E-fulfilment in grocery retailing: design insights for a store-based distribution system

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Abstract: E-commerce dynamics are making the design of distribution systems more and more challenging, especially in grocery retailing. The use of stores as picking location for e-fulfilment brings the opportunity of both offering fast deliveries and exploiting synergies with the traditional channel. However, efficiently designing a store-based distribution system turns out to be a critical task. This paper addresses the tactical problem of selecting stores to be used as picking location and defining the related delivery zones. We developed a model for the delivery cost estimation using the continuous approximation approach, as well as a heuristic procedure to compare multiple store-based distribution systems. The model was applied to a real case. Results showed that properly selecting the picking locations in a store-based distribution system is recommended because cost saving can be up to 40%. The most cost-effective number of picking locations decreases with an increase in the online demand.

Keywords: e-fulfilment; grocery retailing; distribution system; continuous approximation approach.

1 Introduction

E-commerce is one of the most surprising economical phenomenon of the last twenty years, being able to radically change the way companies sell their products to end-customers. In particular, grocery shopping has emerged as a rapid growth sector within online retailing (Kirby-Hawkins et al., 2018). One of the big challenges in e-commerce is the 'last mile' delivery, i.e., the home delivery service for the online customer (Punakivi et al., 2001). This is especially critical in grocery retailing because of high complexity of online orders and high quality of service requirements (Davies et al., 2019). An average shopping basket contains between 60 and 100 items, up to 60 times more than in non-food retailing (Punakivi et al., 2001; Hübner et al., 2016), and customers expect the fulfilment process to be extremely fast and reliable as their online orders cover immediate needs.

In the design of the last mile delivery service, a key issue is the setting of the distribution system for e-fulfilment in terms of number and types of picking locations and related delivery zones (Agatz et al., 2008; Hübner et al., 2016). While many retailers use the distribution center to fulfil online orders (i.e., the central warehouse supplying also traditional stores or a separated fulfilment center), other companies prefer, at least in the initial stages when online demand is still low, to involve traditional stores (De Koster, 2003; Davies et al., 2019). Especially in grocery retailing, the store-based distribution system is an attractive opportunity for two main reasons (Marchet et al., 2018). As regards the picking activities, using stores as picking location allows to leverage the unused capacity of personnel and space, obtaining synergies among channels and thus reducing costs. Furthermore, setting the picking location very close to the customer enables to provide very fast delivery services, element of competitive advantage in such sector. Wollenburg et al. (2018) noted as enabling different delivery and pick-up modes across-channel is a recent and growing phenomenon in grocery retailing.

Implementing the store-based distribution system implies to define how many and which stores should handle online orders, and which zones should be served by each selected store at a tactical level, and to organise local delivery routes as operational problem. Based on private communication with a number of leading e-grocery retailers, tools supporting the tactical decisions with a view to minimising delivery cost given a certain service level are needed. In particular, this research effort is motivated by one of the leading players in Italian grocery retailing. Started in 2014, with a test-phase of the Click&Collect service (i.e., possibility for end customers to pick up their online orders in store) in four stores of Milan, e-commerce has shown an impressive growth forcing the company to re-design its delivery service. Few years later, the company introduced, in addition to the Click&Collect, the home delivery service still using stores as picking location. Focusing on Milan urban area, the company selected twelve, out of one hundred or so, stores for serving the online demand. Each store is provided with a fleet of vehicles that, during each time slot, cover closed-loop tours within their delivery zone to deliver online orders. This distribution system minimises the distance covered as each vehicle remains within its delivery zone. However, this setting does not allow economies of scale, that could result from aggregating demand of multiple delivery zones and, thus, vehicles have often unused capacity. Therefore, the company is considering to re-structure its distribution system, looking for a solution that increases the operational efficiency without reducing the service level.

In the academic literature, the interest in designing logistics for e-fulfilment has recently grown and the contributions of academic experts in this field are increased rapidly (Hübner et al., 2016; Kembro et al., 2018; Melacini et al., 2018). Several studies compare multiple distribution systems, i.e., store-based and warehouse-based, focusing mainly on inventory management issues (e.g., Alptekinoğlu and Tang, 2005; Hovelaque et al., 2007). More recently, some authors have also analysed delivery management problems by introducing a realistic evaluation of delivery routes and transport costs (e.g., Boyer et al., 2009; Agatz et al., 2011). To the best of authors' knowledge, this is the first attempt to design the store-based distribution system in terms of joint selection of stores and allocation of the delivery zones to those stores.

Carried out in close operation with e-grocery retailers, this paper concentrates on the tactical problem of selecting stores to be used as picking location and defining the related delivery zones. It proposes, first, a model for estimating the delivery cost once defined the stores used to fulfil online orders and the related delivery zones, and, second, a heuristic procedure capable of identifying the best distribution system for e-fulfilment by jointly considering the selection of stores as picking locations and the allocation of the delivery zones to those stores. We also provide numerical experiments showing the benefit of using such methodologies through their application to the real case that motivated this research, and investigating the impact of the online demand.

The reminder of the paper is organised as follows. The next section summarises the relevant literature. Then, the problem is described, as well as assumptions and notation are introduced. Subsequently, the model for estimating the delivery cost is developed and a solution approach is illustrated. In the final sections, first, the results of the numerical experiments are presented. Second, the main insights of this study, together with the directions for further research, are summarised.

