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Evolutions of Omni-Channel Fulfillment Performance: An In-Depth Case Study in Grocery Retailing

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ABSTRACT

The rapid adoption of omni-channel strategies has prompted grocery retailers to reconfigure their back-end fulfillment operations to efficiently and effectively meet the demands of online and offline retail channels. Viewing back-end fulfillment operations in omni-channel grocery retail as a complex adaptive system, we present an eight-year multi-method case study of the UK operations of a leading global grocery retailer. Over this period the share of online sales significantly grew as proportion of overall sales. We observe four evolutions in the back-end fulfillment complex adaptive system to respond to the operational demands associated with increasing online sales. Complex adaptive systems theory suggests that such evolutions should eventually lead to a state of equilibrium, where the system is reconfigured to effectively and efficiently respond to the market. However, we observe that this equilibrium was never achieved and propose this results from two opposing and irreconcilable environmental energies preventing optimal adaptation. Drawing on both in-depth interviews and a proprietary fulfillment dataset from the organization, we expose the implications of conflicting energies being imported from the environment, and propose three strategies, drawn from paradox theory, for reconciling these energies within a complex adaptive system.

1 | Introduction

Omni-channel retailing has dramatically changed the shopping experience for customers, as well as the supply chain and fulfillment operations that support it (Ren et al. 2023). Additional channels mean that customers can personalize their experience, shopping for what they want, at any time and from any location (Barann et al. 2022). For example, in addition to completing purchases in-store, retailers may choose to give customers the option of buy-online pick-up-in-store (BOPS) (Cao and Li 2015; MacCarthy et al. 2019), deliveries to the home (Hübner, Holzapfel, et al. 2016), locker boxes (Agnihotri 2015) or even car trunks (Gibbs 2018).

Transitioning to omni-channel is associated with increased revenue (Rosenblum and Kilcourse 2013), convenience for customers (Ailawadi and Farris 2017) and customer loyalty (Armstrong 2016). However, it also creates inefficiencies arising from competing priorities between online and offline channels (Gong et al. 2022) that result in increased distribution costs to fulfill online orders (Thomas et al. 2024), reduced profit margins, and high pressure to cut costs and lead times (Kembro et al. 2022). A recent report by IDG indicated that despite the retail benefits associated with omnichannel, the adoption of omni-channel in logistics presents a significant challenge across the retail sector (Jones 2022). Further, previous studies have made it clear that the introduction of omni-channel retailing might cause significant inefficiencies in a range of functions across a range of industry sectors, including grocery retailing (Wollenburg et al. 2018), footwear (Buldeo et al. 2019), clothing and electrical (Bernon et al. 2016), and general merchandize (Saghiri et al. 2017). Indeed, Hübner, Holzapfel, et al. (2016) uncover inefficiencies across fashion, consumer electronics, and DIY within a single paper. This suggests that (a) there is an efficiency challenge linked to the introduction of omni-channel retailing, and (b) that it is prevalent across different types of retailers. To the best of our knowledge, what is missing in the academic literature is a sense of the magnitude of these inefficiencies, particularly within backend fulfillment operations.

While conceptual studies suggest that the integration of distribution channels should yield synergies (Jeanpert and Paché 2016; Saghiri et al. 2017), empirical research indicates that omni-channel fulfillment and supply chains require significant investment to reconfigure infrastructure to remain flexible and efficient (Abdulkader et al. 2018). Extant literature has focused on the efficiency implications of adding online channels for inventory costs (Nath and Eweje 2021), in-store picking (Wollenburg et al. 2018; Zhang et al. 2021), Ship-to-Store ([STS], Akturk et al. 2018), BOPS (Akturk and Ketzenberg 2022) and last-mile delivery (Lim et al. 2018; Olsson et al. 2019). However, back-end fulfillment studies are underrepresented (Galipoglu et al. 2018; Akturk et al. 2018), with those that do exist being either conceptual (Melacini et al. 2018; Yadav et al. 2018) or cross-sectional and largely qualitative in nature (Buldeo et al. 2019; Hübner, Kuhn, et al. 2016; Wollenburg et al. 2018). Back-end fulfillment is an important context as it represents the marketing–operations interface where retailers must manage complex efficiency and effectiveness trade-offs (Rooderkerk et al. 2023).

Complex adaptive systems (CAS) theory has been highlighted as a useful lens to explore tensions between effectiveness and efficiency (Nilsson and Gammelgaard 2012; Saghiri et al. 2017). A CAS comprises four key elements (Anderson 1999): (1) *Agents with schemata* are individuals, groups, or functions that share a common cognition which determines what action the agents will take (Holland 1992); (2) *Imported energy* from the environment forces the agents to react, reorganizing activity to deal with changing environments; (3) *Coevolution* emphasizes the adaptive nature of CAS, where agents are forced to react to the environment and to other agents, leading to agents modifying their schemata (Holland and Miller 1991); and (4) *System evolution based on recombination*, which examines how new agents emerge after periods of unsettled activity (Pathak et al. 2007). When applied to the shift to omni-channel, CAS theory would suggest that tensions will exist until a preferred state of equilibrium between fulfillment operations and the environment is reached (Anderson 1999).

We build on the study of Saghiri et al. (2017), which recognizes omni-channel as a CAS, by adopting a longitudinal quasi-experimental case study design, combining description, narrative, and quantitative data collection and analysis within the UK operations of a leading global omni-channel grocery retailer to explore the flexibility–efficiency tension as they progress from a largely bricks-and-mortar retailer in 2012 to a full-service omni-channel retailer by 2019. We use semi-structured interviews to identify flexibility–efficiency tensions in responding to the omni-channel environment and expose the four main systems evolutions the case organization implements (a change to ambient delivery times; commencing third-party order delivery; the opening of a new parcel sortation DC; and, changing the chilled distribution delivery windows). These systems evolutions are an attempt to adapt to the customer proposition in an evolving environment and uncover the adaptations to agents' schemata used in addressing the emerging tensions. We then use a quasi-experimental approach on a proprietary dataset from January 2012 to December 2019. Our dataset includes daily sales performance from the distribution and retail store operations to identify the magnitude and type of fulfillment efficiency gains/losses experienced by the retailer through each of the system evolutions.

Our study makes the following contributions. First, we advance the omni-channel literature by quantifying the magnitude of fulfillment operations inefficiencies associated with the transition to an omni-channel customer proposition in the grocery retail context. This extends previous research that was either conceptual or qualitative in nature and provides further evidence that, at least in the short term, omni-channel will directly impact the efficiency with which retailers can manage their fulfillment logistics. Second, we leverage the strengths of our longitudinal quasi-experimental research design to show that the implementation of omni-channel cannot be captured in a single, one-off event but as a series of specific interventions that are required within the case study's fulfillment operations to deliver its new customer proposition. We find that increases in online sales (BOPS and to-store delivery of home shopping combined) lead to an increase in internal complexity, reducing flexibility and efficiency with every increase in internal complexity. In explaining this, we thirdly contribute to the CAS literature regarding the implications of conflicting energies being imported from the environment. In contrast to many empirical CAS investigations, we find that online and offline demand import distinct and oppositional energies from the environment. This creates considerable and irreconcilable differences in the schemata for fulfillment agents operating in each space, leading to a CAS cycle where self-organizing networks, coevolution, recombination, and systems evolution (Anderson 1999) fail to progress to a preferred state of equilibrium. Even the evolution of CAS subsystems fails to address issues of efficiently fulfilling the omni-channel proposition due to the need to integrate channels in second-stage fulfillment. This leads us to propose three potential strategies for exiting a problematic CAS cycle by adapting strategies identified in the paradox theory literature.

2 | Literature Review

This section gives an overview of the emergent themes in omni-channel fulfillment research, then explores the use of CAS as a lens for understanding the operational implications of omni-channel adoption.

