Improving small-sized items replenishment process in store operations

The Case Study of Worten

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Abstract

Driven by technological developments, people increasingly demand instant access to information, products, and services. For this reason, retail companies are currently forced to constantly adapt and optimise their operations and structures. Otherwise, they may be replaced by competitors that are better prepared to supply their consumers' needs. To increase its operational efficiency, Worten – a Portuguese retail company of consumer electronics, home appliances, and entertainment – decided to implement in its warehouse an automatic storage system for small-sized items with an integrated Goods-to-Picker system. In this sense, the company proposed challenge was to study the impact of different configurations of this system on the overall efficiency of the replenishment process of its stores. First, an academic literature review was performed on the concepts of retail operations, warehouse operations, physical store operations, and simulation models. After that, based on the knowledge acquired from the literature, a six-module methodology was composed. This methodology's final module is a stochastic simulation model, developed in software *AnyLogic*, which intends to replicate the store replenishment process of small-sized items with the Goods-to-Picker system incorporated. Through this methodology, several possible scenarios of store configurations were tested. The performance of each scenario was evaluated according to three indicators equally important to the company: the filling efficiency of the order totes, the occupation of the system resources, and the time spent to perform each operation – picking and shelf replenishment. Finally, the conclusions of this study and suggestions for future work are presented.

Key-words: Logistics; Warehouse Operations; Store Operations; Order Picking; Replenishment; Simulation model.

1. Introduction

Today's world is increasingly instantaneous. The information available on the internet about every subject is enormous and creates the expectation that information is just one click away. Consequently, to survive, organisations are forced to adapt their structure to meet these new expectations, while maintaining their business sustainability and profitability.

Worten, a retail company of consumer electronics, home appliances and entertainment, has also evolved its business, following the worldwide trend. For the upcoming years, with the growth of the online flows and keeping the operations as they are, the company will not be able to meet the predicted demand, because its warehouse does not have capacity to hold the stock that will be demanded, and the total store supply operation is costly, both in time, storage, machinery, and human resources. Thereupon, the company has decided to automate its process, redesign its operations and is analysing the implementation of a Goods-to-Picker (G2P) system for small-sized items in its warehouse.

The current research focuses on studying the benefits of implementing a G2P system that optimises the global store replenishment process, regarding lead time, transports optimisation and the operators' occupancy rate of the Worten warehouse and stores' operations.

2. Case Study

2.1 Worten and its Supply Chain

Worten is a specialised in electronic retail company, operating in Portugal and Spain, which belongs to the Portuguese Sonae group.

Currently, the company commercialises its products through retail and online channels, offering its customers more freedom to choose the channel to interact with the company. The emergence of several different channels and the interconnection between them make this supply chain particularly complex.

2.2 Worten Warehouse

The whole operation of the company's supply chain goes through its warehouse in Azambuja. This warehouse of 50 000 square metres and 8 metres in height operates 18 hours a day with a workforce of 300 people and 70 000 different Stock Keeping Units (SKU) in its portfolio. This warehouse receives, stores, and ships all the products sold by the company through any channel. Due to the huge diversity of products sold, the company categorises them according with their characteristics and stores them in different areas of the warehouse: the 701 and 708 areas. The layout of the warehouse is shown in Figure 1, where these areas are represented in blue and red, respectively.

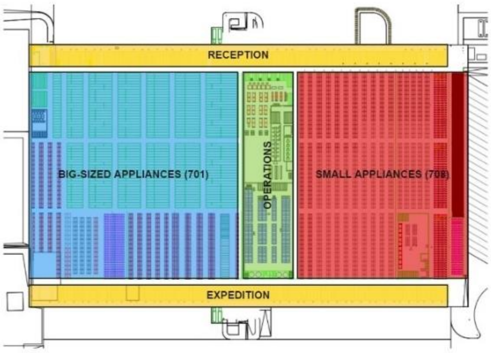

Figure 1 – Layout of Worten's warehouse in 2022

The 701 area (in blue) indicates the area of big-sized appliances. 708 (in red) is the name given to the small appliances area, encompassing small-sized and medium-sized products, which fall into three categories: (1) small-sized items (under 18 litres in volume), (2) medium-sized items that can be carried by a single person, and (3) medium-sized items that need to be carried by two workers at once. All the inbound and outbound operations in the warehouse house are carried out in the areas in yellow and green in Figure 1.

