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An AHP-based framework for logistics operations in distribution centres

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ABSTRACT

In retail distribution centres (DCs), the handling and storage of products typically represent the largest share of operational costs and its design depends on a balance between supply and demand processes. As hundreds of options are possible, it is a challenge to plan and run these operations effectively. The objective of this research is to propose a framework for designing operations in DCs based on a joint study of three elements: distribution strategy, internal activities, and the characteristics of the distribution operations. The methodology is developed based on theory-building research using three case studies. The data collection was performed by three top managers at large logistics providers (LPs). The analytic hierarchy process (AHP) method was applied, and the framework was validated by the LPs. This framework was then applied to a sports fashion retail operation and was reported to enable the decision-making process regarding operations at DCs, creating scenarios for evaluation.

1. Introduction

A key component in a supply chain (SC) is the distribution centre (DC), which plays the vital role of obtaining materials from different suppliers, performing value-added activities, and assembling (or sorting) products to fulfil customer orders and offer a high level of service (Baker, 2007, 2008; Parikh and Meller, 2008). Warehouse operations (such as storage management and picking) are very complex and involve different activities, and warehouse planning based on experienced knowledge is crucial in achieving the goals of cost efficiency and effectiveness (Lam et al., 2015; Hou et al., 2010).

According to the framework of Baker (2007), the role of DCs depends on the SC strategy, which is derived from the company's business model (a focus on either supply or demand) and is based on two different objectives: service level and costs (Baker and Canessa, 2009). To perfectly coordinate supply and demand, reliable transportation and a quick response via automation (Baker and Halim, 2007) are necessary. However, this combination results in high costs. Therefore, efficient design of the DC is necessary to provide better flow of materials and reduce facility logistics costs (Parikh and Meller, 2008; Hong, Johnson and Peters, 2012; Pan et al., 2014; Dotoli et al., 2015). The literature reveals a gap in the contributions made by studies on these issues, which suggests that warehouse design evolves only by continuous improvement. Due to the lack of literature review and analysis, further study of the distribution strategy is necessary to guide companies' strategies for DC design and influence internal activities depending on its distribution focus: supply or demand (Baker, 2004). Moreover, different configurations and designs (Gu et al., 2007) are available to service the demand and to handle different product types (Lam et al., 2015) using different operating methods, equipment and procedures. Additionally, identifying the "optimum" solution is not possible due to the high number of possibilities (Baker and Canessa, 2009). For Thomas and Meller (2015), this decision includes, among other aspects, the number of pallet locations, the number of stock-keeping units (SKUs), the number of cases per pallet, and the throughput requirements, which are used according to the equipment (automatic or manual) chosen for handling the materials. This environment can be thought of as the characteristics of the distribution operations in a DC, which are interrelated. Costs (Rouwenhorst et al., 2000; Bartholdi and Hackmann, 2011), supply (Koster et al., 2007),

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items (Tompkins et al., 2003) and orders (Hackman et al., 2001; Petersen, 2002; Koster et al., 2007) are criteria to which special attention must be paid to support practitioners and companies in the design of distribution operations. Therefore, these studies lead to the following research question: *How can the design of the logistics operations of a DC be defined from the distribution strategy of a company, the complexity of the internal activities of the DC, and the characteristics of the distribution operations?*

The DC framework helps the decision makers (DMs) select suitable equipment and operating methods (Baker and Canessa, 2009) to organize internal activities, which is not a simple task. Regarding this discussion, Thomas and Meller, p 741) (2015) attest that "moreover, the decision variables in warehouse design are interrelated, and this further complicates the design process." Although various studies on DC design have been conducted, resulting in a high position of this subject in the logistics research stream, some authors suggest that its activities demand additional studies to address the common interests of both academics and practitioners (Baker and Canessa, 2009; Koster et al., 2007). Although there appears to be consensus on the overall structure of the approach, there is less consensus on the exact nature of the tools (equipment) to be used for each step (Baker and Canessa, 2009).

The objective of this research is to propose a framework for designing operations in DCs based on a joint study of three elements: distribution strategy, internal activities, and the characteristics of the distribution operations. The main contribution of this research is to propose a decision model for distribution operations in a DC based on strategic, tactical, and operational aspects, which are evaluated by a multi-criteria approach. Hence, the proposed framework may facilitate decisions regarding DC operations because it systematizes the selection of the variety of equipment and defines suitable operating methods for use in the DC.

The article is organized as follows: the introduction is presented first, followed by the literature review, which focuses on strategy in a DC, the internal activities of a DC, and the characteristics of distribution operations. Subsequently, the methodology is presented. Then, the framework for logistics operations is developed, including a practical example of the proposed framework. The article ends with final considerations.

2. Literature review

Although studying a DC's design and problems during its operations is important, the characteristics of the distribution strategy also influence the DC's design. Christopher et al. (2006) present a taxonomy of global SC strategies that are distinguishable along two dimensions: supply characteristics (the length of the lead time) and demand characteristics (predictability). The strategies vary from lean to agile and leagile (Mason-Jones et al., 2000) and have implications for the role of warehouses in global SCs, i.e., their location and operations and the value-adding activities performed. Baker (2007) underlines the requirements for safety stocks in international SCs because the supply lead times may be very long and a rapid response is required on the distribution side.

Moreover, warehouse design decisions are strongly coupled and are difficult to separate; the warehouse must be designed before it is built because such tactical decisions can be very expensive or impossible to change after the facility is ready to use (Gu et al., 2010; Gong et al., 2013). Although planning and control have been studied quite thoroughly, there is a lack of discussion on warehouse design (Rouwenhorst et al., 2000). To evaluate a specific warehouse design, Rouwenhorst et al. (2000) define some relevant performance criteria: investment and operational costs, volume and mix flexibility, throughput, storage capacity, response time, and quality of order fulfilment (accuracy). With this purpose, Gu et al. (2007) present a framework to jointly classify research on different, but related warehouse problems: warehouse design and operation.

According to Lin and Lu (1999) "how to determine the type of orders, and then to select a strategy for a DC has become an important task for practice". For an order-picking system design, there are a variety of design considerations, including order-picking strategies, product storage policy, the picker routing pattern and the levels of decision making (strategic, tactical, and operational) (Lin and Lu, 1999; Rouwenhorst et al., 2000).

Based on this discussion regarding DC design and the internal and external characteristics of a DC (Sandberg, 2013), the following subsections present the three elements, i.e., the distribution strategy, the activities and sub-activities of a DC, and the characteristics of the distribution operations, that are part of the framework for the design of operations in DCs.

2.1. Distribution strategy

Operational excellence in a business environment is the primary goal of companies that offer products and services, and its objectives are to maintain leadership in price, reduce costs and optimize operations (Shavarini et al., 2013). However, due to the uncertainty and speed of changes in this environment, the performance of warehouse operations is affected by the logistics strategy-planning process.

Although some books and articles separate SC from warehousing subjects, the classification of SC strategy (referred to in this paper as "distribution strategy") joins the two areas, as discussed by Baker (2004). Baker says that the DC strategy classification depends on the focus of the SC: demand or supply, which involve an agile (service-level emphasis) or lean (cost emphasis) SC, respectively.

When strategy focuses on demand (agile concept), the project of a DC aims at quick response operations to seize opportunities in a volatile market. Therefore, its objective is to reduce the response time with a high degree of precision. Here, agility is similar to the concept of volatile market places; thus, the ability to respond quickly to market opportunities is the critical factor (Vonderembse et al., 2006). Consequently, the success of a company's distribution strategy plays a critical role in supporting the internal operations of DCs. The DC's mission is to efficiently ship products to the next node in the distribution network without altering its form (Tompkins et al., 2003).