2.1 | Omni-Channel Retailing

An omni-channel retail strategy focuses on providing customers with a seamless integration of sales and distribution channels across both online and physical retail touchpoints (Abdulkader et al. 2018; Verhoef et al. 2015). To achieve this proposition, retailers demand an omni-channel supply chain and fulfillment solution that is both cost-effective and responsive to customer needs, regardless of channel choice or customer journey (Chopra 2018). While omni-channel supply chains are defined as integrated (Ailawadi and Farris 2017), in practice, they are often independent channels with conflated front- and back-end logistics (Kembro et al. 2018; Wollenburg et al. 2018). This conflation is an attempt to reduce costs, but in practice, retailers attempt to ship all products through their existing distribution system rather than redesign their infrastructure (Abdulkader et al. 2018; Lim et al. 2024). To deliver on the customer proposition, product selection for all channels is integrated at the distribution center level (Hu et al. 2022). This practice creates complexities, as distribution systems vary according to the channel used and type of product purchased (Jeanpert and Paché 2016; Lim et al. 2024). Additionally, online sales are difficult to forecast owing to high dynamics and strong growth (Hübner et al. 2015). It is important that this additional complexity is effectively managed, as the online channel cannot be to the detriment of the offline, where customers still demand fresh products and a great experience (Kuhn and Sternbeck 2013).

Extant empirical work investigates the transactional implications of STS and BOPS on sales and returns (Akturk et al. 2018; Akturk and Ketzenberg 2022; Hu et al. 2022) and customer responses to fulfillment lead times over different channels (Lim et al. 2024); however, there is limited empirical examination of the impacts of transitioning to an omni-channel proposition on fulfillment operations. Hübner, Holzapfel, et al. (2016) propose that omni-channel fulfillment can be understood in terms of two stages: "back-end fulfillment" which is concerned with the picking and packing of orders, and "last-mile distribution" which is concerned with delivery to the end customer. Extant work explores the profitability of the last-mile distribution stage (for recent reviews, see Lim et al. 2018 and Olsson et al. 2019). However, "back-end fulfillment" studies are under-represented in the literature (Galipoglu et al. 2018; Kembro et al. 2018).

Back-end fulfillment can be conceptualized as comprising three dimensions: distribution network design, inventory and capacity management, and delivery planning and execution (Hübner et al. 2015; Melacini et al. 2018). Distribution network design is defined as the strategic configuration of distribution capabilities and logistics to efficiently manage the flow of goods and services from points of production to points of consumption (Melo et al. 2009). Studies have shown that omni-channel can reduce productivity at distribution centers and in stores as offline and online orders are integrated, causing lower picking efficiency (Ishfaq and Bajwa 2019; Hübner, Kuhn, et al. 2016; Hübner et al. 2015). The suggested explanation is that distribution centers are configured to ship large quantities of products to a small number of store locations, not individual items to a large number of customer locations (Hübner et al. 2015). Moreover, it can also negatively impact logistics efficiency as retailers increase the number of drops per shipment to accommodate the reduced lead time associated with online retailing (Buldeo et al. 2019; Melacini and Tappia 2018; Wollenburg et al. 2018).

Finally, omni-channel also impacts delivery planning and execution, defined as the strategic and operational processes used to ensure that goods are delivered to customers efficiently and effectively (Cudzilo and Voronina 2020). The objective of delivery planning and execution is to optimize delivery routes and schedules to reduce costs, improve service levels, and enhance customer satisfaction (Campbell and Savelsbergh 2005). The challenge in this part of the fulfillment network largely stems from the need to increase the number of channels (and associated services) to the customer while simultaneously attempting to reduce costs in order to compete within the retail sector (Hübner, Wollenburg, et al. 2016). These studies provide valuable evidence to suggest a link between the implementation of omni-channel and the efficiency of back-end fulfillment; they are, however, largely conceptual (Chopra 2018; Jeanpert and Paché 2016; Yadav et al. 2018) or qualitative (Buldeo et al. 2019; Hübner, Holzapfel, et al. 2016; Melacini and Tappia 2018; Wollenburg et al. 2018) in nature and are in need of testing empirically. This leads us to our first proposition:

P1. *An omni-channel strategy reduces the efficiency of back-end fulfillment.*

Despite the cross-sectional nature of extant empirics on omni-channel retailing (Buldeo et al. 2019; Hübner, Holzapfel, et al. 2016; Wollenburg et al. 2018), approaches to delivering on the customer proposition are emergent over time (Melacini and Tappia 2018; Wollenburg et al. 2018). To address the complex dynamics of fulfillment efficiency in omni-channel retail, we, therefore, turn to CASs to unpick the managerial dilemmas associated with adapting the fulfillment network to address the inefficiencies which emerge when implementing an omni-channel strategy over time.

2.2 | Omni-Channel Fulfillment as a CAS

Saghiri et al. (2017) wrote the first study proposing that omni-channel retail operates as a CAS. A key feature of a CAS is that it contains many parts with many interactions (Anderson 1999). Omni-channel systems are similarly characterized by multiple customer touchpoints (Verhoef et al. 2015) with heterogeneous operational activity (Ailawadi and Farris 2017), supported by many integrated supply chain stakeholders (Hübner, Wollenburg, et al. 2016). In a CAS, the typical response to increased environmental complexity is increased internal complexity (Galunic and Eisenhardt 1994; Schneider et al. 2017). This is also observed within omni-channel systems by the adoption of technology infrastructures to meet customer service demands (Hübner et al. 2021; Verhoef et al. 2017) and the transformation of distribution and supply networks to enhance the customers' value-added journey (Lim et al. 2024; Wollenburg et al. 2018). Omni-channel retailers, therefore, have complex systems, with levels of both internal and external organizational hierarchy, controlling departments and functions over geographical locations (Pereira et al. 2018). Due to these factors, it is appropriate and useful to adopt a CAS lens to understand omni-channel and its efficiency challenges over time.

A CAS comprises four key elements often represented as a cycle (Anderson 1999). (1) *Agents with schemata* can be an individual, a group, or a function. Still, their agency is determined by their schemata, which are a common cognition shared by the members that determines what action the agents will take (Holland 1992). A review of the extant literature would suggest agents in the omni-channel system would include retail stores (Brynjolfsson et al. 2013; Gao and Su 2016), logistics providers (Lim et al. 2018), suppliers (Galipoglu et al. 2018), distribution centers (Galipoglu et al. 2018; Hübner, Holzapfel, et al. 2016), store merchandisers (Armstrong 2016) and centralized logistics teams (Ishfaq et al. 2016). Agents in a CAS are partially connected to each other to the extent that the actions of a particular agent depend on the actions of the other agents in the system. Agents are connected to one another through feedback loops, meaning that each agent observes and acts upon local information obtained from those other agents to whom they are connected (Anderson 1999). The result is that omni-channel agents act based on their own priorities, interests, and capabilities (Saghiri et al. 2017). (2) These agents are influenced by environmental stimuli (change in the operational environment), which cause them to develop self-organizing networks sustained by *importing energy from the environment*. CAS defines energy as the stimuli that force agents to organize themselves in a certain way (Prigogine and Stengers 1984). In the omni-channel context, energy is the requirements of the retail channels in terms of the range of goods offered and replenishment lead times. These environmental stimuli force the agents to react, organizing activity to deal with these elements (Holland and Miller 1991). (3) This constant shifting of agent behavior creates a *coevolution* of the system and the environment (Oughton et al. 2018). This coevolution produces a system that is then forced to create new opportunities to survive (Nilsson and Darley 2006). The process of coevolution has forced the omni-channel system to adopt more customer touchpoints (Caro and Sadr 2019; Rodríguez-Torrico et al. 2020) and modify the supply chain significantly to support this augmented proposition (Ailawadi and Farris 2017; Galipoglu et al. 2018). (4) After periods of unsettled activity, resulting from the agents trying to adapt to each other and their environment and learning from previous experience, new agents ultimately emerge (Pathak et al. 2007), resulting in *system evolution based on recombination*. Based on this premise, it is possible for a CAS to contain other "sub" CASs (Gell-Mann 1995). Again, this is observed in the omni-channel CAS through subsystems such as last-mile delivery networks (Lim and Winkenbach 2019), omni-channel returns (Akturk et al. 2018) and reverse logistics networks (de Borba et al. 2020), which could justifiably be viewed as CASs (in their own right) and encompass new agents in the system with new schemata.

Complexity theory posits that organizations act unpredictably because they are nonlinear (Casti 1994). This means that small operational changes can result in significant changes in performance (Holland 1992; Rousseau and House 1994). Similarly, large operational changes can result in little or no change in performance. By focusing on the components of an organization, the rules they follow, and how they interact with the external environment, CAS models demonstrate how complex outcomes flow from these simple interactions (Anderson 1999; McCarthy et al. 2006; Miller and Page 2009).