2 Literature review

To the best of authors' knowledge, this is the first attempt to design the store-based distribution system for e-fulfilment in retailing in terms of joint selection of stores and allocation of the delivery zones to those stores. To address this topic, the literature review focuses on two research streams: (i) contributions offering an overview of the logistics issues involved in e-fulfilment and (ii) contributions providing mathematical models on specific logistics issues.

Regarding the first research stream, we found three literature reviews that analyse the significant logistics variables involved in e-fulfilment and provide a summary of the contributions available in literature (Swaminathan and Tayur, 2003; Agatz et al., 2008; Kembro et al., 2018). Similarly, some authors have proposed comprehensive frameworks classifying the key logistics issues for the design of the e-fulfilment process, using empirical analyses to examine companies' choices. For instance, Lang and Bressolles (2013) analysed four e-fulfilment models, looking at the facility in charge of the order (distribution center or store) and the delivery mode (home delivery or Click&Collect), whereas Hübner et al. (2015) identified four main strategic areas (network design, warehouse operations, inventory management and capacity management) and explored the interdependences among them. Focusing on grocery retailing, Kamarainen and Punakivi (2002) compared multiple operational models (e.g., receiving alternatives, home delivery solutions) adopted by grocery retailers. More recently, Fernie and Grant (2008) discussed the on-shelf availability difficulties resulting from using stores to fulfil both online and traditional orders, whereas Nilsson (2015) developed a comprehensive set of grocery store attributes and investigated their importance for customers. Finally, Hübner et al. (2016) developed a framework for the last mile order fulfilment and delivery in grocery retailing, based on explorative interviews with retailers and experts in the grocery industry. According to this framework, the key logistics issues experienced by companies adding the online channel to their traditional channel mix are: picking location, picking automation, picking integration, delivery mode, delivery time, delivery area and returns. All these contributions highlight that the choice of the number and type of picking locations is one of the first key decisions for serving the online demand. Furthermore, they confirm that the store-based distribution system, subject of our research, is largely used in grocery retailing.

The second research stream regards modelling-based contributions that concentrate on a specific logistics issue, comparing various available solutions in terms of costs and benefits. Most of existing studies focus on the comparison between the logistics to serve the traditional and online channels (e.g. Mangiaracina et al., 2016 provide a quantitative model to compare the carbon emissions of the two logistics processes), or on the selection of the type of picking location to be used in e-fulfilment, comparing alternative distribution systems, i.e., store-based, warehouse-based and drop-shipping (e.g., De Koster, 2003; Alptekinoğlu and Tang, 2005; Hovelaque et al., 2007). The only contribution available in literature that studies the number of locations to be involved is the one by Bretthauer et al. (2010). However, this work concentrates on inventory management without a realistic evaluation of transport costs that represent a high share in total logistics costs (Vanelslander et al., 2013).

Regarding the operational problems, several researches have addressed delivery management problems by analysing delivery routes (e.g. Sakhala and Jha, 2017; Azad and Hasin, 2019). Considering the online channel, for instance, Nidhi and Anil (2011) considered the vehicle routing problem in a stochastic scenario, whereas Punakivi and Saranen (2001) and Agatz et al. (2011) studied the time slot management problem in attended home delivery. When addressing delivery management problems, different approaches are used to consider the operational decisions related to vehicle routing. A full vehicle routing problem can be incorporated or, like in Agatz et al. (2011), routing decisions can be included in a more aggregate model using the continuous approximation method (Daganzo, 1987a, b). For an overview of continuous approximation models for distribution problems, we suggest Langevin et al. (1996). Toth and Vigo (2014) reviewed the body of literature on vehicle routing and Goel and Maini (2017) presented some of the recently employed solution methodologies in the field of vehicle routing problem (VRP) and its variants.

Recently, several researchers have started to develop dispatching strategies for same-day delivery in which delivery requests need to be fulfilled within a short time period. The main challenge is related to the timing of the vehicle dispatches and the assignment of the delivery requests to the vehicle routes given the continuous arrival of new requests (Klapp et al., 2016, 2018; Voccia et al., 2017). A new line of research is on the use of pickup points. For instance, Kim et al. (2017) studied the factors that determine the intention to use the in-store pickup service, while Mahar and Wright (2017) developed a model to determine the optimal subset of stores in which in-store pickup and return capabilities should be located.

3 Problem description and assumptions

The problem requires to determine which stores to be selected as picking location and to define the related delivery zones so to minimise the total delivery cost, taking into consideration the average daily demand and the service requirements in terms of delivery lead time. We focus on a setting in which there is sufficient capacity in each store for serving the online demand. This means that we concentrate on the transport activity, i.e. the most significant item cost in the logistics process for home delivery (Vanelslander et al., 2013; Melacini and Tappia, 2018).

We consider a set of stores selected to be used as picking locations N, indexed by i, and a set of delivery zones Z, indexed by j. Let I_{ij} be the Boolean variables that assign the delivery zones to the stores (I_{ij} = 1 when delivery zone j is assigned to, and thus served by, store i; 0 otherwise), each delivery zone j can be assigned to one, and only one, store i. The distance between store i and delivery zone j is d_{ij}. Each delivery zone j has a size a_j and an average travel speed v_j, as well as an average daily demand e_j that corresponds to the number of deliveries requested in that area. To meet the service requirement, the delivery service is organised in time slots, so that when customers place their orders can select the slot that best fits with their needs. Let S be the number of time slots during the day. We assume that the daily demand of each delivery zone is evenly distributed over the set of time slots offered to online customers. This is a reasonable assumption as retailers can create this balance condition in time slots popularity and smooth demand by differencing delivery fees (Agatz et al., 2008; Klein et al., 2017).