2.3 Worten Stores

At the moment, Worten has 160 stores operating in Portugal. In all these stores, the provisioning and shelf replenishment operations pursue a similar process: when the shipment arrives, the backroom operators perform a Quality Control activity, unwrapping the pallets and audit all the products, and, simultaneously, sorts the items according to their position in the store to speed up the task of shelf replenishment. As the pallets are being checked, its items are sent to the store and placed on the shelf if there is space available. Otherwise, they are brought back to the backroom and stocked.

Despite having similar processes, the universe of Worten stores in Portugal exhibits a wide variety in economic and logistics terms. Therefore, according to their characteristics, this study groups Worten stores in three types A, B, and C:

- Type A represents the flagship store of the company. This store has a selling area of 4000 square metres (sqm), and a storage area of 500 sqm. Moreover, its delivery window is open every weekday, receiving usually between 20 and 30 pallets a day (80 to 90 pallets a day in high season). To handle the backroom operations of this store on normal days there is a team composed of 12 people.
- Type B represents 52 Worten stores with 2000 sqm of selling area and with 250 sqm of the storage area. Their delivery window is opened every weekday. They receive between 10 and 15 pallets per day on common days (35 to 40 in the high season). Their backroom team has three people.
- Type C stands for the smaller 107 stores considered in this study, which have about 500 sqm of selling area and a small but variable storage area. They receive between three and five pallets per delivery window (10 to 15 pallets in high season), which is usually scheduled for three days a week. There are no operators assigned only to backroom operations, so these are conducted by any operator available.

2.4 Problem Definition

Recently, Worten's logistics operation has increased greatly due to the development of new sales channels. In the upcoming years, the expectations are for an increase in sales volume until 2026 which implies an 80% increase of the average warehouse inventory of the small-sized products in the 708 area, and a 150% increase of storage area required for this category of items, maintaining the warehouse as it is. As such, to continue operating in the current warehouse space, it will be required to develop a solution which increases storage density and the efficiency of the warehouse operations.

Bearing this in mind, the company decided to install an automated storage system for the small-sized products of 708 area and, to execute the picking operation of these products, it opted to set up a G2P system. Therefore, focusing on the small-sized items going from the warehouse to the stores, this research will assess for each type of store (and per period of the year), the picking operation configuration that optimises: (1) the efficiency of the picking in the warehouse, (2) the efficiency of the in-store replenishment process, and (3) the trade-off caused by the integration of these two processes.

3. Literature Review

This chapter presents a literature review on the theoretical topics and concepts relevant to what is being studied.

3.1 Retailing

Zentes et al. (2016) define Retailing as the activity of purchasing products from other organisations with the intent to resell them without transformation. Retailers are the entities responsible for handling retailing operations, delivering the right products, in the correct quantity, at the right place, at the right time, in the right conditions, at the right price, and to the right customer [1]. They have an extremely demanding exercise managing the multiple trade-offs existing in retailing operations, especially in the warehouse and in-store [2]. Improving the operations efficiency of these two facility types, and the connection between both, contribute to the development of the entire supply chain as one. Due to their relevance in the supply chain and to the scope of this paper, warehouses and physical stores deserve an in-dept analysis of the related literature.

3.2 Warehouse Operations

A warehouse is a stock-holding entity of the supply chain where virtually all products flow through in the logistics process of a company [3]. Thus, its operational efficiency is critical to ensure the success of the supply chain [4]. Currently, warehouses are receiving even more strategic importance in the supply chain since many of them are being adapted into cross-docking, transhipment centres, reverse logistics centres, among others [1], [5]. The new activities in the warehouses imply a reconfiguration of their operations, layouts and flows [6].

Current warehouses predominantly conduct six different operations: receiving, put-away, storage, cross-docking, order picking, and shipping [1], [3], [7]. Order picking is the operation of picking the right amount of the right product, from storage, to satisfy customer orders [7]–[10]. It is one of the most vital activities of the supply chain, because an underperforming order picking operation leads to a growth of operational costs that can affect the service levels of the whole chain [7]. Vijayakumar & Sgarbossa (2021) state that the order picking methods design must be based on five key decision areas: layout design, storage assignment, zoning, batching, and routing. Furthermore, it is possible to recognise three moments during an order picking operation: the travel moments, picking the items, and the remaining activities [8]. From these, the travel moments are the ones considered to be the most easily influenced through operational planning. Based on this, several order picking methods have been created to reduce the order picking operation time [12].