Regarding efficiency, CAS theory posits that adapting schemata and reconfiguring systems to respond to the energy imported from the environment should make the CAS more efficient over time or fail to survive (Nilsson and Darley 2006). The agents of a system will, therefore, strive to adopt the most efficient schemata (Dougherty et al. 2017). The agents make incremental changes in the CAS to maintain a balance point (Goldstein 1994). This balance point allows the system to maintain efficiency while enabling it to respond to environmental changes (Choi et al. 2001). Saghiri et al. (2017) found that omni-channel is a self-organized system capable of adjusting processes and resources quickly to meet environmental fluctuations. In the context of omni-channel retail, the reconfiguring is first likely to result in increased system complexity, but with subsequent evolutions, the internal complexity will be reduced, leading to increased back-end fulfillment efficiency (Zhao et al. 2019). This leads to our second proposition:

P2. *System evolutions in the omni-channel CAS lead to improved fulfillment efficiency over time.*

3 | Data and Methodology

3.1 | Research Setting

We collaborated with a global grocery retailer headquartered in the United Kingdom. The retailer operates over 600 stores and 20 distribution centers, employs more than 140,000 staff, and generates revenues above £20bn p.a. The UK is the most advanced and fastest-growing OECD country in terms of online grocery sales (Kantar 2019; Simmons et al. 2022), and therefore represents an ideal context for our study. Our retail partner operates within an oligopolistic market where the top four retailers hold 67.1% of the market share (Statista 2023). At the time of our data collection, it faced challenges from evolving technology, changing patterns of consumption, and low profitability.

Our study focuses on the period between January 2012 and December 2019 to remove the major effects of changing grocery shopping patterns associated with COVID-19 regulations. The period from 2012 saw this retailer move from a predominantly brick-and-mortar retailer to an established omni-channel retailer by 2019. The change in omni-channel activity between these two points in time is considerable; in 2012, this retailer sold an average of 304,535 online grocery items per week, which increased to 31,599,218 by 2019. Similarly, in 2012, the retailer did not sell any non-food items (e.g., clothing or electrical products) online. By 2019, an average of 32,812 such items were sold online per week, making it a particularly revelatory case for investigating the development of omni-channel fulfillment operations.

The case organization decided to transition from a brick-and-mortar grocery retailer to an omni-channel grocery retailer as a direct response to competitor activity. The case organization was not the first of the big four to adopt an omni-channel proposition, but they realized if they failed to integrate an online retail channel, then they would be offering inferior service to their competitors, and this would likely damage their position within the market. The grocery retail market experienced intense competition in the period observed. Increasing competition from discounters and pure-play online retailers led the retailer to lose market share. Net profits rose from 2.68% in 2012 to a 3.96% peak in 2016, declining to 2.55% in 2019. During that time, the online channel experienced significant growth against a decline in total retail sales. While this aided profits in the beginning, a mixture of the cost of operating omni-channel and channel cannibalization resulted in eroded profits.

3.2 | Data Description

Data was recorded between January 2012 and December 2019 at weekly time intervals and comprised 404 observations across each variable. To disaggregate the weekly observations to daily observations, we used observed daily weights to calculate daily observations (Hendry and Richard 2003). The dataset is split between Ambient and Chilled product lines, as different distribution centers and trucks are used to fulfill orders for these separately, which are combined at the store level when merchandising and servicing BOPS or home delivery. Distribution performance data was extracted from weekly depot performance reports. *Volume*, *cases per journey (CPJ)* and *miles per store journey (MPSJ)* are key distribution performance metrics recorded by the case organization. The online sales data for the years 2012–2015 was gathered from the organization's database. A change in software in 2016 meant that this data was not available in the same format, so third-party data from the Institute of Grocery Distribution (IGD.com) was used to calculate the online sales data for 2016–2019 (as per Cantelmo et al. 2020). The third-party data was at the annual level, so we used the known daily online distribution volume levels as a proxy (Fisher and Raman 1996) to estimate online sales activity at the daily activity measurement level.

We also collected qualitative data to identify the four main system evolutions within the fulfillment operations (set out in Section 4.2) undertaken to address the external shocks experienced in adapting to an omni-channel proposition. This provides an understanding of the "how" and "why" of these changes. We conducted interviews with 15 senior managers (see Table 1 for details) who had significant responsibility for the management of omni-channel fulfillment. Interviews lasted between 50 and 90 min and were recorded and transcribed immediately after the interviews to ensure descriptive validity (Beverland and Lindgreen 2010).

TABLE 1 | Interviewee positions.

Position of participant	Number of participants
Director, supply chain strategy	1
Senior manager, grocery home shop	1
Senior manager, supply chain	2
Senior manager, inventory management	1
Senior manager, supply chain finance	1
Senior manager, fulfillment planning	2
Senior manager, strategy	1
Senior manager, 3rd party operations	1
Senior manager, retail	2
Senior manager, distribution operations	2
Senior manager, primary transport	1

3.3 | Methodology and Research Design

Our methodology and research design consists of three stages. First, we use descriptive analysis and OLS regression to explore our first proposition. Specifically, we observe the relationship between online sales as a percentage of total sales, x_1, and back-end fulfillment efficiency between 2012 and 2019. Given that our case is a traditional brick-and-mortar retailer transitioning to omni-channel with the addition of online channels (home delivery and BOPS), omni-channel activity is operationalized as the value of online sales as a percentage share of total retail sales. As home delivery and BOPS are delivered to store as part of outbound logistics and shipped at the same time through the same system, this measure captures the entirety of the change to fulfillment operations and is an appropriate measure of omni-channel activity (cf. Hübner, Kuhn, et al. 2016; Teixeira et al. 2022). We examine two critical forms of back-end fulfillment efficiency: logistics efficiency and route efficiency (Léonardi and Baumgartner 2004). Logistics efficiency measures vehicle fill and is concerned with increasing the load factor. This is represented by the dependent variable of CPJ (the number of cases invoiced from depot to stores divided by the number of store deliveries). Route efficiency is concerned with the optimization of the route taken and is represented by the dependent variable MPSJ (the total number of miles divided by the number of store deliveries). A store journey is a route taken by a delivery vehicle that originates and terminates at the distribution center and is made to deliver goods to one or multiple stores each trip. The OLS regression model is presented in Equation (1):

$$y = \beta_0 + \beta_1 x_1 + \varepsilon \tag{1}$$

where y is the measure of back-end fulfillment efficiency, β_0 is the intercept, β_1 is the coefficient of online sales, x_1 is online sales as a percentage of total sales, and ε is the error term. We implement this model six times; three times for CPJ in the contexts of ambient, chilled and total deliveries and three times for MPSJ in the same manner.

Second, we integrate the interview data with the quantitative to analyze our second proposition. We employ segmented regression with interrupted time series design to explore whether system evolutions in the omni-channel CAS lead to improved fulfillment efficiency over time. Interrupted time series design is a quasi-experimental approach commonly used to evaluate the impact of an intervention over time (Song and Noyce 2019; Fuller et al. 2019; Li et al. 2021). It has been used extensively in many areas of study to assess the impact of change is policy and practice, such as transportation (Li et al. 2021), assessments of health technology (Ramsay et al. 2003), and policy interventions (Wagner et al. 2002). It is of particular value in studies such as this one where control groups are impractical. Here, we apply segmented regression with interrupted time series to estimate the magnitude of an intervention (in our case, system evolutions), by estimating the trend change in outcome variables (CPJ and MPSJ) associated with the changes in management practice (Bernal et al. 2017). In the first step, we use an open coding approach to develop a timeline that distinguishes distinct periods of systems evolution, the relevant agents, and their respective schemata to gain an understanding of the different periods of adaptation (Yin 1994). In the second step, we progress to alternating between open and axial coding to organize these codes into themes to better understand the new systems and the agents' schemata (Hashimov 2015). Internal validity was ensured through the use of constant comparative analysis, whereby responses from multiple respondents were compared for consistency (Strauss and Corbin 1994). External validity was ensured by comparing interview responses to the quantitative data where the effects of system evolutions were visible with changes in delivery times, routing changes, and vehicle utilization (George et al. 2022; Johnston et al. 2019; Friesike et al. 2019). The impact of these changes was then tested through the segmented regression with interrupted time series design.