Each store $i \in N$ is provided with a number of dedicated vehicles (nv_i). At the beginning of each time slot, vehicles collect orders prepared in the store and then perform closed-loop tours starting from the store and covering one or more delivery zones assigned to that store during the available time t for home deliveries during a slot. The time spent at each stop is τ.

As showed in Figure 1, each delivery route is characterized by three components (note that the index related to the generic store i is dropped for the sake of brevity):

- distance from the store (i.e., picking location) to the delivery zone (d^0)
- distance between two consecutive stops in a delivery zone (d^n)
- distance between two consecutive stops in different delivery zones (d^z).

[Figure 1 near here]

The total distance covered during the day multiplied by the variable transport cost per kilometre c defines the distance-based component of the delivery cost. Then, we consider that each vehicle is characterized by a fixed daily cost f that includes vehicle, driver and necessary equipment.

Table 1 summarises the main notation that will be used in the reminder of the paper.

[Table 1 near here]

4 Problem formulation

In this section, we first develop a model for estimating the delivery cost of a store-based distribution system, given the sets of stores used as picking locations and the allocation of the delivery zones to those stores. Then, we introduce a heuristic procedure to identify the best distribution system (i.e., the joint selection of stores and allocation of the delivery zones to those stores minimising the total delivery cost).

4.1 Model for estimating the delivery cost

Based on the problem description reported in the previous section, the total delivery cost for a generic picking location can be structured into two components:

(1) Distance-based component, i.e., the variable costs related to the total distance covered for satisfying the online demand to customers' home;

(2) Fixed component, i.e., the rental costs for the fleet of vehicles, drivers and equipment required for satisfying the online demand to customers' home.

In line with previous studies addressing tactical problems of delivery management (e.g., Agatz et al., 2011), the delivery cost estimation is based on the continuous approximation approach (Daganzo, 1987a, b). This method allows keeping a high-level perspective, without including operational details of routing and aggregating discrete and eventually inaccurate parameters. Furthermore, it requires limited computational efforts and provides solutions easy to understand and implement in the field.

According to this approach, the estimation of the distances that compose the total travel distance per tour reported in the previous section (i.e., d_i^0, d_i^n, and d_i^z) can be obtained as follows:

- Distance from the store i (i.e., picking location) to the delivery zone (d_i^0). d_i^0 is estimated by considering the average distance between the store i and the related delivery zones:

$$d_i^0 = \frac{\sum_{j \in Z} d_{ij} I_{ij}}{\sum_{j \in Z} I_{ij}} \tag{1}$$

- Distance between two consecutive stops in a delivery zone covered by store i (d_i^n). d_i^n is estimated by taking the average distance between two consecutive stops within a delivery zone, considering the delivery zones allocated to store i:

$$d_i^n = \frac{\sum_{j \in Z} d_j^n \, I_{ij}}{\sum_{j \in Z} I_{ij}} \tag{2}$$

In line with Daganzo (2005), we assume online orders evenly distributed over the delivery area and approximate the distance between two consecutive stops within a delivery zone d_j^n by $k1/\delta_j^n$, where $k1$ is a dimensionless constant that is independent of the region shape and δ_j^n denotes the demand density within the delivery area covered by the selected picking location ($\delta_j^n = \sqrt{\frac{e_j/S}{a_j}}$).

- Distance between two consecutive stops in different delivery zones (d_i^z). Similarly to Agatz et al. (2011), we apply the approach used for estimating d_j^n by using:

$$d_i^z = \frac{k2}{\sqrt{\delta_i^z}} \tag{3}$$

where $k2$ is a dimensionless constant and δ_i^z is the density of delivery zones assigned to the same picking location and belonging to the neighbor of delivery zone i. Let Z_i' be a collection of delivery zones in the neighbourhood of delivery zone i. In our calculations, we define Z_i' as the set of delivery zones within a given maximum distance from the center of delivery zone i. Thus,

$$\delta_i^z = \frac{\sum_{j \in Z_i'} I_{ij}}{\sum_{j \in Z_i'} a_j I_{ij}} \tag{4}$$

Knowing the three components of the delivery route, the number of stops in a route, N_i^r, can be obtained by combining the expected number of stops in a delivery zone, N_i^n, and the expected number of delivery zones visited on a route, N_i^z:

$$N_i^r = N_i^n \, N_i^z \tag{5}$$

N_i^n can be obtained by using the average number of stops in a delivery zone for routes starting from store i:

$$N_i^n = \frac{\sum_{j \in Z} N_j^n \, I_{ij}}{\sum_{j \in Z} I_{ij}} \tag{6}$$

where the number of stops in each delivery zone j, N_j^n, is limited both by the demand during the time slot (e_j/S) and the time slot length (t). Note that, in line with the real case that motivated this research, we assume that the time constraint is stronger than the vehicle capacity. Let $N_j^{n,max}$ be the maximum number of stops that can be made in the delivery zone j considering the time constraint, and $h_j^n = d_j^n / v_j$ the average travel time between consecutive stops in the delivery zone j, it should be valid that $t = N_j^{n,max}\, \tau + h_j^n \left(N_j^{n,max} - 1\right)$. Therefore, $N_j^{n,max} = \left(t + h_j^n\right) / \left(\tau + h_j^n\right)$ and N_j^n is $min\left(N_J^{n,max}, e_j / s\right)$.

