Maria João Afonso Gil Pires

U. PORTO
FEUP FACULDADE DE ENGENHARIA
UNIVERSIDADE DO PORTO
DEPARTAMENTO DE ENGENHARIA E GESTÃO INDUSTRIAL

Effective design of backroom storage facilities in grocery stores

Submitted to Faculdade de Engenharia da Universidade do Porto in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Industrial Engineering and Management, supervised by Pedro Sanches Amorim, Assistant Professor of Faculdade de Engenharia da Universidade do Porto

Department of Industrial Engineering and Management
Faculdade de Engenharia da Universidade do Porto
2018

This research was supported by SONAE MC.

"Nothing ever goes away until it has taught us what we need to know."

Pema Chödrön

Acknowledgments

First and foremost, I would like to thank my advisor, Pedro Amorim. Thank you for this opportunity, it would never have been possible without your trust. My PhD was an amazing experience and I thank you wholeheartedly, not only for your tremendous academic support, but also for the help and encouragement in more challenging moments. You challenged me to grow both professionally and as person. I quite simply cannot imagine a better supervisor! For all this, I am forever grateful.

Besides my supervisor, I want to thank Jorge Liz, former director of Space Management department at Sonae MC, for believing and supporting this research since the beginning. Moreover, he helped to provide funding for this thesis, and for that I owe him my deepest gratitude. I really appreciated the fruitful and interesting meetings that we had during the project. I would also like to show my gratitude to Joaquim Pratas for his support during the project. Joaquim helped by sharing with me his knowledge and by giving me many opportunities, such as visiting stores and meeting with people from several departments, which allowed me to learn more about the store design process and its many stakeholders.

In Sonae, I had the opportunity to learn from many people, specially José Soares, José Carlos Pinto, Mariana Ribeiro, Ricardo Fonseca, Sérgio Lapela, Pedro Marques and Nuno Fonseca, to whom I express my gratitude.

I will always cherish the time I spent at INESC TEC, in large part due to the many friends who became a part of my life. Thanks to all the members of *ilha 2*: Sofia, for “creating" the *Sofs cafe*, which encouraged us to talk more and contributed to the friendship we have today, Fábio, for going along with my pseudo jokes, Mário, for all the songs that made our days more interesting and Prof. Rocha for being the muse for them! I would also like to thank the *CEGI girls*, Sara, Beatriz, Elsa, Teresa and Diana, for all the friendship and support from the very begining of my PhD. Lastly, I would like to thank Gonçalo, Xavier, Álvaro, Maria João and so many others I can only list a few. I am grateful to all of you!

I would like to thank my co-authors, Ana Camanho and Elsa Silva for all the help and for the incredible contributes in the papers that are part of this thesis. I would also like to thank the professors of the Industrial Engineering and Management department, specially Maria Antónia Carravilla, José Fernando Oliveira and Bernardo Almada-Lobo, for their support and guidance throughout these years. Lastly, I would like to thank Teresa Galvão for the opportunity of teaching with her, it was an incredible and enriching experience.

During my PhD I had the pleasure to visit Catholic University of Eichstätt-Ingolstadt, in Germany. I am very grateful to Alexander Hübner and Heirich Kuhn for this opportunity and for the way I was received.

In a more personal perspective, I would like to thank my parents, specially my mother. Without her continuous support and encouragement, I never would have been able to achieve my goals. This one is for you, mom!

My friends (who are my second family) are also a big part of me and I must acknowledge them for supporting me all along. José, Ana, Fernando, Joana, Tiago, Francisco and Pedro, words cannot describe how lucky I am to have you all in my life! Furthermore, I must acknowledge Hugo's family for being so welcoming and supportive! Lastly, I cannot avoid to acknowledge my most faithful friend, Simba, who was always the happiest to see me!

My last words are to Hugo. I sincerely do not know how to thank you for your patience, support and words of encouragement in many (too many!) critical moments. I am so lucky to have you in my life. Thank you so much for everything, I love you!

To all, my wholehearted thank you!

Abstract

The ongoing transformation of retail is impacting every aspect of its operations, requiring ever greater operational efficiency, namely regarding the optimization of the store scarce resources, such as the store space. This space is generally divided into the sales area and backroom. Backrooms are essential in retail stores since the replenishment orders for a given item that arrive at a retail store may not fit on the allocated shelf space, making this area indispensable. The design of retail backroom has a great impact on in-store operations, customer service levels and store life-cycle costs. Moreover, backroom storage in modern retail stores is crucial to several functions, such as acting as a buffer against strong demand lifts yielded by an increasing promotional activity, seasonal peak demand and e-commerce activities.