3.4 | Segmented Regression With Interrupted Time Series Model and Model Checks

Our methodology employs a single in-depth case study that examines the transition to omni-channel retailing and subsequent system evolutions directly following this change. The segmented regression with interrupted time series model comprises only time-related variables: *time, intervention*, and *time after intervention*, as presented in Equation (2)

$$Y_t = \beta_0 + \beta_1 * \text{time}_t + \beta_2 * \text{intervention}_t + \beta_3 * \text{time after intervention}_t + \varepsilon_t \tag{2}$$

where for each day (t), Y_t is the dependent variable (CPD or MPSJ), time_t is the number of days since the beginning of the observation period, intervention_t is a dummy variable which takes a value of 1 only if the intervention has been made by day t, and $\text{time after intervention}_t$ counts the number of days since the intervention, taking a value of zero if an intervention has not occurred by day t, and ε_t is the error term. The coefficient β_0 represents the intercept, β_1 relates to the pre-intervention slope, which estimates the trend of the dependent variable before the intervention, β_2 is an estimation of the change in level at the estimation point, β_3 is an estimation of the change of slope from pre- to post-intervention.

The error term ε_t consists of a normally distributed random error and an error term at time t that may be correlated to errors at preceding or subsequent time points (Wagner et al. 2002). As the dependent variables occupy very different scales of measurement, we standardized the data to enable meaningful comparison (Murad et al. 2019). To address potential autocorrelation between an error term and its previous error terms, we employ an autoregressive error term in the segmented regression with interrupted time series model as expressed in Equation (3)

$$\varepsilon_t = \phi_1 \cdot \varepsilon_{\{t-1\}} + \phi_2 \cdot \varepsilon_{\{t-2\}} + \dots + \phi_p \cdot \varepsilon_{\{t-p\}} + u_t \tag{3}$$

where $\phi_1, \phi_2, \dots, \phi_p$ are the autoregressive parameters and u_t is the white noise error term.

To ensure stationarity, we differenced the dependent variables when estimating each model. An exploration of the AR (1) coefficient confirmed that autocorrelation was not a concern in any of the models, as in all models the AR (1) value was 1, indicating effective adjustment for autocorrelation (Greene 2003). We employed *Online Share* as an instrumental variable and used the Hausman specification test to test for endogeneity in the models (Nakamura and Nakamura 1998) (see Appendix 1). The robustness analysis conducted indicates that the models are robust and control for endogeneity (Lu et al. 2018).

4 | Results

4.1 | Proposition 1

P1 suggests that the introduction of an omni-channel strategy reduces the efficiency of back-end fulfillment for a grocery retailer. We predicted that the additional complexity of planning, managing, and executing multiple channels would negatively impact their efficiency. Our descriptive analysis, provided in Figures 1–4, shows the impact of an increase in the percentage of online sales on CPJ and MPSJ for both the ambient and chilled distribution channels and shows the timing of system evolutions we use in analyzing Proposition 2.

Figure 1 focuses on the ambient back-end fulfillment channel. It shows the trend of CPJ in relation to the share of online sales as a percentage of total retail sales over time. The graph identifies the first three evolutions of management practices in response to increasing online sales.

Figure 2 focuses on the ambient back-end fulfillment channel. It shows the trend of MPSJ in relation to the share of online sales as a percentage of total retail sales over time. The graph identifies the first three evolutions of management practices in response to increasing online sales.

Figure 3 focuses on the chilled back-end fulfillment channel. It shows the trend of CPJ in relation to the share of online sales as a percentage of total retail sales over time. The graph identifies the fourth evolution of management practice in response to increasing online sales.

Figure 4 focuses on the chilled back-end fulfillment channel. It shows the trend of MPSJ in relation to the share of online sales as a percentage of total retail sales over time. The graph identifies the fourth evolution of management practice in response to increasing online sales.

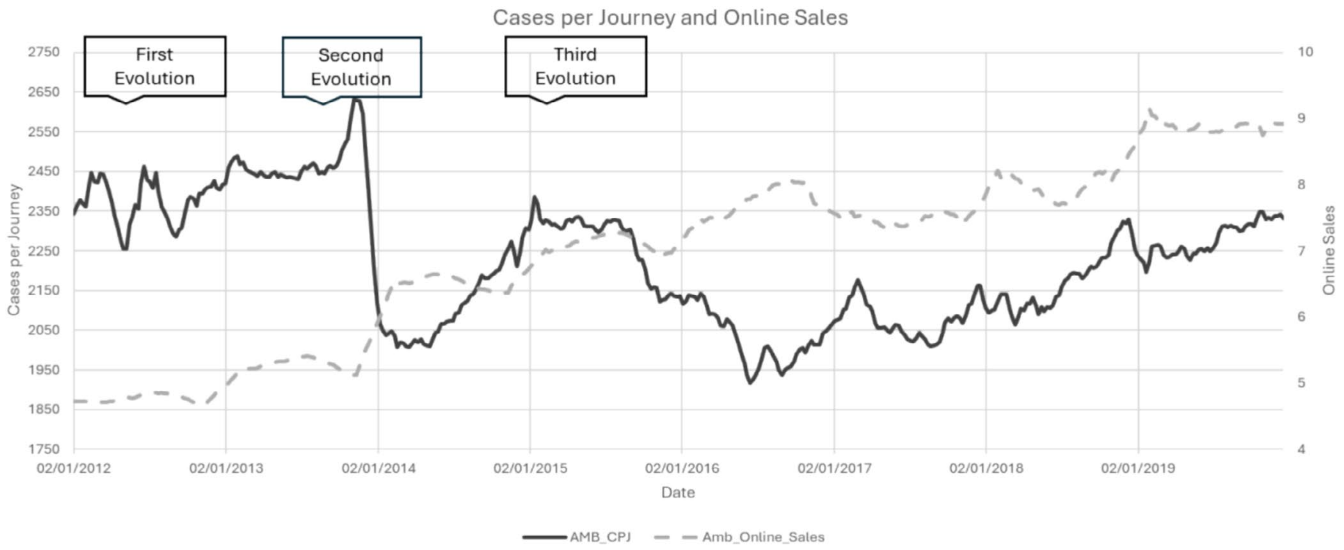

FIGURE 1 | Ambient cases per journey and online Sale.

FIGURE 2 | Ambient miles per store journey and online sales.

FIGURE 3 | Chilled cases per journey and online sales.

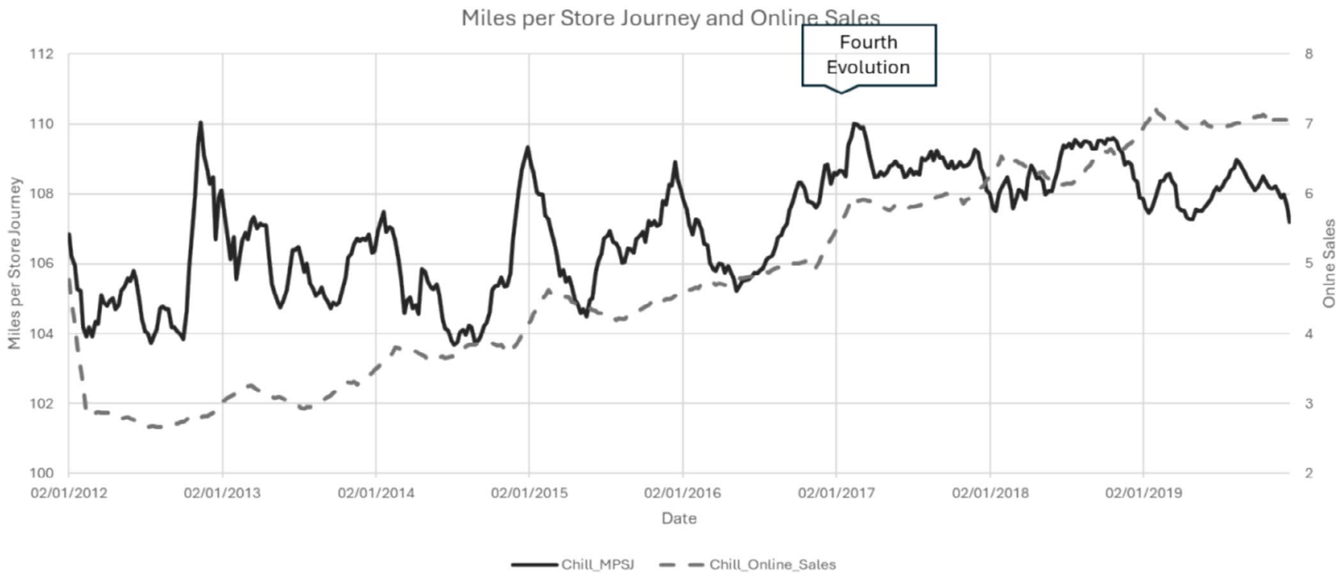

FIGURE 4 | Chilled miles per store journey and online sales.