With reference to the number of delivery zones visited on a route, N_i^z , the upper bound is related to the time available in a slot, t, as well as the number of delivery zones associated to store i, $\sum_{j \in Z} I_{ij}$. This means that the route cannot visit more zones than those assigned to the store, nor overcome the maximum available time. Let $N_i^{z,max}$ be the maximum number of delivery zones that can be visited on a route considering the time constraint. Then, $t = [N_i^n\, \tau + h_i^n\, (N_i^n - 1)] N_i^{z,max} + h^z \left(N_i^{z,max} - 1\right)$, where $v_i = \sum_{j \in A} v_j\, I_{ij} \,/\, \sum_{j \in A} I_{ij}$ and $h_i^n = \sum_{j \in A} h_j^n\, I_{ij} \,/\, \sum_{j \in A} I_{ij}$. Thus,

$$N_i^{z,max} = \frac{t + h^z}{h^z + \left(N_i^n \tau + h_j^n\, \left(N_i^n - 1\right)\right)} \tag{7}$$

and we set $N_i^z = min\left(N_i^{z,max}, \sum_{i \in A} I_{ij}\right)$.

Knowing N_i^r allows estimating the distance per order and the number of vehicles required for serving the online orders for the related picking location i. Excluding the stem distance to and from the picking location, the distance per order for each picking location, DPO_i, can be evaluated as follows:

$$DPO_i = \frac{1}{N_i^r}\, [(N_i^n - 1)\, N_i^z\, d_i^n + (N_i^z - 1)\, d_i^z] \tag{8}$$

The number of vehicles required for serving the online orders for a given picking location i is given by the following equation:

$$nv_i = \frac{1}{integer\left(N_i^r\right)} \sum_{j \in A} \left(\frac{e_j}{s}\, I_{ij}\right) \tag{9}$$

Given the parameters and variables defined above, the total daily delivery cost TC can be estimated as follows:

$$TC = \sum_{i \in N} \left(\sum_{j \in Z} cs \left(\frac{e_j}{s} I_{ij} \; DPO_i + nv_i \, 2d_i^0 \right) + nv_i \, f \right) \tag{10}$$

As shown in Equation 10, the delivery cost incurred by each selected picking location can be expressed as sum of the distance-based and the fixed components. The distance-based component considers the variable transport cost per kilometre, the total distance travelled per order and the daily demand. The fixed component is given by the product between the number of vehicles required for serving the online demand in each time slot and the fixed daily cost for a vehicle.

4.2 Heuristic procedure for comparing distribution systems

The proposed model allows to estimate the expected delivery cost of a given store-based distribution system. In this section, the proposed delivery cost model is included in a procedure to design a store-based distribution system, i.e., to identify the group of stores to use as picking locations and the delivery zones allocation. This optimisation problem is multidimensional, nonlinear and nonconvex. Therefore, we introduce a simple heuristic procedure based on local search algorithms (see Figure 2).

[Figure 2 near here]

In general, the identification of the best distribution system involves three key decisions:

(1) Definition of the number of stores to be used as picking location K^*

(2) Selection of the stores within the delivery region to be used as picking location N^*

(3) Allocation of the delivery zones within the delivery region to the selected picking locations $\boldsymbol{I}^*$.

In the heuristic, we start by setting the number of stores to be used as picking locations K and the number of random initializations to be considered R.

Then, we analyse each possible combination N of K picking locations and we identify the allocation of delivery zones $\boldsymbol{I}_{\boldsymbol{N}}^{*}$ that minimises the total delivery cost, based on the following process. We can start from any feasible allocation of the delivery zones to the selected picking locations $\boldsymbol{I}^{\boldsymbol{r}}$. The only constraint is that each delivery zone is allocated to one and one only store chosen as picking location. In our experiments, we use random initializations complying with this constraint. We determine for each delivery zone the store allocation that results in the minimum expected delivery cost (keeping the allocation for all other delivery zones fixed) by complete enumeration. Then, we adjust the current allocation by changing the allocation for the delivery zone that achieves the minimum expected delivery cost. This process is repeated until there is a reduction in the expected delivery cost, i.e. saving, greater than a pre-defined threshold Δ. In this way, we identify for each possible group of stores the best delivery zones allocation.

Finally, we compare multiple distribution systems to select the best one, i.e., the combination of picking locations and delivery zones allocation that minimises the total delivery cost.

5 Numerical experiments

In this section, we apply the proposed model to the real case that motivated this research. First, the performance of the current distribution system is assessed by using the proposed model for estimating the delivery cost. Then, we show the potential saving that can be obtained by using the distribution system suggested by the application of the heuristic procedure, discussing the delivery cost behaviour varying the number of stores selected as picking location, as well as their delivery zones. The impact of the online demand is also investigated. The proposed model and the heuristic procedure are implemented in Matlab.