Supply strategies (lean concept) focus on the reduction of SC waste, such as excess resources, high levels of inventory and long lead times (Christopher and Towill, 2002; Vonderembse et al., 2006). Lean SC can speed up inventory turns and reduce inventory throughout the chain (Vonderembse et al., 2006). In addition, once project approval is obtained, the goals of improving quality and flexibility can be pursued in parallel with cost reduction (Booth, 1996).

Supply or demand strategies address different lead times provided by different segments of the service level depending on the use of lean or agile thinking (Baker, 2007). Decisions concerning the DC design and storage capacity are often strategic because they will significantly impact the company's future profitability (Cormier and Gunn, 1992). These concepts are not mutually exclusive (we can find leagile SC strategies in the literature, but this discussion is not the core of this paper) because the consensus of SC is that inventory must be minimized (Baker, 2004). In agile SC, the inventory is held at few echelons, if at all (Van Hoek et al., 2001). The distribution strategy will influence warehouse design, including detail operating methods, equipment, staffing levels, layout and costs.

The focus of some companies' strategies have changed from minimizing costs to reducing delivery times to meet demand, which implies that these companies have a demand strategy (agile). Baker and Halim (2007) highlight the importance of warehouse automation (cost, service and flexibility) and recognize that although automation is occurring, the SC must be more agile (i.e., focused demand strategy) to serve rapidly changing markets. The warehouse design does not have to be lean (i.e., with the focused supply strategy) but must provide a

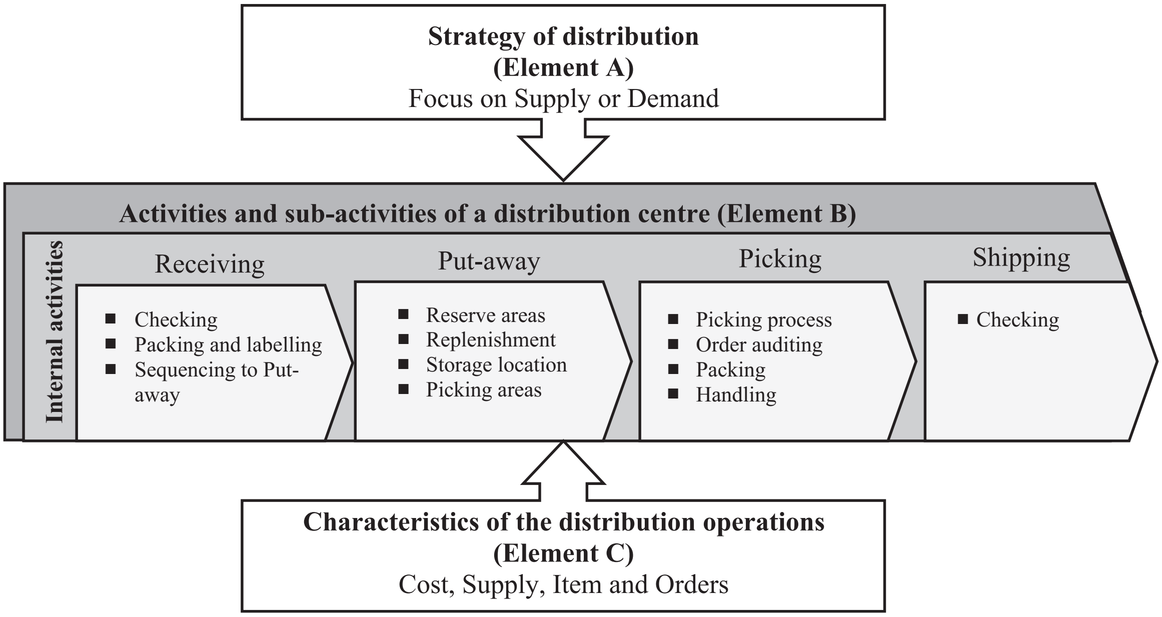

Fig. 1. Framework for the design of logistics operations in a DC.

high level of service for customers. The major motivations identified are to reduce the handling of materials in the warehouse, increase accuracy levels, improve service consistency and increase the speed of service, whereas the main decision criteria are reducing labour costs, increasing the output rate and improving service availability (Baker and Halim, 2007). For Bartholdi and Hackman (2011), the trade-off between the costs involved and the service provided by the logistics activities, especially storage and transport, justifies the existence of DCs.

2.2. Activities and sub-activities of a distribution centre

Currently, modern DCs provide a variety of services, which are divided by researchers into sets of activities, including order processing, inventory management, receiving, sequencing and put-away, order picking/selection, picking, accumulation/sortation (packaging), and shipping (Hou et al., 2010; Parikh and Meller, 2008; Koster et al., 2007; Liviu et al., 2009; Bartholdi and Hackman, 2011).

These activities can be classified into two levels: tactical and operational. The main tactical functions are inventory planning, inventory placing, assignment planning, transport planning, and personnel and equipment capacity planning. The operational decisions, which are related to receiving, stocking, and shipment decisions, are sequencing, programming, orders routing, put-away, and return operations (Faber, Koster and Smidts, 2013). This study follows the proposal of van den Berg and Zijm (1999), which considers four activities: receiving, put-away, picking, and shipping.

Koster et al. (2007) assume that the major and most important facility logistics activity in DCs is order picking. This is the process in which products are retrieved from storage to satisfy customer demand and are operated to fulfil customer orders (Lin and Lu, 1999; Roodbergen and Vis, 2006; Parikh and Meller, 2008; Chuang et al., 2012). The objective of order picking is to maximize the service level subject to resource constraints (Koster et al., 2007). The management of order-picking operations immediately impacts the DC and thus the SC's performance. Hou et al. (2010) assume that storage management and picking planning are among the most important and complicated DC activities.

2.3. Characteristics of the distribution operations

The internal activities of different DCs tend to be similar, but the manner in which they are organized is influenced by the characteristics of the distribution operations, such as the types and quantity of items, supply, costs, and orders. These characteristics consist of criteria that influence how companies organize their production and distribution processes. These processes include order picking/selection, picking, packaging, shipping, and delivery. According to Koster et al. (2007), external factors that may influence picking strategies include commercialization channels, patterns in clients' demands, patterns in suppliers' replenishment, the levels of inventory from the operation, and the general demand for an item.

During the 1980s and 1990s, managing a DC was challenging, and to improve warehouse management, order picking was the focus. To achieve this improvement, the following factors must be considered at DCs: improved delivery time and accuracy standards; increases in the quantity of items to be stored; investment and operational costs; volume and flexibility; efficiency, storage capacity, response time and service quality (Chia Jane, 2000; Petersen, 2002; Rouwenhorst et al., 2000). Aligned with DC improvement, the choice of equipment and the organization of the flow of materials in DCs may be influenced by inventory characteristics (number of items, size, and turnover), service requests (number of lines and orders per day), labour costs, facilities costs and equipment costs (Bartholdi and Hackman, 2011).

In picking operations, travel time is a concern because, among all the activities in a warehouse, it is the most demanding; it is also the most common subject discussed by academics and practitioners (Chuang, Lee and Lai, 2012). Although Chuang, Lee and Lai (2012) note this aspect (travel time), they assume that order picking can be shortened by redesigning the layouts of racks, assigning better storage places, shortening order pickers' routes, and accumulating orders into batches to decrease picking frequency. However, they acknowledge that the layout redesign and order batching may not be realistic; thus, for a real warehouse, assigning appropriate storage locations is a feasible approach to reduce travel time and distance.

