff for delivery, as well as the delivery vans. This could be challenging to justify especially when the online order volume is not high enough.
5. In-store customer shopping experience: for in-store customers, the shopping carts that are used for online order picking could impact their shopping experience. The carts that are used to pick online orders, often for picking multiple orders simultaneously, are usually bulky, and could block one third to one half of the aisles. While the shopping cart has evolved over the past decade, its bulkiness could affect in-store customers, especially when the aisles are narrow, and the stores are busy. Furthermore, the picking efficiency is also affected as the goods required by an online order often spread across the supermarket, and the interference with in-store customers could further slow the picking process down.

4.2 Proposed processes separating in-store and online shopping

Considering the issues discussed above regarding the exiting fulfillment of online grocery orders, we propose an approach which separates in-store and online grocery shopping, as shown in Figure 3. In this approach, the in-store goods still follow the same processes as the existing approach. However, the online orders will be separately handled and picked at the DC and delivered to customers from the DC directly.

Figure 3: Proposed processes to separate in-store and online grocery shopping.



Several advantages could be achieved through this approach. These include the removal of double handling, better in-store shopping experience, improved product availability information for customers, and elimination of the need for refund caused by out of stock, etc. By picking at a DC, the picking efficiency could be significantly improved, and with the consolidated volume, sophisticated picking equipment could be justified and used. Furthermore, fluctuations of online demand could be better absorbed when all the online ordered are pooled together to be processed at the DC. We summarize the advantages and disadvantages of the existing and the proposed approaches in Table 4.

Table 4: Advantages and disadvantages of the existing and the proposed online order handling processes

	Existing approach	Proposed approach
Double handling of goods	Requires double handling	No double handling
Visibility	Lacks visibility	Great visibility
Handling of out of stock events	Out of stock only known when order is picked; alternative	Out of stock will show when order is placed; alternative products can

	products could be picked; refund is often needed	be suggested; no need to arrange for refund
Speed to adopt	Relatively easy to adopt by utilizing picking carts	May require re-design of DC operations
Picking efficiency	Picking efficiency is low due to spread of goods and interference with in-store customers; almost impossible to be automated	Picking efficiency could be significantly higher; offers the opportunity to be automated with appropriate volume
In-store customer experience	Interfere with in-store customers	No interference with in-store customers
Utilization of resources	Utilization of resources could be limited as stores operated independently	Offers significant opportunity to pooling the fluctuations thus better utilization of resources

4.3 Models and sensitivity analyses

In order to quantify the impact of our proposed approach, we build the following two mathematical models to investigate the differences between the existing approach and the proposed approach for online order fulfillment. These models are:

1. Single supermarket chain operating with existing approach, denoted as model *SD*; and
2. Single supermarket chain operating with the proposed centralized approach, denoted as *SC*.

The following notations are used for the mathematical models:

A Service area, measured in km^2.

P_d Population density, measured in number of people/km^2.

H Average people per household.

S Market share of the retailer.

R_a Online shopping adoption rate (i.e., the percentage of households purchasing groceries online).

L	Side length of service square for a supermarket for online orders fulfillment.
$C_{\{SD, SC\}}$	Cost for models *SD* and *SC*.
R_c	Cost ratio between C_{SC} and C_{SD}, i.e., C_{SC}/C_{SD}
N_{SD}	Number of orders that a serving supermarket needs to serve in existing operations.
C	Capacity of delivery trucks in terms of number of orders.
D_{SD}	Number of deliveries required for fulfilling online orders in existing operations for one serving supermarket.
D_{SC}	Number of deliveries required for fulfilling online orders in the proposed approach.
M	Number of supermarkets to serve the service area in existing operations.

Note that in this paper, we are interested in the cost ratio R_c between the existing and the proposed approaches, not the actual costs. When $R_c = 1.0$, both approaches will incur the same costs. When $R_c < 1.0$, the proposed approach will have a cost advantage. In this way, we can eliminate the need of having accurate estimations for common parameters.