As a result, order picking may be done through manual or automated methods [13]. Automated systems are normally associated with the reduction of labour costs [9]. Nevertheless, numerous organisations keep using manual order picking [11]. The most common methods are the picker-to-parts and the parts-to-picker. In the first one, having the picking list prepared, the human picker travels through the aisles, searches for the items ordered and collects the quantities ordered from that item [7], [11]. The parts-to-picker method consists of items moving in the picker's direction from storage supported by automated solutions, and later the human is responsible for picking the items from the distribution system [7]. The remaining methods are adjusted from these methods but less explored in the academic literature [7], [14].

Whichever order picking method is used, the items on the pick list are influenced and determined by the picking policy adopted in that area of the warehouse, which could be, for instance, single, batch, or zone picking [9].

3.3 Physical Store Operations

A physical or brick-and-mortar store is "a large shop where you can buy many different types of goods" that exists in "a physical building, rather than doing business only on the online", according to the Cambridge Dictionary[1].

Physical store logistics operations are divided into two major groups: showroom operations and backroom operations.

The showroom of a store is the space where the merchandise is displayed to the customers. Therefore, there is always an added concern to ensure that it is organized and attractive to customers [15]. Yaw Wong & McFarlane (2007) believe that the efficiency of the showroom logistics is so critical to the entire supply chain that inefficient showroom operations will radically lower the efficiency and service level of the entire chain. The retail operation that takes place in the showroom is called shelf replenishment, i.e., the

[1] From the *Cambridge Dictionary* website: https://dictionary.cambridge.org/dictionary/english/store; https://dictionary.cambridge.org/dictionary/english/brick-and-mortar

practice of refilling shelves by transporting items from the backroom [16].

The backroom space of a retail store is the area where inventory is stored if there are no empty spaces available in the showroom [2]. The benefit of using backroom areas is not at all consensual among companies and researchers, since the trade-offs between their benefits and costs have different impacts from case to case, considering the characteristics and objectives of each one. Saving stock of a few products in a backroom grants more available shelf space for other products in the showroom, however, it also creates additional costs for the products in the backroom because the replenishment frequency and the operational complexity increase [17].

3.4 Warehouse and Store Operations: literature review summary

From the research conducted by the author of this work, it was found that there is a gap in academic research and investigation, as no studies were found that purport to study the improvement of operation between the warehouse and retail stores. Thus, the methodology that best fits this study will be defined through the evaluation of various works carried out in several related areas that are explored in the literature review presented in Table 1 of [18].

From that table, it is possible to distinguish different methodology methods applied in the studies mentioned: data-driven approach, optimisation models, heuristics algorithms, and simulation models. The later one seems to be the most appropriate to accomplish this work since this methodology is mostly used in high-complexity problems, where a relatively high level of reality is intended to exist, like company-related studies [19].

3.5 Modelling and Simulation

A simulation model is a simplified image of the real system [20]. It must stay complex enough to give a plausible answer to the problem raised, but simple enough to focus on the important issues to solve [21]. A simulation study comprises several steps, however, the *Model Conceptualisation* and *Verification and Validation* steps are the most relevant ones [22].

Model Conceptualisation is the part of the process that transforms the real system into a model to simulate through a certain level of abstraction and simplification of reality [22]. This is the most crucial part of a simulation study because it will impact several key aspects of the study, like the data collection, the speed at which the model might be generated, the model's validity, the speed testing, and the trust in the model outputs [23]. During this step, it is also important to classify the system modelled regarding behaviour and time [24]. The system's behaviour is stochastic if its output depends on a probability function; otherwise, it is deterministic. In terms of time, it is a static system if it represents a moment or if it does not change considerably over time; otherwise, it is dynamic. If the state of a dynamic system changes at discrete points in time, it is said to be discrete; otherwise, it is continuous. Further on, there is another equally important step, the Verification and Validation. This step checks if the simulation model reproduces the real-world, determining if the model may be used in the future [20]. It should be noted that a model is not universally valid, i.e., it must be used exclusively to simulate the situation for which it is created [25]. The verification process focuses on the match between the simulation model and the conceptual model of the real-world developed, while the validation process confirms if the model depicts with accurately the real-world [22], [25].

A simulation study can be carried out using several methods, depending on the objectives set by its developers and on the scope of the project for which it is designed [26]. Different approaches have different abstraction levels and are therefore suitable for different types of projects [27].

4. Methodology

The methodology developed to approach the problem under study consists in six modules, as presented in Figure 2.