5.1 Delivery cost of the current distribution system

For our study, we use real-life data from one of the leading players in Italian grocery retailing. Specifically, we focus on Milan urban area, consisting of 38 zip codes grouped into twelve delivery zones. The distribution system currently used by the company foreshadows a picking location for the fulfilment of the online orders in each delivery zone. Each store manages delivery routes in its own delivery zone, using one vehicle. Table 2 shows the size a_j, the average travel speed v_j and the average online daily demand e_j for each delivery zone j.

[Table 2 near here]

Tables 3 and 4 report the distance d_{ij} and the travel time for each combination of store and delivery zone, respectively.

[Table 3 near here]

[Table 4 near here]

In Table 5, we summarise the other base parametric values. The service is organised in 7 time slots, the time available for deliveries in a slot is fixed (t = 1.5 hours) as well as the drop-off time (τ = 13.5 min).

The fixed cost is f = 210 €/day, while the cost per kilometre is c = 0.15 €/km.

[Table 5 near here]

To analyse the performance of the current distribution systems, we introduce the following statistics:

- Total cost per order: the average total cost (i.e., fixed and distance-based costs) needed for delivering an online order to the customer’s home

- Fixed cost per order: overall rental costs for vehicles and drivers required to deliver the online demand in a time slot divided by the number of fulfilled orders in such time window
- Distance-based cost per order: overall costs related to the total travel distance for delivering the online demand in a time slot divided by the number of fulfilled orders in such time window
- Total number of vehicles required per time slot: the number of vehicles needed for satisfying all customers' demand in a time slot considering all the picking locations
- Total distance covered per order: the average distance covered for delivering the online order to the customer's home, defined considering both the distance covered within the delivery zones and the stem distance
- Number of stops per route: the average number of stops per delivery route, defined considering the average number of stops in a delivery zone and the average number of delivery zones visited in a route
- Vehicle saturation: the average time actually used for home deliveries in relation to the time available during the slot.

Table 6 illustrates the performance of the current distribution system estimated through the proposed model.

[Table 6 near here]

The total cost per order turns out to be 12.48 €/order, with a strong impact of the fixed cost component (96%). The vehicle saturation results low (48%), with an average of 3.4 kilometres travelled per order and 2.5 stops per route depending on the current number of online orders. This result confirms the inefficiency of the current distribution system that does not allow economies of scale. Therefore, it is interesting to investigate the effective performance improvement and cost saving that could result from assigning multiple delivery zones to a picking location.

5.2 Optimization of the real case

The application of the proposed heuristic procedure requires to define the number of random initializations to be considered (R), as well as the delivery cost reduction threshold that stops the search for a best solution in terms of delivery zones allocation (Δ). In our experiments, Δ is set to 0 and R to 5, as trade-off between solution time and quality.

We apply the heuristic procedure varying the number of stores selected as picking location. Specifically, we analyse the settings with K = 1, 2, 4, 6, 8, 10, 12. Results of these experiments are illustrated in Figure 3 and Table 7. Note that in Table 7 the first row (base case) refers to the current distribution system.

[Figure 3 near here]

[Table 7 near here]

Figure 3 shows the result of the trade-off between the vehicle saturation and the average distance between the picking location and a customer's home. Increasing the number of picking locations allows being closer to the delivery points but implies a lower number of orders to be fulfilled per store resulting in a lower number of stops per route. In particular, when the number of stores increases, the number of required vehicles and, therefore, the fixed cost per order decreases until the aggregation of the demand allows a very high vehicle saturation and the number of stops per route does not increase anymore. Then, this benefit becomes lower compared to the increase in the distance-based costs related to the higher total travel distance per order.

In this case, the distribution system that minimises the total cost per order is with 6 picking locations, each serving between one and three delivery zones with 1 or 2 vehicles.

Reducing the number of stores involved in the e-fulfilment process to 6 would yield a saving in the delivery cost of 40% (i.e., from 12.48 €/order to 7.46 €/order), given the same level of online demand.

5.3 Impact of the online demand

In this sub-section, we investigate the impact of the online demand on the delivery cost per order and the best number of picking locations. Actually, the online demand affects both the fixed cost as it influences the vehicle saturation and the number of vehicles, and the distance-based cost as it is related to the number of stops per route. As in the previous experiment, we consider seven levels for the number of picking locations (i.e., K = 1, 2, 4, 6, 8, 10, 12) and we analyse two scenarios, with average online daily demand respectively doubled and quadrupled from the level in the base case. Figure 4 shows the changes of the total delivery cost compared to the base case.

[Figure 4 near here]

In the base case, the online demand corresponds to a vehicle saturation of 48%: the analysed company is still in an initial stage in terms of development of the online channel. This leads to a delivery cost of 7.46 €/order considering the best number of picking locations (i.e., 6). By increasing the online demand, the total cost per order decreases due to the higher vehicle saturation and number of stops per route given the same number of picking locations.

However, we observe that as long as the online channel represents a small percentage of total sales as in the base case, the use of some picking locations (e.g., 6 in the specific case) seems to be the most suitable solution in terms of cost. Moreover, this setting is easier to handle and could improve the service level (e.g., opportunity to offer short lead time due to the proximity to customers). When the number of online orders increases, the system efficiency is reached for a lower number of picking locations. In our case, with quadrupled demand, it is more cost-effective to have 4 picking locations instead of 6. However, the curve of the total cost per order becomes flatter when the online demand is very high (i.e., quadrupled demand). Note that our results consider only the transport activity. Then, the retailer should verify that each store selected as picking location has enough capacity for serving its related delivery zones or change the role of store towards a fulfilment hub.