In the store designing process, sales area design is the priority since it is the space that creates direct value to the store. In contrast to the sales area, the remaining space is dedicated to the backroom storage that has its design often neglected. Currently in practice, the design of the backroom areas is mainly established on the perception of the architect that is based on similar stores, when instead it should be carefully studied, considering in-store logistics and operations, expected volume of orders of regular activity as well as seasonal and promotional activity. Additionally, the literature on this topic is very scarce, focusing on the sales area and conventional warehouses design.

Motivated by the space management problems arising in a European Food Retailer, the objective of this thesis is to solve the backroom design problem. This strategic decision involves the size and location of the storage departments in the backroom areas. Moreover, this partnership provided valuable inputs regarding the challenges to be addressed and also allowed to assess and validate the practical impact of the scientific contributions.

Overall, this thesis makes contributions to both theory and practice. On the one hand, we filled the gap in the retail literature by making a first step towards the creation of a basic theory of backroom design. On the other hand, we developed innovative qualitative and quantitative tools to support the design of optimized backroom layouts in practice. The application of the proposed methodology in the designing process demonstrated a substantial potential for space and operational cost savings.

Although the primary focus of the thesis is grocery retail, other sectors of retail may benefit from the contributions here provided.

Resumo

A atual transformação no negócio de retalho alimentar afeta todos os aspetos operacionais, exigindo maior eficiência operacional assim como a otimização dos recursos escassos da loja, tais como o espaço. As lojas estão geralmente divididas em área de vendas e área de retaguarda. A área de retaguarda é essencial nas lojas de retalho, uma vez que o espaço de prateleira alocado para um dado item pode não ser suficiente para armazenar a encomenda que chega à loja, o que torna esta área indispensável para armazenar o *stock* remanescente. O *design* da retaguarda tem um grande impacto nas operações da loja, nos níveis de serviço ao cliente e nos custos ao longo do ciclo de vida da loja. Além disso, o armazenamento de *stock* na retaguarda é crucial para várias funções, tais como atuar como um *buffer* contra flutuações de procura causadas pelo aumento da atividade promocional, procura sazonal e atividades de *e-commerce*.

No processo de *design* da loja, a área de vendas é a prioridade, pois é o espaço que cria valor direto para a loja. Em contraste com a área de vendas, o espaço restante é dedicado à retaguarda, cujo *design* é muitas vezes negligenciado. Atualmente, na indústria, o *design* das áreas de retaguarda baseia-se principalmente na perceção do arquiteto que se inspira em lojas similares, quando este deveria ser cuidadosamente estudado, considerando as operações na loja, o volume esperado de procura regular, bem como proveniente de atividades sazonais e promocionais. Além disso, a literatura sobre este tema é muito escassa, focando-se maioritariamente na área de vendas e no *design* de armazéns convencionais.

Motivados pelos problemas de gestão de espaço existentes num retalhista Europeu, o objetivo desta dissertação é abordar o problema do *design* das áreas de retaguarda. Esta decisão estratégica envolve decidir a área e a localização dos departamentos na área de retaguarda. Além disso, esta parceria forneceu contribuições valiosas relativamente aos desafios a serem abordados assim como na avaliação e validação do impacto prático das contribuições científicas propostas.

Esta dissertação tem contribuições de caráter teórico e prático. Por um lado, preenchemos a lacuna na literatura de retalho, dando um primeiro passo na criação de teoria sobre o problema de *design* das áreas de retaguarda em lojas de retalho alimentar. Por outro lado, desenvolvemos ferramentas qualitativas e quantitativas inovadoras que visam apoiar as empresas na tarefa de desenhar os *layouts* de forma eficiente. A aplicação da metodologia proposta no processo de *design* das áreas de retaguarda demonstrou um potencial substancial para a redução de custos operacionais e de construção.

Embora o foco principal desta dissertação seja retalho alimentar, outros setores/indústrias podem beneficiar das contribuições aqui fornecidas.

Contents

Chapter 1

Motivation and framework

1.1. Introduction

The importance of the food supply chain (SC) is significant, generating nearly 6% of the U.S. GDP (U.S. Bureau of Economic Analysis, 2017) and about 4% of EU-28's GDP (Eurostat, 2014). The last stage of this SC has been evolving over the years and a strong development of modern retail has been seen across Europe. In Portugal, convenience stores and discounters have experienced an increase of 33,9% in total sales in 2015 (Nielsen, 2015b).