In conclusion, DC management depends on its design and is influenced by the size and quantity of items as well as the characteristics of cargo handling (Tompkins et al., 2003). Thus, the characteristics of the distribution operations related to items, supply, costs and orders must be considered criteria in the design of a DC.

After the considerations from literature review, three major elements can be jointly identified as factors that influence DC logistics operations, as presented in Fig. 1.

Element A is related to the focus of the distribution strategy that the company adopts, i.e., the supply focus or the demand focus (Baker, 2004). **Element B** consists of the internal activities and sub-activities of the DC, which must be defined by the DM responsible for DC configuration. **Element C** is associated with the characteristics of the distribution operations, such as the quantity of handled items and the time schedule for receiving or order processing. Elements A and C represent external factors of the DC that influence the operational choices of element B. The DC design of the internal activities must be aligned with the distribution strategy from the retail channel (element A) and with the characteristics of distribution operations (element C).

3. Methodological approach

Due to challenges from the distribution strategy and the characteristics of distribution operations, some requirements from customers must be addressed to offer them a high service level. We developed an exploratory research design to increase our understanding of this logistics operation environment in a DC by studying the distribution strategy, the internal activities, and the characteristics of distribution operations (cost, supply, item and orders).

For exploratory and theory-building research, case studies are often recommended (Woodside and Wilson, 2003; Yin, 1994; Eisenhardt, 1989). In our research, we propose theory-building based on three focused case studies to establish linkages among the three elements of our investigation (detailed in Section 3.1). In theory-building research, for future investigations, having a prior perspective on general constructs or elements and the relationship among them (Voss et al., 2002) is the most important part of this proposal. We have followed the well-established methodological aspects and steps suggested by Yin (1994) and Voss et al. (2002) to increase the validity of our results. We consider a number of cases that may be sufficient in a multiple-case setting and representing a suitable sample of logistic provider (LP) companies in the retail market in terms of size and complex logistics operations in DCs (Baker and Canessa, 2009). We have developed and applied two structured interview protocols based on the literature. Using multiple sources (face-to-face interviews, direct observations, informal conversations, email, telephone calls and the frameworks used by the companies to design logistics operations), all focusing on the same event in our data collection, we also improve the generalizability of the proposal (Yin, 1994; Woodside and Wilson, 2003; Voss et al., 2002). Therefore, we considered the matter of "how" to address triangulation (McCutcheon and Meredith, 1993), i.e., the research protocol and different instruments used to collect the data and the methods used by the LPs to handle distribution operations.

The first interview protocol included two parts: (i) the characterization of the interviewee and the company and (ii) the evaluation of the proposed framework regarding the three elements and verification of the equipment and procedures used in the logistics operations (i.e., whether the elements of the framework can be identified in their current practices and whether this framework could be evaluated by the respondents or DMs). A second interview protocol was developed and applied to those DMs to compare all criteria/sub-criteria (see Table A1, columns 1 and 2 in Appendix A) and alternatives, following the procedures of the analytic hierarchy process (AHP).

To conduct the analysis of the case study, a multiple-criteria decision analysis (MCDA) approach was employed to structure and design the logistics operation for a DC. MCDA is a suitable approach for structuring and appraising the activities of a large and complex decision considering distribution, the logistics strategy, various order situations and multiple ordering features (Lam et al., 2015), as previously introduced. The research problem involves numerous alternatives (see Table A2 at Appendix A) that are chosen based on a set of criteria/sub-criteria.

The literature classifies several methodologies under the heading of MCDA. AHP and multi-attribute utility theory (MAUT) are classic approaches of decision support (Bana e Costa, 1990), and both could have been chosen for this case study. The transitivity axiom is a necessary condition in MAUT but not AHP because we assume that the judgements are always consistent (Harker and Vargas, 1990). The following three aspects of AHP provide relative strengths (Goodwin and Wright, 2009) compared with MAUT (Belton and Stewart, 2002) and other outranking methods (PROMETHEE, see Brans et al., 1986; Brans and Vincke, 1985; ELECTRE, see Roy and Mousseau, 1996) that were considered in this study:

3.1. Simplicity of pairwise comparisons

The pairwise comparison procedure uses a ratio scale instead of the interval scale used in MAUT. According to Harker and Vargas (1990), "ratio scales provide a very useful way to model a variety of situation". Each criterion is rated against every other in a matrix of criteria by assigning a relative dominant value between 1 (i.e., equally preferred) and 9 (very strongly to extremely) to the intersecting cell, thus enabling a DM to make judgements in a systematic manner (Saaty, 2008). Verbal comparisons are also likely to be preferred by the DM to express his/her judgements numerically. For this procedure, see the MACBETH approach (Bana e Costa and Vansnick, 1997).

3.2. Redundancy enables verification of consistency

In the AHP process, DM is required to make more comparisons than are needed to establish a set of final weights for criteria and for alternatives. According to Goodwin and Wright (2009), this is actually considered a best practice because the DMs can reflect on any inconsistencies in the proposed judgements by checking all the criteria automatically on one level independent of another level (axiom 3 of AHP) (Harker and Vargas, 1990).

3.3. Versatility

AHP is applied in various research fields. AHP models have also been used to construct scenarios to evaluate risks that may occur during logistics operations in a DC (Lam et al., 2015).

We adopted the AHP models as follows (Goodwin and Wright, 2009):

3.3.1. Step 1: setting up the decision hierarchy

We start the process of building a tree with the distribution strategies: focus on supply and demand (first level). On the second level, for each strategy, we draw the further activities and sub-activities and then decompose the criteria until the essential criteria for decision making have been specified. The alternatives are added to the hierarchy below each of the lowest-level criteria. In this stage, the interviewee (DMs of the LPs) validates the criteria of the decision tree and the alternatives.

3.3.2. Step 2: Making pairwise comparisons of criteria/sub-criteria and alternatives

First, the relative importance of the criteria and of sub-criteria (Saaty, 2008) are determined according to a point of reference as follows: "*with respect to the strategy or characteristics of distribution or activities/sub-activity, which of the two criteria/sub-criteria (A or B) is preferred, and by how much*"? Second, we compare how well the alternatives perform on the different criteria/sub-criteria. However, each sub-criterion uses a three-level scale represented by scores (e.g., for the criterion item, the sub-criterion dimension can be rated as large (3), medium (2) or small (1), according to Table A1, which will match possible alternatives listed in Tables 6–9). None of the alternatives completely match the different criteria/sub-criteria or can receive the same scores. Thus, for each activity/sub-activity, we must define the scores for the criteria/sub-criteria and then evaluate the alternatives that are appropriately used to address the sub-criteria following the question: *"which alternative listed in* Table B1 *is preferred according to the sub-criteria?"* These alternatives are evaluated by pairwise comparisons comparing the first with the others, the second with the others, and so on.

3.3.3. Step 3: verifying the consistency of the DMs and transforming the comparisons into weights

The AHP converts these comparisons into a set of weights. To verify the trustworthiness of the information provided to establish a comparison matrix of the criteria, a "consistency index - μ" is used (Saaty, 2008). The index can be calculated according to $\mu = (\mu\ \max - n)/(n-1)$, in which n is the number of alternatives used in the comparisons. The consistency index should preferably be close to zero (i.e., less than 0.1); otherwise, the judgements must be reviewed to improve consistency (Saaty, 2008).

After those steps, the tree is complete, i.e., all criteria with weights and alternatives (without the weights) that encompass the framework for logistics operations in a DC are defined (see Fig. A1). The alternative weights are defined after the following steps: first, the characteristics of the distribution operation must be defined (Table A1); second, the alternatives from Tables 6–9 are selected based on these scores; third, pairwise comparisons of the candidate alternatives must be performed (e.g., Table B1).