Based on the above, the number of supermarkets that will be serving online order fulfillment in the model SD (i.e., existing operations) is:

$$M = \frac{A}{L^2}$$

Note in this case, we ignore the need to round up the numbers as we believe it is possible to accommodate small fluctuations across all serving supermarkets. The number of orders that each serving supermarket will fulfill every day is:

$$N_{SD} = \frac{AP_dSR_a}{7MH} = \frac{L^2P_dSR_a}{7H}$$

Correspondingly, the number of delivery trips per serving supermarket is:

$$D_{SD} = \frac{N_{SD}}{C} = \frac{L^2P_dSR_a}{7HC}$$

In the e-commerce and home delivery scenario, optimal routes will be dependent on the locations of customers. Daganzo (1984) and Burns et al. (1985) estimated that the distance traveled for delivering to *m* randomly located customers within a service area *A* to be $K\sqrt{Am}$, where *K* is a constant based on the distance calculation. In this case, each delivery for existing operations will be:

$$K\sqrt{L^2C} = KL\sqrt{C}$$

Consequently, the total delivery cost C_{SD} will be:

$$C_{SD} = MD_{SD}KL\sqrt{C} = \frac{A}{L^2} \cdot \frac{L^2P_dSR_a}{7HC} \cdot KL\sqrt{C} = \frac{KAP_dSR_aL}{7H\sqrt{C}}$$

For the model SC (i.e., the proposed approach), the number of deliveries every day is:

$$D_{SC} = \frac{AP_dSR_a}{7HC}$$

Area for each delivery is:

$$\frac{7HC}{P_dSR_a}$$

Cost for each delivery is:

$$K\sqrt{\frac{7HC}{P_dSR_a} \cdot C} = KC\sqrt{\frac{7H}{P_dSR_a}}$$

Total delivery cost is:

$$C_{SC} = K\sqrt{A \cdot \frac{AP_dSR_a}{7HC}} + \frac{AP_dSR_a}{7HC} \cdot KC\sqrt{\frac{7H}{P_dSR_a}} = KA\sqrt{\frac{P_dSR_a}{7H}}\left(\frac{1}{\sqrt{C}} + 1\right)$$

Note that the first part of C_{SC} is the cost to get the deliveries to all the delivery areas, and the second part is the delivery cost within all the delivery areas.

As a result, the cost ratio R_c between C_{SC} and C_{SD} is:

$$R_c = \frac{C_{SC}}{C_{SD}} = \frac{KA\sqrt{\frac{P_d S R_a}{7H}}\left(\frac{1}{\sqrt{C}} + 1\right)}{\frac{KAP_d S R_a L}{7H\sqrt{C}}} = \frac{1 + \sqrt{C}}{L}\sqrt{\frac{7H}{P_d S R_a}}$$

We can see from the above that the cost ratio R_c depends on the capacity of delivery vans C, the side length of service square L, and the parameters P_d (population density), S (market share of the supermarket), R_a (adoption rate of online shopping) and H (size of household) which determine the number of online orders per unit area.

As we mentioned earlier, our interest is on the cost ratio R_c. We will first check how R_c behaves using Gold Coast as the case, and then extend for sensitivity analyses. Based on the information presented in Section 3, we take population density P_d = 1,000 people/km^2 for Gold Coast. The household size H is assumed to be 3 per household as per the information from ABS (2021a). Market share for the supermarket S is assumed to be 30%. Number of orders per delivery van C is assumed to be 50 orders/van, and the online purchase adoption rate R_a is assumed to be 20%. The side length of a service square L is assumed to be 5 km, i.e., a supermarket serves a 5 km by 5 km square. Consequently, we have R_c for Gold Coast as:

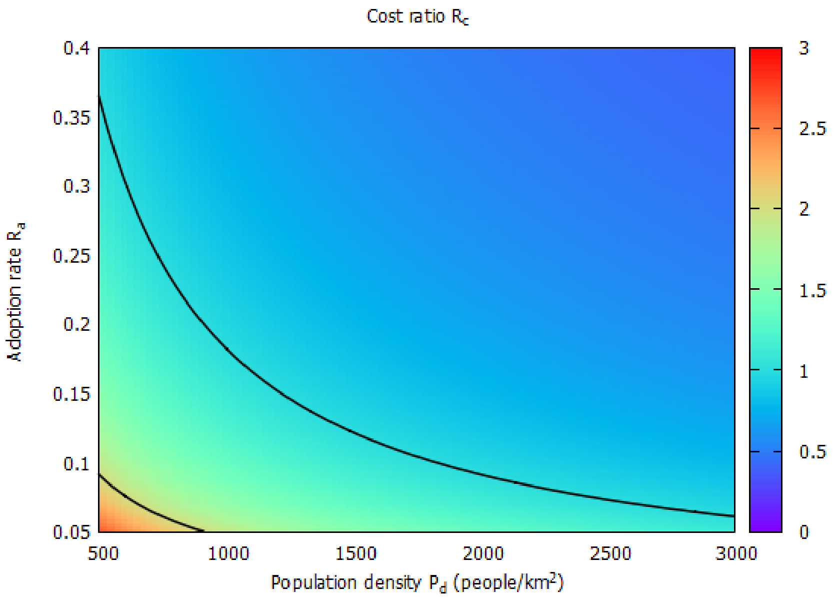
$$R_c = \frac{1 + \sqrt{C}}{L}\sqrt{\frac{7H}{P_d S R_a}} = \frac{1 + \sqrt{50}}{5}\sqrt{\frac{7 \times 3}{1{,}000 \times 0.3 \times 0.2}} = 0.955$$

Based on the above result, we can clearly see that taking a centralized approach has both cost and emission advantages. With the above assumptions for Gold Coast, there is a room of 4.5% savings for both costs and emissions.

Given the clear advantage of the proposed approach, we want to see how the population density and online shopping adoption rate could impact the results. Other parameters could be investigated in a similar way. To achieve this, we let the population density change between

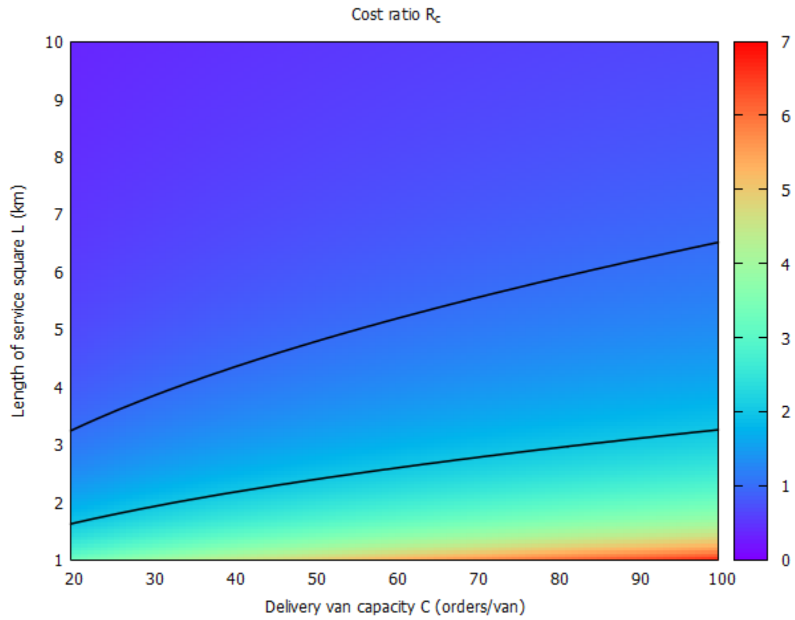
500 and 3,000 people per square kilometer, and the adoption rate of online shopping from 5% to 40%. Other parameters remain unchanged, i.e., $C = 50$, $L = 5$, $S = 30\%$. Figure 4 plots the contour of the cost ratio R_c when the population density and adoption rate change within the given ranges. The first contour curve from the top-right corner indicates where $R_c = 1.0$. We can see that the population density and adoption rate work together to maintain the cost advantage of the proposed approach. Within the $R_c < 1.0$ contour, for a fixed population density, the higher the adoption rate, the more benefits provided by the proposed approach. Similarly, for a fixed adoption rate, the higher the population density, the more benefits provided by the proposed approach.