6 Conclusions

This paper is the first to study the tactical problem of jointly selection of stores to be used as picking location and definition of the related delivery zones, decisions particularly relevant in grocery retailing. We develop a model for estimating the total delivery cost once defined the picking locations and their delivery zones and we introduce a heuristic procedure to compare multiple store-based distribution systems identifying the best one in terms of cost. The model has been developed and applied considering the grocery industry but it is also valid for the other industries facing the same logistics problem.

The model is used to provide new insights. Based on our experiments, we show that the total delivery cost is basically related to the number of vehicles required for serving the online demand. Increasing the number of picking locations allows being closer to the delivery points but implies a lower number of orders to be fulfilled per delivery zone resulting in a lower number of stops per tour as well as lower vehicle saturation. In the initial stages of the online channel development, when the online demand is still low, the use of an intermediate number of picking locations is the most suitable solution (e.g., 6 in the base case). Then, when the online demand increases the best number of picking locations decreases (e.g., four with quadrupled demand).

The practical relevance of our contribution has been demonstrated through the model application to a real case study. Using the number of stores suggesting by the model leads to saving in the delivery cost of 40%.

There remain several interesting directions for further studies. First, an extension of the proposed model that analyses the entire e-fulfilment process, including the picking and packing process managed in-store in addition to the delivery process as suggested by Moons et al. (2017), is recommended. Future work can also introduce more complex distribution systems (e.g., mixed store- and warehouse-based model) and delivery service settings (e.g., variable time slots). Finally, we see many opportunities for additional research on the dynamic management of e-fulfilment problems: dynamic allocation of online orders to picking locations and delivery routes following the available capacity (e.g., stock, personnel, space).

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K	Number of picking locations
N	Set of stores selected as picking location (index by i)
Z	Set of delivery zones within the considered delivery region (index by j)
a_j	Size of delivery zone *j*
e_j	Average daily demand of delivery zone *j*
v_j	Average travel speed within delivery zone *j*
d_{ij}	Distance between store *i* and delivery zone *j*
nv_i	Number of vehicles needed for store i
$\boldsymbol{I}$	Allocation matrix of the delivery zones to the picking locations. I_{ij} is the Boolean variable that is 1 if delivery zone *j* is assigned to store i; 0 otherwise
d_i^0	Average distance to and from store i and the related delivery zones
d_i^n	Average distance between two consecutive stops in a delivery zone covered by store *i*
d_i^z	Average distance between two consecutive stops in different delivery zones covered by store *i*
S	Number of time slots within the day
t	Available time for deliveries in a slot
τ	Drop-off time (product delivery, payment) at customer home
c	Variable transport cost per kilometre
f	Fixed daily cost for a vehicle

Table 1. Main notation.

Delivery zone	a_j [km^2]	v_j [km/h]	e_j [Orders/day]
Zone 1	16.0	23.8	14
Zone 2	10.5	20.3	7
Zone 3	9.9	19.2	21
Zone 4	6.4	14.9	35
Zone 5	19.5	16.2	7
Zone 6	20.3	22.0	21
Zone 7	12.8	17.2	21
Zone 8	1.1	17.7	7
Zone 9	8.8	19.9	21
Zone 10	12.2	16.7	7
Zone 11	18.0	18.2	14
Zone 12	5.7	23.6	35

Table 2. Real case: size, average travel speed and average daily online demand of the delivery zones

[km]	*Zone 1*	*Zone 2*	*Zone 3*	*Zone 4*	*Zone 5*	*Zone 6*	*Zone 7*	*Zone 8*	*Zone 9*	*Zone 10*	*Zone 11*	*Zone 12*
Store A	0	6.7	5.4	8.4	14.6	21.3	9.5	20.8	15.7	42.2	34.2	32.8
Store B		0	5.3	4.9	8.3	27.7	7.6	8.9	14.7	26.9	29.4	14.9
Store C			0	4.0	10.3	8.0	5.9	5.0	11.2	14.1	10.0	9.7
Store D				0	6.8	9.8	3.5	5.2	6.7	9.1	8.2	10.9
Store E					0	14.8	7.6	12.1	7.5	11.7	12.6	16.4
Store F						0	8.3	3.4	13.3	12.5	8.9	6.7
Store G							0	5.4	5.4	6.0	4.8	7.9
Store H								0	10.7	9.9	5.8	6.0
Store I									0	5.2	8.2	12.0
Store J										0	8.1	10.3
Store K											0	8.4
Store L												0

Table 3. Real case: distance for each combination of store and delivery zone.

t_{ij} [min]	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 11	Zone 12
Store A	0	15	15	22	26	24	35	25	34	39	29	29
Store B		0	12	9	12	28	23	25	19	28	25	34
Store C			0	13	22	19	24	16	27	38	31	24
Store D				0	16	28	14	18	20	29	30	30
Store E					0	38	23	33	18	32	37	42
Store F						0	34	10	38	36	23	17
Store G							0	29	18	24	19	23
Store H								0	32	30	19	16
Store I									0	15	26	32
Store J										0	16	28
Store K											0	10
Store L												0

Table 4. Real case: travel time for each combination of store and delivery zone.