To validate the framework, we also measured the reliability of this research by applying this framework to another company. We chose a company (Company W) that operates in the sports fashion retail sector, with a focus on the distribution of Dispatch eyewear. Company W is European and a global market leader in terms of sales volume. In Brazil, Company W has a DC located in Sao Paulo state, with an area of approximately 2500 m^2 dedicated to the optical operation. The DC is managed by an LP. Approximately 90% of its volume is replenished twice weekly directly from factories located in Italy, China, and the United States. The characteristics of the DC are similar to those found at the three LP companies that were evaluated using the case study methodology. Thus, the framework was applied to the operations director of Company W.

3.4. Characterization of the LPs and the interviewees

This research was conducted with three large LPs (with more than 500 employees) acting in the retail channel to serve consumer packaged goods (CPG) industries and others. These companies are urged to provide a great service level to meet the rapid and timely demands of retailers, which include orders with multiple and smaller quantities of items (Chuang et al., 2012). Thus, retail is a sector that warrants special attention. These companies also have a high diversity of items and a diversity of distribution channels, as shown in Table 1. The profiles of the DMs are also presented.

Face-to-face interviews were chosen as the main procedure for collecting the data due to advantages of effective feedback from the key subjects, greater amplitude in the collected data, and inclusion of relevant facts that did not arise in the literature review (Yin, 1994). The results of the interviews reveal that the companies have an area dedicated to DC design. However, they do not adopt a structured methodology to define the distribution operations based on internal and external environments. Therefore, our proposal can improve their decision-making processes.

4. Proposal of a framework for logistics operations in DCs

Following step 1 of AHP, Section 4.1 structures the decision-making process based on the three elements, A, B and C. Section 4.2 describes pairwise comparisons of the criteria/sub-criteria for each element (step 2 of AHP). Section 4.3 details the proposition and the evaluation of the activities and sub-activities of a DC. Section 4.4 details the transformation of the comparisons into weights (step 3 of AHP), and the complete tree is presented (Fig. A1).

4.1. Problem definition: structuring the decision-making process

Table 2 summarizes these three elements. Element A considers the two distribution strategies: focus on supply or focus on demand. Element B provides a set of four activities and their respective sub-activities related to DCs (van den Berg and Zijm, 1999). Element C provides a set of characteristics of the DC operations that consists of the criteria obtained from the literature review, i.e., costs, supply, items and orders, and their specific sub-criteria.

4.2. Pairwise comparisons of criteria and sub-criteria

The framework (elements A, B, and C) is evaluated by the DMs from the LPs. As previously mentioned, in this step, pairwise comparisons are made according to a scale ranging from 1 to 9, i.e., from equally preferred to extremely preferred, respectively.

4.2.1. Distribution strategy (Element A)

The framework starts with the decision between the "focus on supply" or "focus on demand" strategies, which depends on the company's goal.

All DMs reported that they aim to achieve the highest service level when the distribution strategy is "focus on demand" (Table 3). Thus, the operations of the internal activities of the DC must be aligned with the characteristics of the distribution operation. Thus, for a given characteristic (e.g., criterion orders), the focus is to configure the internal operation to best meet this characteristic.

When the interviewees chose the strategy of 'focus on supply', the costs are defined as having greater importance (value 5) than the service level. For the 'focus on demand' strategy, the service level has greater importance (value 6) than costs. This is reasonable when, for instance, in the "focus on demand" strategy, in which the objective is to attend to the customers more quickly, it is necessary to reduce the delivery time and avoid incomplete and lost deliveries as well as misplacement and cargo theft, among other practices. This increase in the service level is certainly associated with a higher operational cost. However, for companies that have chosen this strategy, a higher cost is tolerated by the market and can even be compensated by supplying greater volume, customer loyalty and recurring transactions.

4.2.2. Activities of a DC (Element B)

Table 4 shows the pairwise comparison between the criteria for all sub-activities of receiving and put-away activities, with a focus on "demand" strategy. "Items" has the greatest comparative importance. Quantity, variety of physical groups, dimensions, weight and value of the items are the sub-criteria that most influence the organization of the internal activities of a DC (see all criteria/sub-criteria in Table A1). This result corroborates those of Petersen (2002), who states that an increase in the quantity of items of various sizes requires more storage room and increases the complexity of picking and checking activities. The results show that for the checking sub-activity, for instance, the criterion "item" is moderately more important (value 4) than the criterion "supply". A similar result can be observed for the "put-away" activity, which has a score of 5 for "item" compared with the criterion "supply" for equipment and methods in the reserve areas sub-activity and a score of 4 for "item" compared with "orders" in the replenishment sub-activity.

Regarding the other two activities, "picking" and "shipping", and their respective sub-activities, all criteria are "equally preferred".

Table 1
Characterization of the LPs and the interviewees.

Companies[a]	**X**	**Y**	**Z**
Turnover (2014) (MM)	US$400	US$136	US$19
Capital	Germany	Brazil	Switzerland
Number of nationwide DCs	60	13	6
Number of SKUs	> 100,000	> 80,000	> 30,000
Sector	Electronics, CPG industry, Pharmaceutical, Automotive	Automotive, Chemical, CPG industry	Electronics, Automotive, CPG industry
Decision makers[b]	**DM1 (X)**	**DM2 (Y)**	**DM3 (Z)**
Age (years)	52	44	36
Experience (years)	22	20	13
Current Position/Time (years)	Operations director/7	Supply Chain director/4	Senior Project manager/7
Main functions	Warehouse management; Inventory management. Planning management	Warehouse management. Procurement management. Production planning	Project management. Transportation management. Warehouse management
Experience/Time (Years)	Supply chain manager/5 years Logistics group manager/11	Supply chain director/2 years Logistics and operations manager/15	Logistics coordinator/5 years Logistics analyst/ 1
Interview duration	4 h	5 h	4 h

[a] Note: Numbers in Brazil.
[b] The interview modes were face-to-face interview and by email.

Table 2
Decision elements that influence the DC design.

Distribution strategy (Element A)	Activities and Sub-activities of the DC (Element B)				Characteristics of the distribution operations (Element C)
Focus on supply	**Receiving**	**Put-away**	**Picking**	**Shipping**	Cost,
or	Checking	Reserve areas	Picking process	Checking	Supply
Focus on demand	Packing and labelling	Replenishment	Order auditing	–	Item
	Sequencing to put-away	Storage location	Packing	–	Orders
		Picking areas	Handling	–	

Table 3
Pairwise comparisons of criteria for different distribution strategies.

Focus on supply		**Focus on demand**	
	Service Level		Cost
Costs	5	Service Level	6

Table 4
Pairwise comparisons of criteria by activity/sub-activity.

Receiving activity				
Checking		Supply	Cost	
	Item	4	1/2	
	Supply		3	
Packing and labelling		Supply	Cost	
	Item	3	1/3	
	Supply		1	
Sequencing to put-away		Supply	Cost	
	Item	4	1	
	Supply		1	
Put-away Activity				
Equip/Methods at reserve areas		Supply	Cost	
	Item	5	1/2	
	Supply		1	
Replenishment		Orders	Cost	
	Item	4	1/4	
	Orders		1	
Storage location		Orders	Supply	Cost
	Item	4	4	1
	Orders		3	4
	Supply			1
Equip/Methods at picking areas		Orders	Supply	Cost
	Item	3	5	3
	Orders		5	5
	Supply			1

Consequently, these activities are not shown in Table 4.