The implications of an omni-channel strategy grew over the 2012–2019 time period. While online sales represent a relatively small share of total sales at the start of our analysis (4.83% of total ambient sales and 2.67% of total chilled sales), they become much more significant over the 7 years of our analysis (10.14% of total ambient sales and 8.15% of total chilled sales). Our qualitative analysis also highlights this trend:

> Because we have had so much growth in the online channel we have now run out of space in the network. We have been growing and growing and growing and we have taken more space and it's not great space we're going to sort things and we burst on storage each time.
>
> (Senior Manager, Inventory Management)

> Areas of omni-channel grow faster than the core business so it's definitely the growth and the strategy for the future.
>
> (Senior Manager, Grocery Home Shop)

When considering the data over time, a relationship between online sales and back-end fulfillment performance is evident in both the chilled and ambient distribution networks. In the ambient network, low levels of online sales were associated with an increase in CPJ. However, higher volumes of online sales have caused a reduction in CPJ due to multiple operational changes, as we discuss in Section 4.2. In line with the observations made with respect to chilled fulfillment, an increase in ambient online sales is also associated with an increase in MPSJ.

> If we weren't waiting for the online stock, then we could schedule our deliveries better, which would save us miles and also get the stock there earlier.
>
> (Senior Manager, Depot Operations)

In the chilled network, our data suggest that an increase in online sales are associated with a reduction in CPJ. Additionally, our data suggest that increases in online sales tend to be associated with increases in MPSJ. Interviewees explained that this was due to online orders, which were initially low in volume, filling up existing capacity on loads and being picked and packed effectively in-store. However, as online orders increased, they found that there was insufficient capacity in the distribution system to meet this demand, and they had to consider alternative approaches to fulfill the online channel. Each of these panels highlights a different response of back-end fulfillment efficiency to increased online sales. This descriptive understanding of the dataset indicates that further inferential statistical analysis is warranted to explore the nature of the relationship between the variables.

For several reasons, we chose ordinary least squares (OLS) regression to analyze our data. First, exploring the cross-sectional relationship between observations reduces the likelihood of biased statistical inference, as observations that are correlated over time, such as those found in panel data analysis, contain less information than independent observations (Cameron and Trivedi 2005). Additionally, OLS regression is superior in settings where the focus is on a limited number of predictor variables, as it allows for the interpretation of the relationship between the predictor and the outcome variable. This clarity is sometimes obscured in more complex models, such as fixed-effects or random-effects models, which are better suited for panel data with a substantial number of cross-sectional units (Wooldridge 2010).

Potential issues with OLS regression need to be addressed, namely violation of the normality assumption, heteroscedasticity, and multicollinearity (with the constant term). After computing the dependent and independent variables, we verified that the predicted residual scores met the assumptions of normality, consistent variance, and independence

(Wooldridge 2010) for each of the models. The Jarque-Bera test (Jarque and Bera 1980) for residual normality indicated that the standard errors were normally distributed in the models ($p > 0.5$). The Breusch-Pagan (Breusch and Pagan 1979) and White (White 1980) tests suggested that heteroscedasticity was a concern in both models. To address the concerns relating to heteroscedasticity (Petersen 2008), the OLS regression analysis was completed with robust standard errors clustered at the unit level (Koenker and Hallock 2001). As a final test, we employed Instrumental Variable Estimation analysis to test for endogeneity in the models (see Appendix 2).

Table 2 shows our regression models that test the effect of an omni-channel strategy on back-end fulfillment efficiency. Models (1) and (2) analyze the impact of online sales activity upon back-end fulfillment at the system level, models (3) and (4) the impact of online sales upon back-end fulfillment efficiency for the ambient distribution subsystem, and models (5) and (6) the relationship for the chilled distribution subsystem. The *F*-statistics for each model are significant for each model, except model (2), signifying the fit of most models for the data. Overall, and in line with proposition one, we find broad support that an omni-channel strategy reduces back-end fulfillment efficiency, specifically that it has a significant and negative effect on CPJ and a significant and positive effect on MPSJ. At a system level, increased omni-channel activity is associated with a significant reduction in CPJ ($\beta = -52.89$, $p < 0.000$), but the relationship between omni-channel activity and MPSJ is not significant. At the subsystem unit of analysis, increased omni-channel activity has a significant and negative effect on CPJ ($\beta = -53.19$, $p < 0.000$) and MPSJ ($\beta = 0.37$, $p < 0.000$) for ambient back-end fulfillment and a significant and positive effect on CPJ ($\beta = 8.38$, $p < 0.000$) and a negative and significant effect on MPSJ ($\beta = 0.54$, $p < 0.000$).

TABLE 2 | OLS regression with robust standard errors.

Dependent variable	Independent variable	Coefficient (robust std. error)	R^2
Combined CPJ (1)	Online sales	−52.887 (2.329)***	0.58
	Intercept	1994.064 (15.392)***	
Combined MPSJ (2)	Online sales	−0.246 (0.053)***	0.03
	Intercept	96.855 (0.327)***	
Ambient CPJ (3)	Online sales	−53.108 (3.144)***	0.23
	Intercept	2655.122 (22.334)***	
Ambient MPSJ (4)	Online sales	0.372 (0.054)***	0.05
	Intercept	96.270 (0.346)***	
Chilled CPJ (5)	Online sales	8.376 (1.990)***	0.02
	Intercept	1316.916 (9.500)***	
Chilled MPSJ (6)	Online sales	0.539 (0.042)***	0.17
	Intercept	104.144 (0.236)***	

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

4.2 | Proposition 2

P2 suggests that evolutions in the CAS would help the organization adapt to the introduction of omni-channel, improving efficiency over time. The senior management team of the grocery retailer identified four system evolutions over the period 2012–2019 that were specifically introduced to help manage the external shocks to the system caused by the evolving environment of the omni-channel strategy within back-end fulfillment. The first three shocks occurred in the ambient distribution subsystem. The first shock occurred on 4 June 2012 in a dataset ranging from 13 February 2012 to 7 January 2013. The second shock occurred on 2 September 2013 in a dataset ranging from 7 January 2013 to 29 December 2014. The third shock occurred on the 7 September 2015 in a dataset ranging from 5 January 2015 to 4 November 2019. The fourth shock occurred in the chilled distribution subsystem on 2 January 2017 in a dataset ranging from 13 February 2012 to 23 September 2019. These are discussed below, including results from our qualitative interviews and the segmented regression analysis.

4.2.1 | System Evolution 1: Ambient Delivery Times

The first evolution in schemata described by the management participants was a shift in the delivery windows used to fulfill products from ambient distribution centers. Before omni-channel was introduced, ambient products were scheduled with a delivery window of 06:00–22:00 to ensure stock could be merchandised overnight, ready for the following day's trade. The introduction of online ordering for customers meant that the delivery window needed to be reduced by 8 h to 06:00–14:00 to ensure they would be sorted, picked, and ready for collection the next day. This evolution in schemata resulted in efficiency challenges for the agents managing ambient fulfillment:

> Most stores get their ambient product delivered in 2 hits, one at the start of the schedule, and one at the end, but guess what's in the middle–that click and collect delivery with a 2 pm deadline. The first delivery is too early because the trunk hasn't arrived at the depot and the second one is too late. Now I've got to get this other channel product to the shop, I've got to add it to a delivery for a nearby store and deviate.
>
> (Senior Manager, Distribution Operations)

> Any extra deliveries resulting from store requests we must defer to head office, so they put it in the poll for

> the next day, on the next available planned delivery, rather than add it to the current delivery schedule.
>
> (Senior Manager, Fulfilment planning)

The evolution of schemata put pressure on the distribution center to send deliveries earlier, creating pressure on completed loads, increasing the need for multi-store top-up deliveries and increasing MPSJ. The result of the segmented regression analysis for the first system evolution can be seen in Table 3. These results indicate that the evolving schemata, which reduced the delivery window for ambient product fulfillment, did not have a statistically significant impact on the CPJ measure. However, the new schemata impacted the routing efficiency of the distribution vehicles, resulting in a 0.6781 standardized unit increase in MPSJ as a result. Whilst this may appear small, in the context of the case organization, the impact was that the distribution fleet traveled an average of 524 more miles per day due to this shift in schemata.