Number of delivery zones	$Z = 12$
Number of time slots within the day	$S = 7$
Available time for deliveries in a slot [hours]	$t = 1.5$
Drop-off time (product delivery, payment) [min]	$\tau = 13.5$
Constant for estimating distances in a delivery zone	$k1 = 1.15$
Constant for estimating distances between delivery zones	$k2 = 0.9$
Variable transport cost per kilometre [€/km]	$c = 0.15$
Fixed daily cost for vehicle and driver [€/day]	$f = 210$

Table 5. Real case: other base parametric values.

Total cost per order	12.48 €/order
Fixed cost per order	11.99 €/order
Distance-based cost per order	0.49 €/order
Total number of vehicles	12
Total travel distance per order	3.4 km/order
Number of stops per route	2.5 stops/route
Vehicle saturation	48%

Table 6. Main performance of the current distribution system.

No. picking locations	Total cost [€/order]	Fixed cost [€/order]	Distance-based cost [€/order]	No. vehicles required	Total distance per order [km/order]	No. stops per route	Vehicle saturation
12 (base case)	12.48	11.99	0.49	12	3.4	2.5	48%
10	10.45	9.99	0.46	10	3.1	3.0	58%
8	8.43	7.99	0.44	8	3.0	3.8	76%
6	7.46	6.99	0.46	7	3.2	4.4	92%
4	7.51	6.99	0.51	7	3.6	4.4	97%
2	8.57	7.99	0.57	8	4.1	4.3	100%
1	8.69	7.99	0.69	8	4.9	4.1	100%

Table 7. Results varying the number of picking locations.

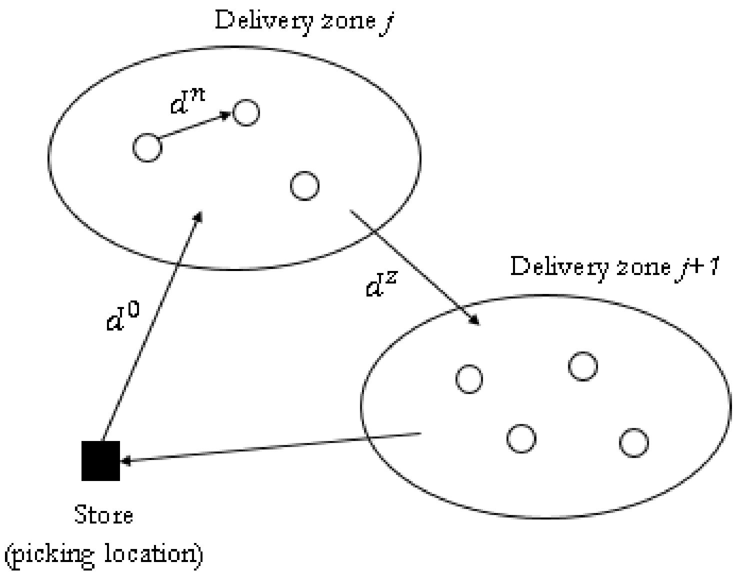

Figure 1. Routing components.

Algorithm 1 Heuristic procedure for comparing distribution systems

Input: an integer vector $\boldsymbol{K}$, an integer value R, a real value Δ

Output: best distribution system, i.e., number of picking locations K^*, set of stores used as picking location N^*, matrix that allocates the delivery zones to the picking locations $\boldsymbol{I}^*$, and the related delivery cost TC^*

```
1: $N^* \leftarrow \emptyset, \boldsymbol{I}^* \leftarrow \emptyset, TC^* \leftarrow +\infty$
2: for each $K \in \boldsymbol{K}$ do
3:   $N_K^* \leftarrow \emptyset, \boldsymbol{I}_{\boldsymbol{K}}^* \leftarrow \emptyset, TC_K^* \leftarrow +\infty$
4:   for each combination $N$ of $K$ stores do
5:     $\boldsymbol{I}_{\boldsymbol{N}}^* \leftarrow \emptyset, TC_N^* \leftarrow +\infty$
6:     for $r \leftarrow 1$ to $R$ do
7:       create a random matrix $\boldsymbol{I}^r$ that allocates the delivery zones to the picking locations, satisfying the following conditions $\sum_i I_{ij}^r = 1 \; \forall j \in Z, I_{ij}^r = 0 \; \forall i \notin N \; \forall j \in Z, I_{ij}^r = \{0,1\} \; \forall i \in N \; \forall j \in Z$
8:       compute the delivery cost $TC^r$ using Equation 10, $saving \leftarrow +\infty$
9:       while $saving > \Delta$ do
10:        $\forall i \in N, \forall j \in Z$ compute the delivery cost $TC^{ij}$ resulting from allocating delivery zone $j$ to store $i$ (keeping the allocation for all other delivery zones fixed) using Equation 10
11:        $TC_{min}^{ij} \leftarrow$ minimum delivery cost $TC^{ij}$ computed at line 10
12:        $saving \leftarrow TC^r - TC_{min}^{ij}$
13:        if $saving > \Delta$ then
14:          $\boldsymbol{I}^r \leftarrow \boldsymbol{I}^r$ changing the allocation for the delivery zone that achieves $TC_{min}^{ij}$
15:          $TC^r \leftarrow TC_{min}^{ij}$
16:        end if
17:      end while
18:      if $TC^r < TC_N^*$ then
19:        $\boldsymbol{I}_{\boldsymbol{N}}^* \leftarrow \boldsymbol{I}^r, TC_N^* \leftarrow TC^r$
20:      end if
21:    end for
22:    if $TC_N^* < TC_K^*$ then
23:      $N_K^* \leftarrow N, \boldsymbol{I}_{\boldsymbol{K}}^* \leftarrow \boldsymbol{I}_{\boldsymbol{N}}^*, TC_K^* \leftarrow TC_N^*$
24:    end if
25:  end for
26:  if $TC_K^* < TC^*$ then
27:    $K^* \leftarrow K, N^* \leftarrow N_K^*, \boldsymbol{I}^* \leftarrow \boldsymbol{I}_{\boldsymbol{K}}^*, TC^* \leftarrow TC_K^*$
28:  end if
29: end for
```