The pairwise comparison of criteria by activity/sub-activity with a focus on "supply" strategy follows the same methodology to obtain the complete tree (Fig. A1). However, the scores given by the DMs and the steps to obtain the results are not detailed in the text.

4.2.3. Characteristics of the distribution operation (Element C)

Table 5 summarizes the pairwise comparisons of the criteria related to the characteristics of the distribution operations: cost, supply, item and orders. These comparisons are independent of the distribution strategy (Element A).

Table 5 indicates how the sub-criteria are compared with each other. For example, logistics DMs tend to value operational costs most because the operational monthly result indicator is one of their most relevant figures.

In the "supply" criterion, the volume is slightly more relevant than the frequency (2), receiving time (3) and storage policy (2), and the frequency is also slightly more relevant than the receiving time (3).

Regarding the "item" criterion, the relationship between quantity and physical groups is given a rating of 5, which characterizes a strong intensity of importance; that is, the quantity is more relevant than the physical groups. Dimension and weight are also more relevant than physical groups (4) and slightly more important than quantity (2). Concerning the other criteria, the values for 'items' indicate that the favouring relationships are small (2) or identical (1).

The remaining pairwise relationships are almost equally relevant. For instance, regarding the "orders" criterion, the different sub-criteria do not differ greatly among them. The pairwise comparison presented a maximum of small (2) relevance.

Undoubtedly, the "item" criterion was revealed as the most relevant in the decision-making process of the DC framework, especially

Table 5
Pairwise comparisons of sub-criteria for each criterion.

Cost	Operation				
Investment	1				
Supply	Frequency	Receiving time	Storage policy		
Volume	2	3	2		
Frequency		3	1		
Receiving time			1		
Item	Physical groups	Dimension	Weight	Value	
Quantity	5	1/2	1/2	2	
Physical group		1/4	1/4	1/2	
Dimension			2	1	
Weight				1	
Orders	Fragmentation	Quant. of lines	Ratio by lines	Processing time	Precision
Quantity	2	2	2	2	2
Fragmentation		1	1	1	1
Quantity of lines			2	2	2
Ratio by lines				2	2
Processing time					1

regarding operational issues conditioned by the sub-criteria of the quantity of items, dimensions and weight. These sub-criteria deeply influence the selection of machines and control of material-handling systems.

4.3. Evaluation of the alternatives: activities/sub-activities of a DC

In this section, the characteristics of an item are evaluated within different activities and sub-activities for each available alternative. The internal activities and sub-activities are based on the literature, and the criteria/sub-criteria scores were given by the DMs. These scores will be used further to make pairwise comparisons between the available alternatives and the sub-criteria. Sections 4.3.1 to 4.3.4 are organized as follows:

a) For each activity (receiving, put-away, picking, and shipping) and their corresponding sub-activities, different alternatives and their respective criteria (items, supply, orders and costs) are listed.
b) The corresponding evaluation is presented, indicating its score or its possible use. This evaluation was defined by costs (Rouwenhorst et al., 2000), the supply (Koster et al., 2007), items (Tompkins et al., 2003), and orders (Petersen, 2002; Koster et al., 2007). The evaluation uses a three-level scale represented by a score (see Tables 6–9): a lower score (1), which is attributed to small/low/bad/worst characteristics; an intermediate score (2), which is attributed to average/medium/intermediate/regular characteristics; and (3) an upper/higher score, which is attributed to great/high/good/best characteristics. This classification is used to identify and match the different alternatives to one or more criteria. If the sub-criterion does not present any relationship to that alternative, the sub-criteria score is considered non-applicable (n.a.). The specific evaluations for the cost criteria (investment and operation) and time criteria (receiving time and processing time, based on the supply and orders criteria, respectively) have an inverse interpretation; a score of 3 represents a good result (e.g., low cost or short time). Notably, when defining the criteria, only those that were agreed upon by at least two DMs of the LPs were considered.

4.3.1. Receiving

Table 6 presents a comparison of the different alternatives for the receiving activity with its respective evaluation related to the following criteria and sub-criteria:

a) Cost: the capital required for the alternative regarding its investment and operation;
b) Supply: the characteristics of the cargo to be received in terms of volume (the quantity of items), the frequency with which the operation is demanded, and the expected times for receiving the goods and making them available for storage;
c) Item: the products to be received, with the sub-criteria of the quantity of different items, dimensions and weights.

4.3.2. Put-away

Table 7 compares the alternatives for the put-away activity and its respective evaluation for the following criteria and their sub-criteria:

a) Cost: the capital necessary to acquire and to operate an alternative involved in put-away activity;
b) Supply: receiving time and storage policy for each available alternative in the put-away activity;
c) Item: quantity, dimensions, weight and physical groups of items to be stored at DCs;
d) Orders: processing and fragmentation times for put-away activities.

Table 6
Receiving sub-activities and scores of the alternatives.

Sub-activity	Alternative	Criteria scores							
		Cost		Supply			Item		
		Invest	Operat	Volume	Freq	Receiving time	Quant	Dimen	Weight
Checking	Picking list	3	2,3	1,2	1,2	1,2	1	n.a.	n.a.
	Aided by portable devices	1,2	1,2,3	1,2,3	1,2,3	3	1,2,3	n.a.	n.a.
Packing and labelling	Manual	n.a.	1,2,3	n.a.	n.a.	1,2	1,2,3	1,2	1,2
Sequencing to put-away	Non-motorized devices	2,3	2,3	1,2,3	1,2,3	1,2	1,2,3	1,2	1,2
	By vehicles	2,3	1,2,3	1,2,3	1,2,3	2,3	1,2,3	1,2,3	1,2,3
	By conveyors	1	1,2,3	2,3	1,2,3	3	1,2,3	1,2	1,2
	On foot	3	2,3	1	1	1	1	1	1

Table 7
Put-away sub-activities and scores of the alternatives.

Sub-activity	Alternative	Criteria Scores									
		Cost		Supply		Item				Orders	
		Inv	Oper	Recieve Time	Store policy	Quant	Dim	Weight	Phys Group	Process time	Frag
Storage location	Manual	3	2,3	1,2	n.a	1	n.a.	n.a.	1,2	1,2	n.a
	WMS	1,2	1,2,3	1,2,3	n.a	1,2,3	n.a	n.a	1,2,3	1,2,3	n.a
Equipment and methods (reserve and picking areas)	Block stacking	3	3	1,2	3	1	2,3	2,3	1	1,2	1
	Shelves and storage drawers	2,3	2,3	1,2,3	1	1,2,3	1,2	1	1,2	1,2,3	1,2,3
	Racks	1,2,3	1,2,3	1,2,3	2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2
	AS/RS	1	1,2	2,3	3	2,3	1,2	1	1,2	2,3	3
Replenishment	Manual	3	2,3	n.a	n.a	1	n.a	n.a	1,2	1,2	n.a
	WMS	1,2	1,2,3	n.a	n.a	1,2,3	n.a	n.a	1,2,3	1,2,3	n.a

Defining whether one (picking) or two (reserve and picking) areas will be used for storage is a decision that must be made previously by the DMs. If there is only one storage area, there will not be a replenishment sub-activity from the reserve to the picking areas. When there are two storage areas, however, the criteria of orders in the reserve area must be excluded because this area will be used to replenish the picking area. The picking area will continue to use all sub-criteria because it can directly receive items.