Figure 4: Contour of cost ratio R_c with different population densities and adoption rates.



Similarly, Figure 5 shows the contour of cost ratio R_c with different van capacities C (ranges from 20 to 100) and side length of service squares L (from 1 km to 10 km), while other parameters remain unchanged, i.e., $P_d = 1{,}000$, $R_a = 20\%$, $S = 30\%$. In this case, the first contour curve from the top-left corner indicates where $R_c = 1.0$. We can see that, in this case, when the side length of service squares L decreases and/or the van capacity increases, the cost advantage of the proposed approach starts to diminish.

Figure 5: Contour of cost ratio R_c with different van capacities and lengths of service squares.



5. Discussion

5.1 Summary of study findings

The aim of this research was to examine how online grocery orders should be fulfilled in areas where the population density is relatively low. Specifically, this study sought to determine whether a centralized order fulfillment approach is better than the existing approach which fulfills online orders from local retail stores. Our qualitative analyses showed that there are several benefits offered by the proposed centralized approach, such as streamlined business processes and better shopping experience for both in-store and online customers. The centralized approach can support policies incentivizing vehicle and infrastructure sharing settings and decoupling the last mile delivery from the core grocery retail services (Aktas et al., 2021). The quantitative results, which were based on the city of Gold Coast, demonstrated clear cost and environmental advantages of the proposed approach. Further sensitivity analyses based on the mathematical model dynamically showed how the parameters such as population density, adoption rate, van capacity, and side length of service square interact with each other.

In fact, we can see from the cost ratio equation that R_c has direct proportionality to van capacity C and household size H, and inverse proportionality to side length of service square L, population density P_d, market share S, and online grocery shopping adoption rate R_a. Note that, $\frac{H}{P_d S R_a}$ in the equation basically represents the number of orders per unit area. Therefore, we can say that R_c has direct proportionality to van capacity C, and inverse proportionality to side length of service square L and number of orders per unit area.

Our results reveal that facilitating a supply chain capable of handling e-commerce operations in grocery retailing can have a positive effect on long-term sustainability, within the given parameters and variable ranges studied. The separation of in-store and online retailing processes improves the shopping experience of customers, especially for in-store customers as they will feel the interference with in-store order picking. Online customers will gain more visibility for the products they want to purchase and can be reminded promptly when a product is unavailable, which improves customer satisfaction and simplifies the payment processes. The separation also means that there will be less double handling and therefore improves the operational efficiency and reliefs some pressure for in-store staff.

Picking orders at a central place could make the processes more efficient. Furthermore, it is possible to harvest more benefits from automation, which is impossible for the existing in-store picking approach. Cost could potentially be a hurdle for automation. However, supermarket chains could apply the idea of co-opetition (Brandenburger & Nalebuff, 2021) and work with other supermarket chains, or stores that have similar needs (e.g., department stores) for such investments in online order fulfillment (Dethlefs et al., 2022). Dispatching online orders from the DC can also accommodate more usage of environmentally friendly delivery vehicles and help build more sustainable grocery retailing supply chains.

5.2 Theoretical implications

From a theoretical perspective, our paper contributes to the sustainable supply chain management literature base by shedding light on the economic and environmental impacts of the transition of online grocery retailing. Doing so in the context of the Australian grocery retailing industry is likely a contribution itself due to the limited research within this domain. However, this does not preclude our findings from being applied in other regions across the world. Our developed mathematical model was built with generalization in mind.