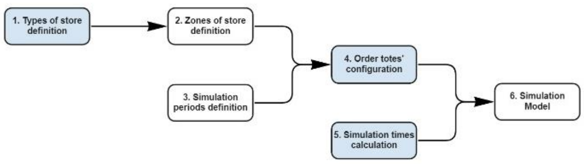

Figure 2 – Proposed Methodology Overview.

The **first module** of this methodology aims to categorise all the **Worten stores in Portugal into categories**, already defined in section 2.3.

Then, the **second module** was developed based on the necessity to improve the connection between the warehouse and store operations. Currently, the store operators sort the products according to their location in-store, to simplify shelf replenishment since the picking operations in the warehouse do not considering the affinity of the products. In order to abolish this sorting task, it was defined a method to perform the picking which will lead to a shelf replenishment method analogous to the zone picking policy. If the order totes are composed only by products of the same **zone in the store**, the operator in charge of shelf replenishment of an order tote is assigned to only one zone during that activity. The determination of a logical division of each type of store was reached through the observation of the store layout and the perception of the replenishment operation. Thus, each model store was divided into seven zones with small-sized products:

1. Small home appliances 1
2. Small home appliances 2
3. Hi-Fi
4. IT
5. Entertainment & Gaming
6. Promotions, Mobile & Printing
7. Mobile Panel

In the **third module** are set the **periods of the year to simulate**. The focus is to simulate different periods that represent different challenges for the company's picking and store replenishment activities. Since the shipments from the warehouse to the stores are planned on a weekly basis, it is logical to assume that the time length of each simulation period is one week. Based on the Worten shipment records from the last full year (2021), it was possible to break down it in four different periods, of which a week was chosen to simulate:

- *Low season*: from week 2 to 18 (week to simulate: 7)
- *Summer holidays*: from week 19 to 35 (week to simulate: 25)
- *Back to school*: from week 36 to 41 (week to simulate: 37)
- *Black Friday and Christmas (peak season)*: from week 42 to 53 (week to simulate: 48)

Based on inputs from previous modules, the **fourth module** is an algorithm[2] which determines **the content of each order tote**, influenced by the arrival order of the inventory totes at the G2P station and the store's configuration (number of zones of store considered) of the experiment. For the arrival order of inventory totes, it was considered that it could be: (i) random, (ii) with priority to the SKUs with higher volume, and (iii) with priority to the SKUs with lower volume. For the possibilities (ii) and (iii), the system that commands the selection of the inventory totes from the automated warehouse is configured to receive them sequentially so that the SKUs with higher (or lower) volume are picked first. If the available volume in the order tote is greater them the item's volume, it was assumed that the item fits in the order tote. Moreover, once Worten is implementing in its distribution process reusable order totes (60 cm x 40 cm x 40 cm), these were the only order totes considered (to consider the waste generated by incompatible packages, the order totes can only be filled to 79.20% of their volume). Also, one order tote must contain only items from SKUs assigned to the same zone of store to be shipped on the same day and for the same store. The algorithm follows the rationale described below:

1. The first item in the shipment list not assigned to any tote is associated with an order tote, and the volume available in the order tote updated.
2. If there is any item to be shipped on the same day, to the same zone and store, which fits in the order tote, the item is associated with that order tote, and its available volume updated.
3. Otherwise, it creates new order totes and repeats step 2 until all the items to be shipped on that day, to that zone and store are assigned to an order tote.
4. When all the items to be shipped on that day, to that zone and store are assigned, the algorithm creates a new order tote and repeats steps 1, 2 and 3 to the items to be shipped to other zone, on the same day and to same store.
5. When all the items to be shipped on that day and to that store are assigned, the algorithm creates a new order tote and repeats steps 1, 2, 3 and 4 to the items to be shipped to other store on the same day.
6. When all the items to be shipped on that day are assigned, the algorithm creates a new order tote and repeats steps 1, 2, 3, 4 and 5 for the items to be shipped on other day.
7. The algorithm ends if all the items are assigned.

Furthermore, the **fifth module** determines the **operational times** of the relevant operations to the case in hand – the picking time and the shelf replenishment time. Each of these times were broken into three components, which were calculated using different methods, depending on the ease to determine or obtain valid values at each moment of the operation. The time representation of each the components follows a triangular distribution which allows a suitable approximation to the real variation of time, knowing only the minimum, maximum and mode times. The picking time is the time it takes to pick all the units that make up an order tote to be shipped to store and is defined by the components in equation 1.

$$Picking\ time = switchSKUtime + setToteTime + pickItemTime \qquad (1)$$

- The *switchSKUtime* component is linked to the moment of changing inventory totes in the picking station (from the moment an inventory tote leaves the station until a new one is set).
- The *setToteTime* component represents the time required to replace a full order tote with a new empty one.