4.3.3. Picking

Table 8 presents the comparison between the different alternatives for picking and the respective evaluations for the criteria and sub-criteria.

a) Cost: the investment cost and the operational cost necessary for a given alternative;
b) Item: products to be picked for shipment; these criteria consist of the quantity, dimensions, and weight;
c) Orders: the quantity of orders for the operation, the need for fragmentation, the number of lines per orders (items to be picked), the quantity of pieces per line to be picked (ratio), the time for accomplishing picking, and precision.

4.3.4. Shipping

Table 9 presents the comparison between the alternatives for the “orders” and “costs” criteria related to shipping and their respective sub-criteria.

a) Costs: the necessary investment cost for the specific alternative and its respective operation cost;
b) Orders: The quantity of orders to be shipped and their processing time affect the operation. The precision focuses on the criticality of an incorrect dispatch because this may result in penalty charges to the customer.

4.4. Decision tree for the framework of the DC operating environment

After the pairwise comparison was performed by the DMs, we calculated the weights and the consistency index. All values in the index are below the cut-off (0.1) defined by Saaty (1980). Fig. A1 shows the complete decision tree.

Based on the perspective of the DMs, the complete tree reveals that under the “focus on demand” strategy, in general, the “item” criterion has the greatest weights among the criteria in all sub-activities, except for the “replenishment” sub-activity for the put-away activity. The “items” criterion has large weights for its sub-criteria of “quantity”, “dimensions” and

Table 8
Picking sub-activities and scores of the alternatives.

Sub-activity	Alternative	Criteria Scores										
		Cost		Item			Orders					
		Inv	Oper	Quant	Dim	Weight	Quant	Frag	Lines	Ratio /line	Proc Time	Prec
Picking process	Picking list	3	2,3	1	1,2,3	1,2,3	1	1,2	1	1,2	1,2	1
	Aided by portable devices	1,2	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3
	Vision	1	1,2,3	1,2	1,2	1,2	1,2,3	1,2,3	1,2,3	1,2,3	2,3	1,2,3
	AS/RS	1	1,2,3	2,3	1,2	1,2	1,2,3	1,2,3	1,2,3	1,2,3	2,3	2,3
Order auditing	Manual	3	2,3	n.a.	n.a.	n.a.	1,2	1	1	1,2	1	1
	Aided by portable devices	1,2	1,2	n.a.	n.a.	n.a.	1,2,3	1,2,3	1,2,3	1,2,3	2,3	2,3
Packing	Manual	3	3	n.a.	n.a.	n.a.	1,2,3	n.a.	n.a.	n.a.	1,2	1,2,3
	Automatic	1,2	1,2	n.a.	n.a.	n.a.	1,2,3	n.a.	n.a.	n.a.	2,3	1,2,3
Handling	Non-motorized devices	2,3	2,3	1,2,3	1,2	1,2	1,2,3	n.a.	1,2,3	1,2,3	1,2,3	n.a.
	Vehicles	1,2,3	1,2	1,2,3	1,2,3	1,2,3	1,2,3	n.a.	1,2,3	1,2,3	1,2,3	n.a.
	Conveyors	1	1,2	1,2,3	1,2	1,2	2,3	n.a.	2,3	2,3	2,3	n.a.
	Conveyor belts	1	1	1,2,3	1,2	1,2	2,3	n.a.	1,2,3	1,2,3	2,3	n.a.
	On foot	3	2,3	1,2	1	1	1	n.a.	1	1	1	n.a.

Table 9
Shipping sub-activities and scores of the alternatives.

Sub-activity	Alternative	Criteria scores				
		Cost		Orders		
		Investment	Operation	Quantity	Processing Time	Precision
Checking	Picking list	3	2,3	1	1,2	1
	Aided by portable devices	1,2	1,2,3	1,2,3	1,2,3	1,2,3

Table 10
Equipment and operating methods selected for logistics operations of Company W.

Activity							
Receiving		Put-away		Picking		Shipping	
Sub-activity	Alternative	Sub-activity	Alternative	Sub-activity	Alternative	Sub-activity	Alternative
Checking	Aided by portable devices	Storage location assignment	WMS	Picking	Aided by portable devices	Checking	Aided by portable devices
Packing and labelling	Manual	Equipment and methods: reserve area and picking areas	Racks or AS/RS	Auditing	Aided by portable devices		
Sequencing to put-away	Conveyors			Packing	Manual or automatic		
		Replenishment	WMS	Handling	Vehicle or conveyor belts		

"weight". The "item" criterion in the sub-activities "packing and labelling" and "sequencing to put-away" (receiving activity) obtains weights of 0.55 and 0.70, respectively. For both sub-activities, the "quantity" of items has a weight of 0.20, "dimensions" has a weight of 0.49, and "weight" has a value of 0.31. These results reinforce the importance of the quantity of items as one of the main drivers of the logistics configuration of DCs (Petersen, 2002; Bartholdi and Hackman, 2011).

For picking and shipping activities, the "item" criterion is present in the picking process and handling sub-activities and has the same weight as the other criteria. Indeed, for the other sub-activities (order auditing and packing at picking activity and checking at shipping activity), the quantity of items is not relevant because these sub-activities exclusively address the orders, with goods already having been picked and readied for packing and shipping.

Considering the "focus on supply" strategy, the "costs" criterion shows the highest weight for every sub-activity. The smallest figure is a weight of 0.66 in the "picking area" sub-activity of the "put-away" activity. The investment and operational costs have equal weights (0.5 for each) in all sub-activities, except for the "packing and labelling" sub-activity, in which only operational cost is considered. Incidentally, the "items" criterion obtained weights of approximately 0.2 in the "put-away" activities, the second highest weight among the other criteria. We infer that the greater weight attributed to the costs criterion is due to competition from companies in physical distribution, which forces a reduction in prices when the strategy focus is the supply.

These results obtained by the deployment of the decision tree align with the previous discussion of the targets of both strategies with regard to DC design (Element A) based on supply or demand (Baker, 2007; Baker and Canessa, 2009). When a decision regarding DC operations is required, the "focus on demand" strategy will always lead to better service-level attendance towards the customers, with some disadvantages in terms of costs. The "focus on supply" strategy will always consider costs as a prior criterion because the DC design must operate under lower financial margins.

The characterization of the DMs presented in Table 1 shows that their main function at their LPs is related to operations management, which means that they may prioritize operational issues. All DMs have more than 6 years of experience in the logistics area, and their main functions include warehouse management. Specifically, DM1 and DM2 have more than 10 years of experience as logistics managers. If the DMs were from the top management teams of the LPs, i.e., not directly related to operations, the weights might differ.

5. Evaluation and choice of solution: a practical example of the proposed framework

This section aims to apply the proposed framework for the design of a DC to Company W as follows:

1. The DM defined the distribution strategy as focused on demand (with service-level prioritization). Thus, the first branch of the tree will be detailed to further considerations, including the weights.
2. The characteristics of the distribution operations (sub-criteria) were provided by the DM of Company W (see Table A1).
3. The cross analysis between these scores and the alternatives for each activity/sub-activity (defined on Tables 6–9) provided the candidate alternatives for pairwise comparisons, followed by the selection of the appropriate alternatives (see the example in Appendix B for the activity 'Receiving' and sub-activity 'Sequencing to put-away').

Table 10 shows the final results for all activities/sub-activities, considering the proposed framework, the pairwise comparisons of the criteria/sub-criteria and the available alternatives, which were set according to the preferences of the DM from Company W.

For each internal activity and the corresponding sub-activities, an alternative (operating method/equipment) was suggested. For example, considering the receiving activity, the suggested alternatives were the following: "aided by portable devices" for the checking sub-activity, the "manual" process for packing and labelling, "non-motorized devices" for sequencing to put-away in the picking area, and "by vehicles or conveyors" for sequencing to put-away in the reserve area. Considering the characteristics of the products handled in the DC and the sector in which the company operates (optical sports goods), the alternatives for logistics operations suggested by the framework were considered suitable by the DM.