The emergent narrative from the case at this stage, at both distribution center and store levels, is that online sales create additional activities, which complicate fulfillment. This is in line with previous studies, which indicate that omni-channel fulfillment is associated with increased complexity (Ishfaq et al. 2016; Jones et al. 2022; Pereira et al. 2018).

4.2.2 | System Evolution 2: Third-Party Order Delivery

To offset the increased costs associated with the enhanced service demanded by the online channel, the case organization collaborated with other retailers to use their distribution infrastructure for third-party order delivery:

> It's a service that has grown significantly over the last two years in particular, so here we collaborate with many significant brands, many fast fashion retailers and get their customers coming into our stores to collect those items and hopefully spend some money when they're in the shop as well.
>
> (Senior Manager, Strategy)

As well as downstream collaboration, the retailer started to work more closely with their suppliers to coordinate delivery schedules within back-end fulfillment:

TABLE 3 | Segmented regression with interrupted time series for System Evolution 1.

	Cases per journey	Miles per store journey
Post intervention	0.337	0.678***
N	96	96
R^2	0.963	0.969
AR (1)	1.000***	1.000***

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

> We did a lot of work with suppliers to move our inbound profile earlier to allow us to get into the store earlier.
>
> (Senior Manager, Primary Transport)

These findings are consistent with prior literature that supply chain collaboration is a key enabler of omni-channel fulfillment (Bijmolt et al. 2021; Melacini et al. 2018). We extend the current understanding of the benefits of collaborations by demonstrating how retailers can extend their omni-channel distribution CAS by incorporating network agents into their system to generate revenue, thereby offsetting the impact of the inefficiencies associated with the misalignment of energies imported from the environment.

> We offer the opportunity for retailers to come and work with us and allow their customers to either collect or return an order in our store network. It's a service that we launched the back end of 2013 and has grown significantly.
>
> (Director, Supply Chain Strategy)

However, while the case organization realized direct financial benefits resulting from the collaboration with third-party retailers, the increased volume flowing through the online distribution channel created significant efficiency challenges for fulfillment operations.

> It has made things a lot more volatile. From a brick-and-mortar perspective, you can be fairly certain of your volumes. You could pretty much sit there and do some decent forecasting in any given week. What we are starting to see now is some real impacts on 3rd party volume swings on the back of some promotional propositions, and we don't really know enough about that. Normally that volume runs at one or two cages per store. But when some of the bigger partners run promotions, this jumps to maybe four or five cages per store, and we don't get any visibility of that. They are now taking up space on vehicles that would traditionally be used to ship brick-and-mortar goods, and we are having to find different transport solutions to move this now.
>
> (Senior Manager, Fulfilment Planning)

> So, the numbers are growing, and we have never systematically got the right solution to make sure that we manage it through. We are constantly looking at ways to improve transport solutions. We are at the point where we have such a volume of third-party traffic, that we must add more vehicles on the road to get it to store.
>
> (Senior Manager, Third-Party Operations)

The introduction of third-party agents made the back-end fulfillment system more complex. To manage the volatility and additional space requirements, the schemata evolved to one where additional space was left on the ambient vehicles to accommodate the third-party volume, which was captured after the loads were built for the replenishment of the brick-and-mortar channel. To offset this reduction in vehicle capacity utilization, the schemata evolved to the practice of splitting full loads down to leave space for the third-party online volume and then, for the later deliveries in the schedule, combining deliveries to stores with close geographical proximity to maximize capacity utilization but increasing the distance traveled. The net impact of incorporating third-party online volume into the distribution network was that the vehicles were less full, and they traveled further, on average, for each trip. Table 4 summarizes the segmented regression analysis for system evolution 2. These results indicate that the evolution of schemata to accommodate third-party online volume resulted in a 0.3598 stanardized unit decrease in CPJ and a 1.8108 standardized unit increase in MPSJ. This impact on efficiency is significant, resulting in an additional 36 journeys per day and an additional 645 miles per day on average.

Whilst collaboration has been highlighted as a key enabler of omni-channel fulfillment (Bijmolt et al. 2021; Melacini et al. 2018), the findings of this study highlight that collaboration can be a source of complexity. The practices demonstrated by the case organization extend current understandings of the implications of collaborations by demonstrating how retailers can extend their omni-channel distribution CAS to create a new subsystem to manage the impact of the energy imported from the environment, but these subsystems still result in increased complexity in the overall omni-channel CAS.

4.2.3 | System Evolution 3: Opening of a Parcel Sortation DC

The increase in online sales presented significant capacity challenges for the case organization. The original schema was to incorporate the online channel volume within their existing brick-and-mortar distribution infrastructure. However, as the range of goods offered and the volume of online sales grew, the incumbent infrastructure could not cope with the fulfillment requirements. To maintain the service level promised by the online proposition, the back-end fulfillment agents reorganized by opening a purpose-designed fulfillment center to supply the regional distribution centers with inventory associated with the online channel. The purpose of the online fulfillment center was to receive and organize all orders for the online channel and ship these to regional distribution centers for onward delivery to stores:

> The majority volume that comes into us will come from one of our sites. With the other online volume, what we try to do is to go and collect from a third-party supplier and take that into a local hub then consolidate everything at the local hub and send that to the online fulfilment center.
>
> (Senior Manager, Third-Party Operations)

By opening a purpose-designed online fulfillment center, the case organization centralized the previously fragmented primary fulfillment operations for online orders and addressed their immediate capacity issues. The transition to this schema did, however, have an impact on back-end fulfillment efficiency.

> From a planning perspective, it's quite a challenge to get every product onto the available loads that we have, especially with the restraints caused by waiting for the inbound trunk from the online fulfilment center. You are attracting clashes in the delivery schedule, increasing driver hours, and vehicle downtime. So, as a general overview, it adds money to this operation, without a doubt.
>
> (Manager, Fulfilment Planning)

> Let's look at the online fulfilment trunk and the extra miles that it generates. There is clear evidence that we are dropping cages of click-and-collect onto vehicles that are not going to that store because we haven't got a schedule that works anymore because the trunk arrives too late, so we have to divert off route. That adds driver hours in, adds miles, uses more fuel, and so on.
>
> (Senior Manager, Fulfilment Planning)

The opening of a purpose-designed online fulfillment center had knock-on effects for back-end fulfillment agents. Introducing a new agent into the system caused the schemata to evolve again: adapting to the environment by splitting the bricks-and-mortar and online shipments for the stores, which had to be despatched before the inbound trunk from the online fulfillment center arrived. The operational impact was again a reduction in vehicle capacity utilization and an increase in miles traveled per journey. The segmented regression analysis for this system evolution is shown in Table 5. The analysis indicates that the addition of a purpose-design online fulfillment center, whilst resolving the

TABLE 4 | Segmented regression with interrupted time series for System Evolution 2.

	Cases per journey	Miles per store journey
Post intervention	−0.359***	1.810***
N	208	208
R^2	0.963	0.914
AR (1)	1.000***	1.000***

*$p<0.05$, **$p<0.01$, ***$p<0.001$.

TABLE 5 | Segmented regression with interrupted time series for System Evolution 3.

	Cases per journey	Miles per store journey
Post intervention	−1.5842***	1.9473***
N	518	518
R^2	0.990	0.989
AR (1)	1.000***	1.000***

*$p<0.05$, **$p<0.01$, ***$p<0.001$.

immediate capacity constraints, resulted in a 1.5842 standardized unit reduction in CPJ, an increase of 39 journeys on average per day, and a 1.9473 standardized unit increase in MPSJ, an increase of 1487 miles on average, per day.