For a given geographical region, the demographic characteristics are fixed. Our mathematical model points to the market share and online grocery adoption rate as the key external parameters to affect the decision regarding how online grocery orders could be fulfilled. Great online shopping experience would be helpful to boost online purchase adoption rate (Kabugumila et al., 2016). In this sense, the benefits discussed for the proposed centralized approach would help create a smoother online shopping experience and contribute to the adoption rate. The other external parameter, the market share, might be difficult to change. However, retailers could utilize the idea of co-opetition (Brandenburger & Nalebuff, 2021) and operate from a centralized location/platform through the concept of e-grocery platform (Wu et al., 2023) to benefit from the collaboration (Aktas et al., 2021).

This paper compares the trend of cost and emission between two approaches to service a given area of consumers. To the best of our knowledge this has not yet been done empirically. As our modeling results showed, in the case of Gold Coast, there is certainly a cost (and thus emission) advantage if the centralized approach is adopted. These findings align with the work of authors such as Doherty and Ellis-Chadwick (2010) and Agatz et al. (2008) in the sense that e-commerce certainly presents many positive opportunities for both consumers and businesses alike.

5.3 Practical implications

Practically, the model built in this paper could be used by practitioners who are interested in conducting their own analyses. The practical implications of such a model are that it provides insight to real-world problems such as assessing whether a certain area could benefit from the centralized approach or not. Furthermore, the side length of service square and delivery van capacity are the parameters that could influence the decision-making but are internal to a grocery retailer. As such, grocery retailers could review their configuration of delivery fleet, as well as their store locations to determine whether they should adopt a centralized approach or fulfill online stores from existing local stores.

Our model could also be used by practitioners to quickly assess their need for change of fulfillment operations. Over time, a grocery retailer's number of online orders could gradually increase or decrease. Once such changes are detected, decision-makers can quickly review their operations and online fulfillment configuration and make necessary changes accordingly.

The sheer size of Australia and low overall population density makes any home-delivery model a difficult task. Since the vast majority of the population is clustered in major cities and near coastal regions, core operations and DCs are typically located near these most densely populated areas for logistical reasons. Our study had this in mind and modeled the problem accordingly. The positive results from our findings could provide assurance to practitioners in revamping their business processes.

6. Conclusion

6.1 Conclusion of research

This study empirically investigated the economic and environmental impact of two online grocery retailing fulfillment practices in Australia. The results contribute to the current understanding of online grocery retailing and its intersection with sustainable supply chain management and last-mile logistics. Our results show that adopting a centralized approach for online order fulfillment in the grocery retailing industry, in most cases, has clear cost, efficiency, and environmental benefits in the last-mile operations. High-level models that were developed in this paper can serve as a decision-making assistance tool for practitioners.

6.2 Limitations and future research

First and foremost, an acknowledged limitation to this research, as is the case with many studies in the field of sustainable supply chain management, is the lack of standardized measurements for sustainability. Hence, we use transport cost as a proxy for economic sustainability, which is further used as a proxy for environmental sustainability. As we were more interested in the differences, we focused on the cost ratio, rather than the actual numbers. While this sufficed for us to reach some conclusions, practitioners might want to have more detailed cost and emission information, for a better-informed decision-making process.

Second, multiple assumptions were required to be made to complete the quantitative analysis. Obviously, the assumptions are generalizations and not entirely accurate for every scenario. This resulted in relatively high-level quantitative analyses in this paper. In reality, numerous uncontrollable factors may also influence last-mile logistics performance and the distance traveled, such as road works, accidents or vehicle breakdowns, time of year (e.g., holidays or special events), and the number of same address deliveries (e.g., high-rise apartment buildings).

Given the above discussed limitations, it is worthwhile to conduct further research in this area. One possible extension of this work is to have a close-to-reality simulation study to examine the actual cost and emissions, taking into consideration more factors such geographical and demographical information. Another area of focus could be to better understand what encourage or discourage customers to use online grocery retailing in Australia, or in other countries and regions with similar population density and living patterns.

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We confirm that the manuscript has been created by the author(s) and not an AI tool/Large Language Model (LLM).

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