In summary, the characteristics of the distribution (Table A2) imply complex operations, specifically for the picking process. The aspects of the handled goods are complicated by their characteristic of fragility, which requires technology-based solutions to support operations, such as a Warehouse Management System (WMS) to assist location assignment and replenishment and the use of portable devices for the picking and checking processes.

6. Final considerations

A comprehensive methodological approach for warehouse operations appears to be a goal that is far from being achieved (Baker and Canessa, 2009), and based on reviews of the literature on warehouse design, relatively little has been written considering the distribution strategy and the characteristics of operations. There are important components of the overall SC strategy and co-ordination among various aspects of the business (i.e., business model), including the logistics and operations of warehouses, that must be planned (Baker, 2007). In an attempt to contribute to this field, the aim of this paper is to propose a framework for designing logistics operations in DCs based on the distribution strategy, the activities of the DC and the distribution operations characteristics. According to Lam et al. (2015), it is very difficult for the DM in warehouse operations to give appropriate order handling instructions regarding product characteristics, an issue that is also affected by the logistics strategy of the company. Therefore, based on criteria and sub-criteria from the literature review and validated by DMs, the decision tree represents the framework that encompasses these concerns. The alternatives and weights of the criteria and sub-criteria were evaluated by the DMs and also incorporated into the tree. The tree can be applied to suggest the available alternatives connected with the internal activities and sub-activities of a DC.

The academic contribution of this study is the proposal of a framework for logistics operations in a DC that considers strategic (the distribution strategy), tactical (the activities of the DC) and operational (the characteristics of operations) aspects. The practical contribution is the provision of a decision-making structure regarding operations alternatives (the information system, the types of equipment or vehicles and operating methods used in the activities); that is, practitioners can use the framework to choose suitable alternatives. Different operations characteristics (costs, supply, item and orders) will produce different decisions. Therefore, the proposed approach helps the decision-making process in physical distribution because it provides a quantifiable method of designing logistics operations in DCs, therein creating scenarios for evaluation.

The limitations of this study are as follows. (a) Each sub-activity was analysed independently; thus, the choice of an operational alternative for the receiving activity does not impact the put-away process, for instance. In this case, 'the use of conveyor belts' in receiving may limit the choice of types of storage. (b) The DMs chose the alternatives and provided the scores; however, the alternative pairwise comparisons were provided only by the DM of Company W because these comparisons depend on specific scores. (c) The profiles of the three DMs show their competence in assigning the values that produced the tree, but they also bring some bias to the proposed framework due to their own experience and knowledge. If DMs decide to add an additional alternative, then the tree must be recreated. Thus, we suggest applying this framework in similar operations. Nevertheless, this framework provides useful steps and insights to also be considered in the development of different logistics operations.

In addition to these considerations, future works may include further details on the criteria related to costs in terms of the weight and evaluation of their components and may conduct a sensitivity analysis according to their preferences. A solution would be to expand the use of the framework proposed here and to develop it for other retail companies that adopt the supply strategy. In addition, a survey of large multi-national companies (manufacturers and operators) acting in other countries could be conducted to choose the criteria and alternatives to provide a generalized structure for designing logistics operations in DCs. Moreover, given that many of these decision variables are interrelated in DC design (Thomas and Meller, 2015), further studies are necessary to address the impact of the variables on internal activities and the interactions among them.

Acknowledgements

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Appendix A

See Fig. A1 and Table A1 and A2.

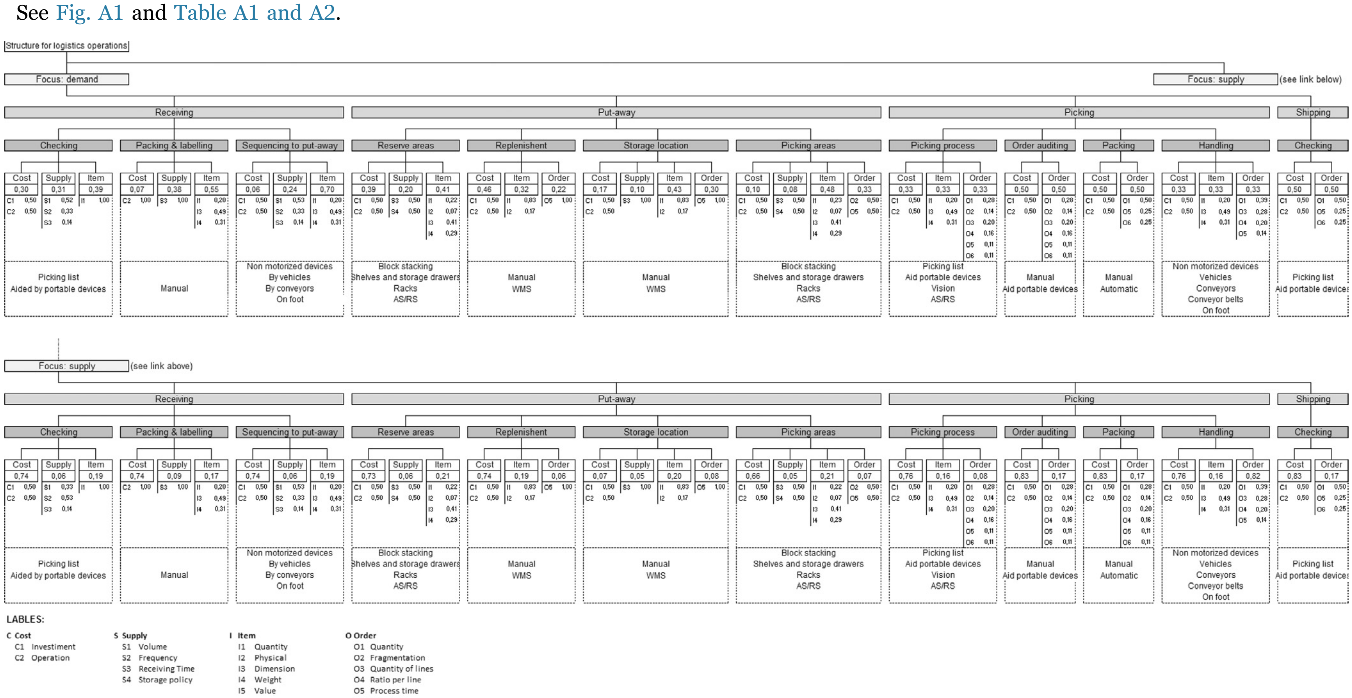

Fig. A1. Decision tree with weights.

Table A1
Characteristics of the distribution operation of Company W.

Criteria	Sub-criteria	Score		
		Upper (3)	Intermediate (2)	Lower (1)
Costs	Investment	Low	Normal	High
	Operation	Low	Normal	High
Supply	Volume	High	Normal	Low
	Frequency	High	Normal	Low
	Receiving time	Short	Normal	Long
	Storage policy	High	Normal	Low
Item	Quantity	High	Normal	Low
	Dimension	Large	Medium	Small
	Weight	Heavy	Normal	Light
	Physical group	Multiple groups	Few Groups	Unique
Orders	Quantity	High	Normal	Low
	Fragmentation	High	Low	Non-existent
	Lines	High	Normal	Low
	Ratio by lines	High	Normal	Low
	Time processing	Short	Normal	Long
	Precision	High	Normal	Low

Note: Investment and operation costs and time criteria (receiving time and processing time, based on the supply and orders criteria, respectively) have inverse interpretations.