The notion of the sort of tension between channels highlighted by the case organization is not novel. However, the emergent narrative in the literature highlights the overall benefit to retailers from channel integration (Barann et al. 2022). Studies exploring channel conflict focus on how retailers should organize their infrastructure to avoid channel conflict (Gao et al. 2022; Jones et al. 2022). This study extends this narrative by highlighting the characteristics of channel tensions at the back-end distribution level of fulfillment. The implications of these findings are significant. Currently, the agent conflict arising from the misalignment between the energies of the omni-channel system results in operational inefficiency. As the tensions increase, agents may continue to coevolve until they reach the edge of chaos, indicating that the current configuration is unsustainable.

4.3 | System Evolution 4: Chilled Distribution Delivery Windows

So far, the evolutions in schemata have occurred within the agents of ambient distribution as they were responsible for fulfilling non-food online orders. As is typically the case with omni-channel grocery retailers, online food orders are selected from the store's inventory and then packaged for shipping to the customer or for collection by the customer in-store (Ishfaq et al. 2016; Hübner, Holzapfel, et al. 2016; Wollenburg et al. 2018). As grocery online orders grew, it became apparent to the retailer that there was not sufficient inventory of fresh food in store. The first grocery food orders were picked from 05:00, and to meet this requirement, there was an adjustment of the chilled distribution delivery window, reducing the end of the window by 5 h from 08:00 to 03:00. Similar to system evolution 1, which necessitated the change in ambient delivery windows, this presented efficiency challenges:

> To hit the proposition offered by online shopping, we must send loads earlier than we would like for store deliveries, causing a reduction in vehicle fill. To overcome this, we multi-drop stores a lot more now.
>
> (Senior Manager, Fulfilment)

The segmented regression analysis for the fourth system evolution is shown in Table 6. The results indicate that because of the schemata evolving to accommodate an earlier delivery window for chilled fulfillment, there was a reduction of 1.618 standardized units in CPJ, resulting in an average of 27 more trips per day, and an increase of 0.824 standardized units in MPSJ, leading to 886 more miles per day.

Contrary to expectations in proposition two, we find that system evolutions continuously reduce fulfillment efficiency over time. The conclusion reached by the case is that adding the online channel to the brick-and-mortar fulfillment network reduces profits and is not a sustainable solution in its current form. These findings suggest that the energy imported from the environment, which allowed the agents to develop a schema that supports efficient brick-and-mortar fulfillment operations, is so different from the energy being imported from the environment of the online channel that there is conflict in the schemata (Choi et al. 2001; Nair and Reed-Tsochas 2019). The result is a system that is sufficiently aligned to meet the needs of the retail proposition but still contains misalignment with the environment, resulting in inefficiency.

TABLE 6 | Segmented regression with interrupted time series for System Evolution 4.

	Cases per journey	Miles per store journey
Post intervention	−1.618***	0.824***
N	808	808
R^2	0.992	0.980
AR (1)	1.000***	1.000***

*$p<0.05$, **$p<0.01$, ***$p<0.001$.

5 | Analysis and Discussion

This study identifies important contributions to the study of omni-channel retailing, CASs, and strategies for addressing systems-level tensions.

5.1 | Contribution to the Study of Omni-Channel

Our study addresses an important proposition emerging in the literature that *an omni-channel strategy reduces the efficiency of back-end fulfillment* (Hübner et al. 2015; Kuhn and Sternbeck 2013). Our findings are consistent with this proposition, indicating that an increase in omni-channel sales results in a reduction in back-end fulfillment performance due to reductions in both flexibility and efficiency. This challenges the findings of previous research that omni-channel retailing should reduce operational costs (Kozlenkova et al. 2015). The study further highlights that even with significant systems evolution, a transition to omni-channel retailing increases online sales but at the expense of operational performance. In addressing this proposition, we extend the current understanding of the operational implications of adopting omni-channel fulfillment to offer three important contributions.

First, our study adds to the existing conceptual and qualitative omni-channel fulfillment literature (Hübner, Kuhn, et al. 2016; MacCarthy et al. 2019; Wollenburg et al. 2018), providing empirical evidence that retailers' fulfillment operations perform less efficiently when adopting an omni-channel strategy (Akturk et al. 2018) (even without considering store-to-home delivery and returns, which we did not explore in this paper). Omni-channel distribution can reduce CJP, increase MPSJ, and thus increase time to complete deliveries, echoing the problems that are often associated with last-mile deliveries (Deutsch and Golany 2018; Hübner, Kuhn, et al. 2016; Lim et al. 2017).

Second, it highlights that omni-channel fulfillment cannot be understood as a singular practice but rather as a collection of interrelated complex adaptive subsystems, each of which will perform differently in delivering the retail proposition. This research provides consensus for the proposition that the addition of retail channels results in operational challenges (Wollenburg et al. 2018) and that performance will vary by channel type (Hu et al. 2022; Jeanpert and Paché 2016; Lim et al. 2024). As chilled BOPS and home shopping items are picked and packed at the retail store level (Hübner, Wollenburg, et al. 2016), this demand volume adds to the offline store volume, promoting greater fulfillment efficiency at low levels of online demand. This echoes Hu et al.'s (2022) findings regarding inventory efficiencies from demand pooling when transaction costs and waiting times are low. Our results do, however, suggest this trend is reversed as online demand becomes a larger proportion of total sales. The online volume that flows through the ambient distribution mode, by contrast, is not integrated with the offline ambient demand volume in the same way. The ambient mode online volume is picked at a separate distribution center (Ishfaq and Bajwa 2019; Marchet et al. 2018), and therefore does not add to the offline demand at the store level, resulting in a greater negative impact upon load factor and no demand pooling benefits.

Third, contrary to the assumption in the omni-channel and CAS literature, evolutions in the CAS do not necessarily help the organization improve efficiency over time. There are two drivers for this outcome. First, customers' expectations of short lead times from retailers of e-commerce lines (Hübner et al. 2015). This means that it is difficult for fulfillment planners to account for the correct amount of space required on vehicles when building delivery plans, so an estimate of the potential volumes is made with contingency, creating inefficiencies. Second, short lead times often mean that goods are shipped nationally; as soon as these goods are received at the depot and cross-docked, they are then dispatched to the store. This time horizon is often optimal for achieving the online proposition but sub-optimal for achieving maximum load fill. As stores are used as fulfillment centers (Wollenburg et al. 2018), food must be shipped earlier than optimal for offline sales so it can be picked for online orders (Hübner, Holzapfel, et al. 2016). Hübner, Holzapfel, et al. (2016) identify that adopting omni-channel means moving inventory more frequently through the network. This is evidenced in this study by the observation of reduced CPJ, and more total journeys despite falling overall sales associated with omni-channel activity, as retailers prioritize the fulfillment of the delivery proposition to customers over operational efficiency. Retailers attempt to mediate the impact of this inefficiency by combining several store deliveries into a single load, which increases MPSJ. An explanation for this response is offered by Hübner et al. (2015), who posit that these operational responses result from difficulties associated with accurately forecasting online sales; hence, operators must react at short notice to customer requirements rather than create an optimal fulfillment schedule.

5.2 | Implications for CASs

Empirical research on CAS recombination tends to focus on reconcilable energy imported from the environment, from which new agents, schemata, and adaptive systems can emerge to create a preferred state of equilibrium (Nilsson and Gammelgaard 2012). Less is known about what happens when irreconcilable energies are imported from the environment.

In omni-channel retailing, energy imported from the environment for online retailing is a growing market, pushing for short lead times (Neslin 2022), flexible delivery options (Daugherty et al. 2018), volatile demand (Wollenburg et al. 2018), and low volume density (Buldeo et al. 2019); whereas the energy in offline retailing is a shrinking market demanding efficient replenishment of largely predictable demand and high-volume density (Chopra 2018). In a CAS, agents react to their environment and adapt to it over time (Holland and Miller 1991). We identify that if two opposing environmental demands exist, the transition between the before and after agents' schemata is disrupted. In our study, this has led to a CAS that isn't effectively adapting to either channel's requirements from the environment. Viewing the two channels as competing tensions is a useful approach to explain the rejection of Proposition 2. In rejecting Proposition 2, an alternative proposition from this research is that a CAS will struggle to locate equilibrium if two competing energies from the environment are acting at the same time. This leads to a revision of our second proposition:

P2 revised. *System evolutions in a CAS lead to reduced fulfillment performance over time in the presence of competing energies imported from the environment.*

5.3 | Strategies for a CAS to Adapt to Competing Energies From the Environment

Tensions can be understood as "opposing concepts or behaviors that push or pull against one another" (Putnam et al. 2014, 416). Previous conceptualizations have identified tensions as existing within systems (Öberg et al. 2020; Tóth et al. 2018; Fang et al. 2011). Whilst operational implications of the tension between the two channels are experienced within the fulfillment system, the data indicates that tensions originate in the environment as they come from consumer market demands for products and services (Choi et al. 2001).