Figure 2. Heuristic procedure for comparing distribution systems.

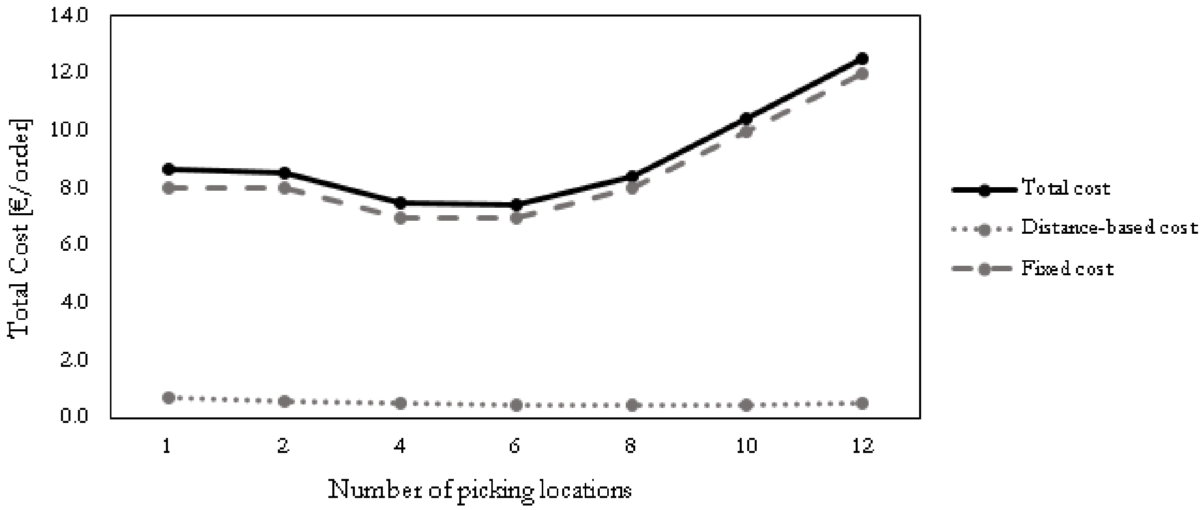

Figure 3. Results varying the number of picking locations: total cost behaviour.

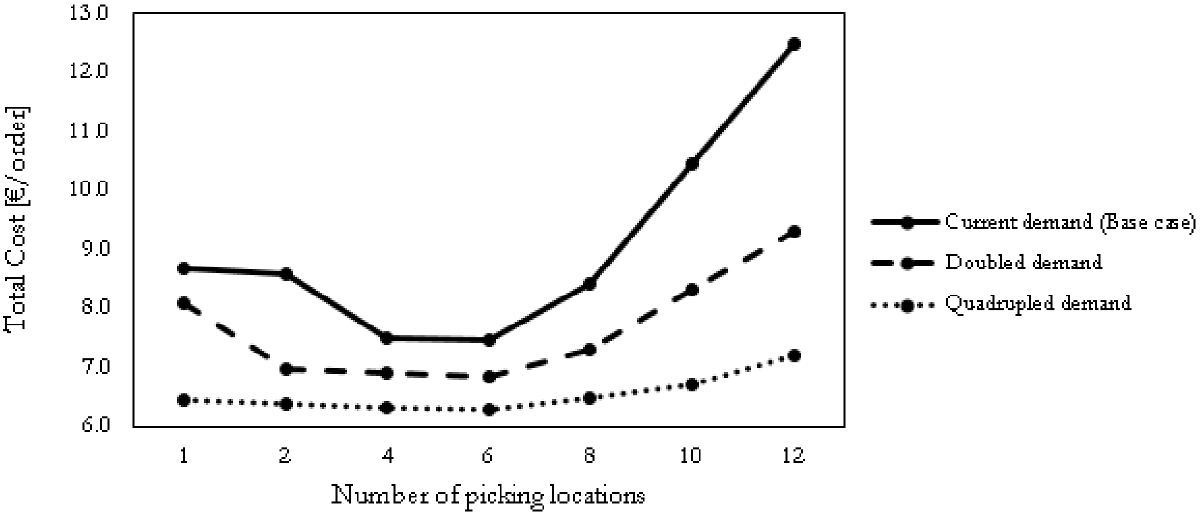

Figure 4. Impact of demand on total cost, varying the number of stores selected as picking location.