[2] Developed in *Python* programming language.

- The *pickItemTime* component stands for the time it takes for the operator to move the items from the inventory tote to the order tote.

The shelf replenishment time is the time it takes to stock all the items inside an order tote in the shelves of the store and is defined by the components in equation 2.

$$Shelf\ Replenishment\ time = interZoneTime + intraZoneTime + + putTime \qquad (2)$$

- The *interZoneTime* component describes the time an operator spends travelling between zones of store.
- The *intraZoneTime* component sets the time spent travelling within each zone of store.
- The *putTime* stands for the time the operator takes to place a single item on the shelf when he/she is right in front of that SKU's shelf.

Lastly, the **sixth module** defines a stochastic **agent-based simulation model**[3] to reproduce the system under study, i.e., the picking in the warehouse, and the shelf replenishment in-store. It focuses in four steps of the simulation study:

- Module Conceptualisation: This simulation model receives as inputs (1) the number of order totes available, (2) the order tote dimensions, (3) the daily number of order totes to be shipped from the warehouse, (4) a description of the content in each tote, (5) the number of workers in each operation, and (6) the figures for each time component. These inputs will then influence the final outputs of the system. To depict the real system with simplicity and focus on the problem at hand, it was decided to abstract the simulation model from the number of inventory totes being used simultaneously during the picking. In addition, the model was simplified considering that the trucks are loaded (and unloaded) at the same time in the warehouse (and stores) every day of the week, the working hours of the operators are the same for every store and the shipments are prepared the day before they arrive in the stores. Finally, it was assumed that there are never inventory, human resources and/or order totes shortages, that both the picking and shelf replenishment of an order tote cannot be performed by more than one operator at the same time, and that the maximum number of order totes being filled up simultaneously during picking by a single picker is six.

- Data Collection: All the input data is entered into an *Excel* file connected with the simulation model. Thus, the user does not amend the *AnyLogic* file, avoiding modifications on the model core and preventing differences on it during the model runs.

- Model Translation: This step turns into a model the conceptualised system. In this case, the model is stochastic, dynamic, and continuous. It has three main agents – Tote, Warehouse, and Store – and an auxiliary agent – Worker – which is used to embody the resource pool of each operation. All the agents interact with each other during the simulation run.

***Warehouse Agent*:** The warehouse operations are described by applying the discrete-event simulation method. Each day, the number of Tote agents needed to fulfil the orders enters the Warehouse operations according to a predefined schedule. These Tote agents will pass through the picking activity. To realise the picking activity, Workers from the related resource pool must be available. Then, the first Tote in the queue starts the picking activity, occupying the Worker that was available until the end of the activity. When the picking of a Tote finishes, the Worker engaged becomes free and available to perform the same activity with another Tote. Afterwards, the Tote agent moves on to the outbound activity. Before leaving the Warehouse, the Tote is forced to wait until 11 pm of the day it was prepared to be shipped and sent to the respective stores. This ensures the Tote agents are all sent to the stores at the same time and that they are never processed in the store on the same day they are prepared, as it was conceptualised.

***Store Agent*:** Likewise, the store operations are also described using the discrete-event simulation method and with a similar modelling configuration. When the Tote agents leave the Warehouse, they enter directly into the agent Store to which they are assigned. Although to simulate the distribution activity from the warehouse to the stores in a simple way, the Totes are firstly queued in the *onTransit* block until 7 am (hour that marks the start of the in-store operations). Like in the Warehouse, to perform the shelf replenishment activity in a Store is needed one Worker available from the related resource pool of that Store. The size of the resource pool depends on the type of store. When there is one Worker available, the first Tote in the queue starts its shelf replenishment activity associated with that Worker. Once the shelf replenishment activity finishes, the Tote leaves, and the Worker engaged becomes free and available to perform the same activity again.

***Tote Agent*:** The Tote agent is defined by a statechart. This statechart recognises the place where the Tote is and controls the activity it is performing at every moment. When the simulation run starts, the entire population of Tote agents in the system are idle (empty and ready to use). While idle, Tote agents only change

[3] Developed in *AnyLogic*.

their state when they are triggered by a message to enter the Warehouse or a Store. If the message received is "pick", the Tote agent enters the diagram of the Warehouse. Otherwise, the Tote is called by a Store to perform the shelf replenishment activity. At the end, when it exits the Store operations diagram, the Tote agent switches back to the idle state. Each agent Tote is identified through a unique *ID* numerical parameter. Moving on from the idle state, it is associated with another unique parameter which is the identification number of the order request to fulfil that Tote.