Table A2
Equipment and operating methods used in the DC's activities.

Available alternatives for activities/sub-activities	Description
Receiving	
Checking: Picking list or aided by portable devices	Confirmation of the arrival of materials at the DC and verification of the types and quantities of items received. This activity can be performed by means of a list or using portable devices such as data collection, for example, which allows the insertion of information in DC's WMS.
Packing and labelling: Manual	Manual packaging and labelling of items, which may include any type of repackaging.
Sequencing to put-away: Non-motorized devices, by vehicles, by conveyors or on foot	Alternatives for shipment of the items to be allocated on the DC for the put-away activity, which can be performed using non-motorized vehicles, by vehicles such as forklifts, by conveyors or on foot.
Put-away	
Storage location: Manual or WMS	Options for allocation and registering the position of items in the DC, which can be performed either manually or through a WMS.
Equipment and methods at reserve and picking areas: Block stacking, shelves and storage drawers, racks or AS/RS	Alternatives for storage in reserve or picking areas, which can be at the floor (block stacking), on shelves and storage drawers, on racks or in an Automatic Storage and Retrieval System (AS/RS).
Replenishment: Manual or WMS	Options to control the replenishment of items in the inventory area, which can be performed manually or through a WMS.
Picking	
Picking process: Picking list, aided by portable devices, vision or AS/RS	Alternatives to guide the picking of items at the DC can use a list or can be aided by portable devices such as palmtops, by vision technology (direction informed by special glasses), or by AS/RS (Automatic Storage and Retrieval Systems).
Order auditing: Manual or aided by portable devices	Orders can be inspected with respect to quantity, customer, and processing times either manually or aided by portable devices such as palmtops.
Packing: Manual or automatic	Item picked can be packed either manually or aided by machines.
Handling: Non-motorized devices, vehicles, conveyors, conveyor belts or on foot	Item handling at the picking process in the DC can be performed using non-motorized devices (pallet trucks), vehicles (forklifts), conveyors (wheel, roller), or conveyor belts or on foot.
Shipping	
Checking: Picking list or aided by portable devices	Similar to checking at receiving activity, alternatives to perform the verification of items to be shipped can be performed using a picking list or aided by portable devices to ensure that the orders are complete and that the items are leaving the DC.

Appendix B. Obtaining weights to select the appropriate alternative – An example of the sub-activity 'Sequencing to put-away' (Receiving activity)

See Table B1.

The sub-activity 'Sequencing to put-away' initially presents four possible alternatives: on foot, non-motorized devices, by vehicles and by conveyors. However, when we match the characteristics of distribution provided by the DM of Company W (in Table A1) to the criteria/sub-criteria scores in Table 6 provided by the DMs, some alternatives are not considered. Then, we consider in the pairwise comparisons only the alternatives that can be chosen according to each criterion/sub-criterion.

Table B1
Pairwise comparisons for the available alternatives.

COST

Cost of investment - High (1)	By conveyors
By conveyors	1

Cost of operation - High (1)	By vehicles	By conveyors
By vehicles	1	1/3
By conveyors		1

SUPPLY

Volume during supply - High (3)	Non-motorized devices	By vehicles	By conveyors
Non-motorized devices	1	1/4	1/3
By vehicles		1	2
By conveyors			1

Frequency during supply - Low (1)	Non-motorized devices	By vehicles	By conveyors	On foot
Non-motorized devices	1	3	2	1/3
By vehicles		1	1/3	1/4
By conveyors			1	1/2
On foot				1

Receiving time during supply- Short (3)	By vehicles	By conveyors
By vehicles	1	1/3
By conveyors		1

ITEMS

Quantity of items - High (3)	Non-motorized devices	By vehicles	By conveyors
Non-motorized devices	1	1/4	1/2
By vehicles		1	1/3
By conveyors			1

Dimension of items - Small (1)	Non-motorized devices	By vehicles	By conveyors	On foot
Non-motorized devices	1	2	1/3	1/2
By vehicles		1	1/4	1/2
By conveyors			1	3
On foot				1

Weight of items - Light (1)	Non-motorized devices	By vehicles	By conveyors	On foot
Non-motorized devices	1	3	2	1/3
By vehicles		1	1/3	1/4
By conveyors			1	1/2
On foot				1

Combining the weights to make a provisional decision

Following the tree below, the alternative can be selected. The weights of the tree come from the branch of Fig. A1, regarding 'Sequencing to put-away' (receiving activity) and the pairwise comparisons for the available alternatives.

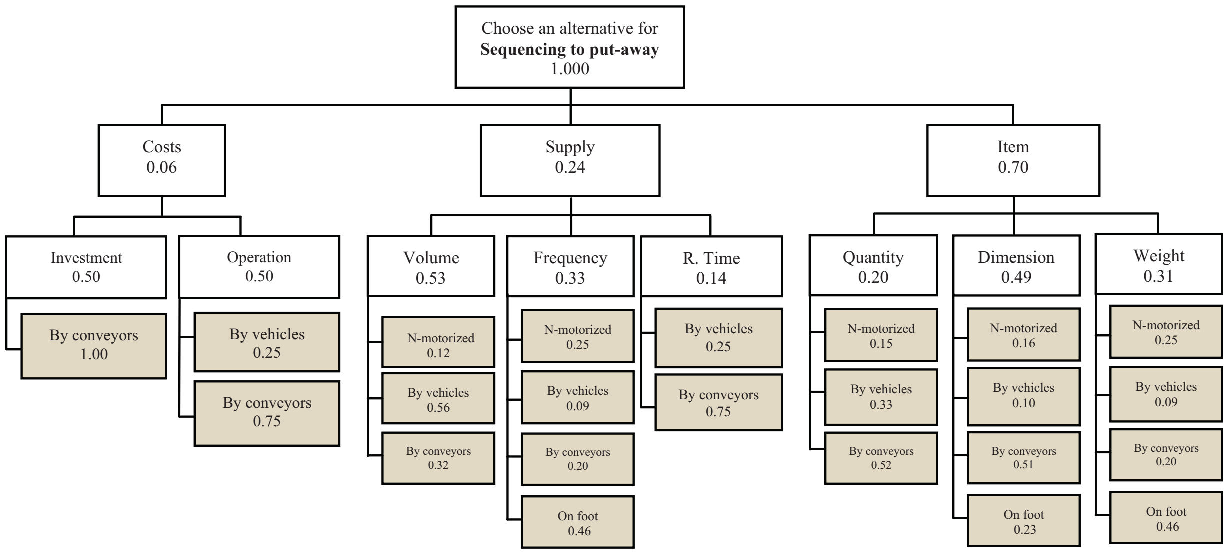

Fig. B1. Tree for the sub-activity 'Sequencing to put-away'.

Although EXPERT CHOICE or Web HIPRE are software that can automatically calculate the scores for the options, it is useful to demonstrate how the score for the '***Non-motorized devices'*** was obtained. In Fig. B1, all paths that lead from the top of the hierarchy to the '***Non-motorized devices'*** option are identified. All weights in each path are then multiplied together, and the results for the different paths are summed, as shown below:

Score for 'Non-motorized devices'=	*0.24×0.53×0.12+* *0.24×0.33×0.25+* *0.70×0.20×0.15+* *0.70× 0.49 0.16+* *0.70×0.31×0.25=0.17*

The scores for all four alternatives are shown below:

'Non-motorized devices'	=0.17
'By vehicles'	=0.20
'By conveyors'	**=0.42**
'On foot'	=0.21

These scores clearly suggest that the procedure 'By conveyors' should be chosen.

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