Adopting a CAS perspective suggests that the tensions from the environment result in increased internal complexity, allowing actors to address the needs of both channels (Galbraith 1973). Yet, this increase in internal complexity can reduce the fulfillment system's performance. The misalignment with the external environment forces further adaptations to the system (Nair and Reed-Tsochas 2019). According to CAS, the omni-channel fulfillment system must either reconfigure to develop new agents capable of addressing the environmental demands (Kauffman and Kauffman 1995), or the system breaks down into separate subsystems (Goldstein 1994). In our case, the need to merge offline and online demand during secondary fulfillment means the two subsystems cannot operate separately, as the literature suggests. What CAS currently fails to explain is how the system might react to two opposing demands shaping the environment, where either new agents are incapable of addressing the tension between demands or the systems are too integrated to be effectively broken down.

To explore this gap, engaging paradox theory presents an opportunity to address these tensions. A paradox can be understood as "contradictory, yet interrelated elements that exist simultaneously over time" (Smith and Lewis 2011, 382), such as the energies found in the omni-channel fulfillment context. Paradox theory complements CAS because paradoxical elements are often associated with complexity (Sandberg 2017). CAS has also been identified as a useful theory to explore paradoxes in an operations management context (Nilsson and Darley 2006). Paradox theory is a useful lens as it explores how it is possible to engage with both energy A and B simultaneously (Lewis and Smith 2014).

The omni-channel fulfillment context is characteristic of the flexibility–efficiency paradoxical tension (Adler et al. 1999), where the flexible omni-channel retail proposition is contradictory to the demand for high-performing fulfillment operations. Poole and Van De (1989) suggest that such paradoxes can be managed through separation or synthesis strategies. The former involves keeping the demands of both elements of the paradox separate via either spatial separation (Zehendner et al. 2021) or temporal separation (Hahn et al. 2015; Smith and Lewis 2011). This has been attempted in our case through the development of specialist agents for dealing with grocery home shopping and specialist online distribution centers. Yet, this is failing due to the requisite need for integration in secondary fulfillment. The latter strategy involves introducing new schemata to accommodate both elements of the paradox, which will remain contradictory and opposing in nature (Hahn et al. 2015). This has also been attempted via building contingencies in fulfillment operations to accommodate the variable demand from online customers in offline ambient delivery schedules, but the inferior performance of this approach is devastating to profit margins. From this, we can propose three potential routes to moving forward where CAS cycles are failing to adequately address the energies imported from the environment.

A characteristic of a CAS is that the agents are partially connected to one another (Anderson 1999) and coevolve in response to the demands of the environment (Holland and Miller 1991). For a spatial separation strategy to be effective, agents responding to one channel type (i.e., offline) should not be connected to agents responding to another channel type (i.e., online). In practice, this would require the physical segregation of operations (Chopra 2018). In the case of omni-channel fulfillment, spatial separation may involve reverting to a multichannel fulfillment configuration, where the two channels are fulfilled separately. However, substantial additional costs and duplication may make this improbable.

A strategy of temporal separation would seek to influence the schemata of agents and the organizational rules that agents follow (Gell-Mann 1995; Holland 1992). Instead of allocating each channel to separate groups of agents as per the separation strategy approach, a temporal strategy would allow agents to respond to both channel types but in isolation from each other. In practice, agents may then attend to the requirements of channel A and then attend to the operational requirements of channel B. In grocery retail, this strategy could involve using dedicated vehicles for each channel, allowing them to be shipped at a time optimized for their respective channel requirements. Both separation strategies would, however, result in a loss of any synergies gained through task integration but would allow for the response to each channel to be optimized, which may produce enhanced system performance in the longer term. However, conceptualizations of agent behavior indicate that if separation strategies are adopted, agents are likely to respond to each channel differently, causing them to evolve at different rates (Mcgahan et al. 2004; Fine 2000), resulting in potential further internal tensions.

With respect to a synthesis strategy, complexity in a CAS refers to levels of disorganization (Weaver 1991), the demands placed upon schemata to intercept and respond to stimuli from the environment (Gell-Mann 1995), or the number of activities that a system must complete (Daft 2012). A synthesis strategy would seek to reduce the system complexity arising from the demands of responding to both channel types by introducing an intervention to the system that could simultaneously manage the characteristics of both channels. In the omni-channel fulfillment context, a synthesis strategy could involve using technology to optimize inventory management (Hu et al. 2022; Park et al. 2021), allowing agents to organize resources to optimally respond to the needs of each channel type. It is likely that as technology develops, synthesis strategies may become available in the omni-channel fulfillment context (Hübner et al. 2022). A further alternative synthesis strategy could be to treat all fulfillment as online (with offline store orders being effectively just big online customers). This would be a major cultural change, especially considering offline store sales still account for circa 80% of total sales, but it would remove the tension between the competing energies from the environment, allowing a single recombination with reduced tensions to emerge.

5.4 | Managerial Implications

The results of this study provide several managerial implications. While previous studies have recognized the efficiency challenges associated with omni-channel fulfillment (Akturk and Ketzenberg 2022; Ishfaq and Bajwa 2019; Wollenburg et al. 2018), this is the first study to demonstrate this inefficiency related to the dimensions of the load factor and offer a quantification of its magnitude. By considering both the retail benefits of an omni-channel strategy (Neslin 2022; Verhoef et al. 2017; Zhang et al. 2021) and the operational costs highlighted in this study, omni-channel retail managers will be better equipped to understand the cost dynamics of their fulfillment operations and develop their strategies accordingly.

Building upon the literature that addresses freight sustainability (Mangiaracina et al. 2015; Martí et al. 2015), reduced CPJ and increased fulfillment mileage are associated with an increased carbon footprint and poorer air quality. Quantifying the impact of adopting omni-channel fulfillment allows retailers to identify the carbon input by distribution mode associated with omni-channel fulfillment. Retailers can use the results of this research to configure their operations to minimize these impacts.

5.5 | Limitations and Future Developments

While this study contributes significantly to the literature, there are limitations and opportunities for future studies. First, while the case data is from a global retailer, representative of the omni-channel retail context, as is evidenced by the strong relationship between the practices observed in this retailer and those accounted for in the omni-channel literature, there are undoubtedly other CAS configurations adopted by retailers. It would benefit future research to approach this problem from an analytical perspective and conduct controlled experiments to test the relationships between different systems evolutions and performance variables. Second, adding an online sales channel could create additional sales in stores. We recognize that this may introduce an element of bias when calculating the magnitude of the impact of increasing omni-channel activity on back-end fulfillment efficiency. While the qualitative findings strongly support the quantitative findings, the potential for bias should be recognized. Third, by using paradox theory alongside CAS, this study offers an important first step in suggesting how challenges associated with tensions arising from two energies being imported from the environment may be managed. To develop this work, future research directions should include analysis of other systems that must respond to two conflicting energies imported from the environment, as well as analytical simulation and empirical testing of the alternative omni-channel fulfillment configurations that arise from the separation and synthesis strategies associated with managing the flexibility–efficiency paradoxical tensions.

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Appendix 1

Hausman Test for Segmented Regression Models

Model	Hausman_stat	*p*
Shock 1 CPD	0.018	0.999
Shock 1 MPSJ	0.019	0.999
Shock 2 CPD	2.026	0.567
Shock 2 MPSJ	2.146	0.542
Shock 3 CPD	0.655	0.883
Shock MPSJ	0.668	0.880
Shock 4 CPD	5.640	0.130
Shock 4 MPSJ	23.740	2.830

Appendix 2

Hausman Test Results for OLS Models

Model	Hausman_stat	*p*
Combined CPJ (1)	−2.252	1.0
Combined MPSJ (2)	−4.671	1.0
Ambient CPJ (3)	0.208	0.647
Ambient MPSJ (4)	−90.498	1.0
Chilled CPJ (5)	0.023	0.879
Chilled MPSJ (6)	3.402	0.065