- Verification: To reduce the complexity of the process and to prevent major adjustments at the end, the Verification process was conducted while developing the model. The process was conducted using practices outlined in the academic literature: incremental and modular model development by more than one person and reviewed by tracing agents and running the model with different inputs. To ensure the results from the simulation are meaningful to evaluate the system, it is essential to define the warm-up period and the number of replications for a certain experiment. In this case, there is no need for warm-up period since there is no initialisation bias for the starting conditions defined. In turn, due to the stochasticity of the simulation model, each experiment must be replicated at least 19 times [28].

5. Metrics

To evaluate the results, four different metrics have been established:

1. **System Throughput:** reports the number of order totes processed in the warehouse to be shipped to the stores in each scenario.
2. **Order Tote Occupancy Rate:** the average ratio of the volume occupied by the items inside the tote to the total volume of the order tote in each scenario. This metric is inversely related to the first metric, as they both assess the efficiency of filling the order totes.
3. **Full-Time Equivalent (FTE) Occupancy Rate:** the ratio of time the resources of the operation are occupied during the working hours of the warehouse and the stores.
4. **FTE Occupancy:** the lead time, on average per tote, to execute the operation (picking or shelf replenishment).

The assessment of the experiments will be accomplished through a Performance Function (equation 3)[4]. Thus, it is required to normalise the FTE Occupancy, which will be presented as a ratio of the maximum value obtained for this metric:

$$Performance\ Function_{ScXX} = \alpha \times OT\ Occup\ Rt_{ScXX} + \beta \times (1 - FTE\ Occup\ Rt_{ScXX}) + \gamma \times \left(1 - {FTE\ Occup_{ScXX}}/{FTE\ Occup_{MAX}}\right) \quad (3)$$

$$Subject\ to{:}\ \alpha + \beta + \gamma = 1, \qquad \forall \alpha, \beta, \gamma \in [0,1] \quad (4)$$

The weight of each metric is equally distributed by the coefficients (α = β = γ = 1/3), according to the company internal knowledge.

The closer to one the Performance Function score is in each scenario, the better the scenario is.

6. Scenarios

To assess the most efficient system configuration, several scenarios were drawn up and tested. These scenarios were generated based on six parameters: (1) initial number of order totes, (2) order tote dimensions, (3) resource pool for each activity, (4) week to simulate, (5) arrival order set-up of inventory totes to the G2P station, and (6) number of zones considered for each type of store.

From the parameters defined, the parameters (1), (2), and (3) will be fixed throughout the analysis since their variation would impact the results of the analysis but it would not contribute to understand the problem at hand. In opposition, the remaining parameters will be tested throughout the different simulation runs. The settings of parameters (4), (5), and (6) were defined in the third, fourth, and second modules of the methodology created, respectively. However, based on Worten's operation know-how, the parameter (6) was tested in only four different configurations for each type of store: 1-zone stores, 2-zones stores, 7-zones stores, and then a customised number of zones depending on the type of store (6 for type A, 5 for type B, and 3 for type C).

Overall, mixing all these parameters results in 48 different scenarios to test.

7. Results

The scenarios defined were first set up and run on the order totes' configuration algorithm. When analysing these results, keeping all the parameters unchanged apart from parameter 5, the scenarios in which the arrival order priority set-up is given to higher volume SKUs are always the winning scenarios. For any given week, the maximum system throughput is always lower in these scenarios (and the order tote occupancy rate always higher) than in their peers of the same week, i.e., they are more efficient filling the order totes.

[4] Given the connection between the first two metrics, it would not make sense to account for both in the function. Hence, the Performance Function considers the Order Tote Occupancy Rate metric and discards the System Throughput.

Considering these results, it was decided to run the simulation model only for the scenarios in which the arrival order priority set-up is given to higher volume SKUs. The remaining scenarios were excluded from further analysis. The results' assessment will be conducted by type of store.

- Assessment of the type of store A

The Performance Function scores for the scenarios of type of store A are very similar. Among the scenarios tested in the peak period, the system has its most efficient performance for a 7-zones store (performance score of 0.6813). Comparing this configuration with the 2-zones store configuration (which presents the worst score for this type of store), it is found that opting for a 7-zones store causes an increase in the system throughput per week, leading to less occupied order totes on average. Yet, both the FTE Occupancy Rate and the FTE Occupancy normalised metrics are lower for the 7-zones store, i.e., when splitting the store into seven zones both the overall operation lead time and the average lead time of an order tote in the system reduce. If the company intends to have a fixed store configuration based on the configuration that best serves its interests in the peak season, the system might lose efficiency whenever this is not the best configuration. For this type of store, the loss shall not be significant since the 7-zones store configuration has also the highest score in weeks 7 and 25, and the second highest in week 37 (with a minimal difference to the best solution). In fact, in week 37, the 1-zone configuration outperforms the 7-zones configuration due to a higher order tote occupancy rate. If the 7-zones configuration is kept, the picking operation will save 13.11 hours per week, but 11.72 extra hours will be spent replenishing 50 additional order totes.

- Assessment of the type of store B

When performing the same type of analysis for the type of store B, it can be found that, on week 48, the system performs most effectively for a 7-zones store (score of 0.7969). Effectively, the best and worst-case (2-zones store) scenarios are only separated by 0.0547 points. In this case, there are 52 stores belonging to this type, thus, the difference in the impact on the system is magnified by this figure. Choosing a 7-zones store configuration over a 2-zones configuration increases the weekly system throughput by 49 order totes per store (i.e., 2548 processed order totes for the entire population of type B stores) since by increasing the stores' division the constraints on joining items increase, leading to a decrease in the number of possible combinations to form an order tote. However, the FTE occupancy rate and the FTE occupancy normalised of the best-case scenario for week 48 are, respectively, 19.89 pp and 0.91 pp lower than in the 2-zones configuration, meaning that, especially the overall operation lead time per store, but also the average lead time of an order tote, are substantially lower under the 7-zones configuration. If the company decides to operate with a 7-zones configuration the full year (which is not the best configuration in any of the other periods), the system will always process more order totes but will always save time in operation, comparing the performances of this configuration with the best configurations for each period.

- Assessment of the type of store C

Finally, from the assessment of the Performance Function score values for stores of type C, it is possible to declare that, during the peak season, the system performs better in a 3-zones configuration (score of 0.8940). Again, the impact on the system of different scenarios is accentuated by the number of incumbent stores of type C, which is 107. Comparing the best and worst-case scenarios for week 48 (respectively, 3-zones and 2-zones configuration), their performances are only 0.0200 points away from each other. Opting for a 3-zones configuration increases the weekly system throughput by 4 order totes per store (428 order totes for the entire population of type C) and, consequently, reduces the average order tote occupancy rate. Nevertheless, the performance of the remaining components of the Performance Function favours the 3-zones scenario. Notably, it is the discrepancy between the figures of the FTE occupancy normalised component that affects the most the difference in the values of the Performance Function of both scenarios. The 7.97 pp gap between the 3-zones and 2-zones configurations for stores of type C in week 48 is given by the large difference in the average lead time values in the two considered operations. Thus, implementing a 3-zones configuration, the system will take less 521.02 minutes to perform the picking operation per store weekly (7.75% of the available time) and less 5421.44 minutes to perform the shelf replenishment operation in a store (80.68% of the available time). It is important to remind the reader that these results do not mean a direct improvement of the operational time since several factors and other activities were not considered but only a reduction in the time spent on this specific activity. In the remaining weeks simulated, if the company keeps the configuration that allows the system to perform better during the most peak period, the system will always have a higher weekly system throughput, when compared to the ideal configuration in this period. However, both the FTE occupancy rate and the FTE occupancy normalised have closely matched values in every period.

- Overall system assessment

From the methodology proposed, the best store configurations for each type of store at each period of the year are exposed in Table 1, considering the results obtained in the Performance Function.

Table 1 - Total lead time (LT) and FTEs per week for Picking and Shelf Replenishment (SR) operations for the entire population of each type of store, in the peak season.

Store Type	No. zones	Total LT Picking	FTEs Picking	Total LT SR	FTEs SR
A	7-zones	19.1 h	3	244.9 h	38
B	7-zones	1686.1 h	260	19390.6 h	2984
C	3-zone	278.0 h	43	3200.6 h	493

As a result, following this methodology and adopting the best performance store configurations for each type of store in a period with demand similar to the peak season of 2021, Worten would spend in the warehouse the equivalent to 1983.2 hours per week in the picking operations of small-sized items to ship for its stores in Portugal, and the equivalent to 22836.1 hours per week in shelf replenishment operations of these items in store. Considering, for illustrative purposes, that a Worten operator works 6.5 hours a day (8 working hours, less one hour for lunch and half an hour of resting time), during the Black Friday and Christmas period of the year, the company would need the equivalent to 306 FTEs per week in the picking operation (approximately, 44 FTEs per day). In the same period, Worten would need the equivalent to 3515 FTE per week in the shelf replenishment operation of its entire population of stores (approximately, 503 FTEs per day), i.e., the equivalent to 38 FTEs per week for a type A store, the equivalent to 58 FTEs per week for a type B store, and the equivalent to 5 FTEs per week for a type C store.

6. Conclusions and Future Work

Worten intends to install an automated storage system for small-sized products, which allows compacting storage of this type of products, with an integrated G2P system. Considering all this, the objective purposed for this work was to investigate the impact of different configurations of the G2P system to implement on the combined efficiency of the order picking and the in-store replenishment operations.

In order to solve the problem at hand, a six-modules methodology was developed, which concludes with a simulation study to replicate the store replenishment process. The first module divided the entire population of Worten stores in Portugal in three types of stores. Secondly, possible store divisions for carrying out the picking operation were defined for each type of store. Then, the third module defined the periods to consider in the simulation study. Additionally, the fourth module comprised an algorithm to define the order totes' composition based on the arrival order of the inventory and on the store configuration restrictions imposed in each scenario. The fifth module determined the activity times of the operations under analysis. The time of each operation was divided in several components according to the activity morphology. Finally, the last module was a stochastic simulation model which was built to replicate the replenishment process of small-sized items to the stores with an integrated G2P system. All previous modules were composed to determine the inputs to this module.

To assess the impact of the different configurations of the system in each store and at each period, several scenarios were developed. These scenarios were evaluated through metrics to determine their performance in three important aspects: the efficiency of filling the order totes, the resource occupation and the average time spent on operation for a single order tote. At last, a function was elaborated to assign a score to each scenario according to its global performance.

Assuming Worten intends to maintain a fixed configuration throughout the year in each store, it is recommended a 7-zones store configuration for type A and B stores, and a 3-zones store configuration for type C stores, as these are the configurations with best performance scores for each type of store in the peak season.

Having concluded this study, it is relevant to highlight its limitations so that they are clear to the reader. Regarding the calculation of the simulation times, none of the time components was determined from empirical measurements, which would be more accurate. Further, the impact of the weight of the products was not considered in the traveling time components (interZoneTime and intraZoneTime), and the number of products on the shelf was not considered to calculate the putTime component, although these factors may have relevance in the components pointed out. In respect of the order totes' configuration, the only characteristic of the items considered was their volume. Although considered a factor for the wasted space with incompatible package formats, if other characteristics were considered (as the weight or dimensions), the determination of the order totes' configuration would be more precise and realistic. In the simulation model, the agent Worker could be more detailed since their experience, morphology or biological characteristics may affect their picking and shelf replenishment performance. Additionally, in the shelf replenishment activity, the sequence of the order totes processed is considered as completely random. However, operators organise their activity to make as few trips as possible in the showroom, thus, it would make sense to consider that the same agent Worker processes sequentially order totes from the same zone.

Furthermore, some suggestions for future work are provided based on the knowledge acquired. First, regarding the order tote configuration, in this research was assumed that the order totes could only be filled by SKUs belonging to the same zone of store. In future research would be interesting to study the impact of joining SKUs from contiguous zones in the same order tote, if the volume of items separated by zones resulted in an order tote with low occupancy rate. Then, regarding the G2P system to install in the warehouse, it was concluded that the system is favoured when the priority of arrival order set-up of the inventory totes is given to higher volume SKUs. Thus, as future work it is important to study how to configurate the automated warehouse and G2P system to be able to implement this set-up in the system. Concerning the in-store replenishment operation, this study considered that one order tote could only be processed by a single operator as a valid simplification of the real system since it does not significantly change the total time of operation. In future work, it would be interesting to study the system without this restriction since this will certainly have an impact on the resource occupation and on the average time spent to replenish a single order tote.

Finally, the fourth suggestion of this work is to perform a cost benefit analysis of each scenario, to complement the performance analysis shown in this work. In this way, the company's decision-makers will have more comparative data on the implementation of each scenario and will be able to decide with greater certainty on the configuration to implement for each type of store.

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