In the retail SC, inventory may be placed in several stages. These might be warehouses, distribution centers (DCs), or retail stores (backrooms and sales area). Despite the fact that backrooms have several similar functions to DCs, they have particularities that deserve a distinct analysis. This link of the SC has been often neglected by academics and practitioners, and it is currently seen as a poorly designed transition point between the DCs and the retail store shelves. However, they are a critical link that is used for much more than just store replenishment (Tompkins, 2014).

Backroom storage is essential in grocery retail stores since the replenishment orders for a given item that arrives at a retail store, coming directly from suppliers or from DCs, may not fit on the allocated shelf space, making this area indispensable (Buttle, 1984; Eroglu et al., 2013; Aastrup and Kotzab, 2010). Moreover, nowadays, backroom storage in grocery stores is becoming more vital to act as a buffer against strong demand lifts yielded by an ever increasing promotional activity, to stock seasonal peak demand for particular categories of products and also on weekends, as well as to leverage other activities, such as e-commerce (Fernie et al., 2010; Mckinnon et al., 2007). Furthermore, backrooms are crucial for in-store performance. Previous research indicates that in-store operations can account for up to 50% of total costs in a retail supply chain and the backroom is responsible for a major portion of these costs (Sternbeck, 2015). Researchers have also identified that inadequate backroom organization and planning is a major source of store out-of-shelves, which negatively impact the store service level (Gruen and Corsten, 2002).

In the store designing process, the sales area design is seen as the priority since it is the space that directly creates value. The sales area is carefully defined considering in-store traffic patterns, shopping behaviour, and expected sales (Lewison, 1994). In contrast to the selling area, the remaining space is dedicated to the backroom storage. Currently, the design of the backroom areas is mainly established empirically, based on the perception of similar stores by the architect. However, it should be carefully studied based on in-store logistics and operations, expected orders' volume of the regular activity as well as seasonal and promotional activity (Pires et al., 2015). Designers should also rely on formal means to assist the design process, rather than just follow ad-hoc procedures. Therefore, there is considerable scope for improvement in this process.

This thesis tackles the strategic backroom design planning problem, which focuses on how to effectively design backroom areas in grocery stores. This involves proposing a definition to the Backroom Design Problem, a conceptual framework to tackle it and, lastly, structuring and proposing mathematical models to help retailers adjust the backroom size and layout to their needs.

This thesis is the result of a problem-driven research, motivated by the space management problems arising in the food retail industry. In collaboration with a European Food Retailer, the aim is to develop innovative methods to optimally design these areas. Working directly with a case study enriched this thesis for two main reasons. Firstly, it provided the motivation to understand the challenges and flaws on the current backroom designing process. Secondly, it allowed to validate the models developed as well as the results obtained and iterate based on the valuable inputs that were given. Nonetheless, despite the straight link with the case study, all the mathematical models emerging from this thesis are expected to be extensible to other food and non-food retailers sharing similar challenges.

This introductory chapter presents an overview of the backroom design planning problem and defines the objectives of this thesis. The remainder of the chapter is organized as follows. In Section 1.2, the backroom design problem is introduced, as well as the case study of the European retailer that we used in this thesis. Section 1.3 presents the research objectives and methodology. Section 1.4 contains a synopsis of the remaining chapters of this thesis and, lastly, Section 1.5 describes the main contributions of each chapter.

1.2. Backroom design problem

Backrooms are a vital link between the store and the complex supply chain that supports it. When designing the layout of their stores, retailers tend to pay closer attention to the sales area, as it is the space that originates sales. On the other hand, backroom areas are often neglected and are not as well understood (Caplice and Das, 2017).

A successful customer experience is based on the entire experience at the store, from price, assortment and shopping experience to buying. Retail backrooms can have a major impact on the product availability on the shelves and, therefore, on customer satisfaction (Gruen and Corsten, 2002). For this reason, it is essential that retailers design their backroom spaces efficiently in order to meet the store's needs.

The main focus of this research is the backroom design problem, which has interesting and challenging characteristics and idiosyncrasies. The goal of this section is to describe the backroom design problem in grocery retailing, as well as the case study that inspired this research.

1.2.1 Backroom design within the retail supply chain

The primary objective of retail is to bridge the gap between the point of production and the point of sales (Hübner et al., 2013).

This gap has been leading to the low average product shelf availability rates of 92% (Gruen and Corsten, 2002). There are several reasons for out-of-stocks (OOS), namely inappropriate demand forecast or other errors. However, backroom replenishment is the cause that contributes the most to store OOS (38%), as depicted in Figure 1.1. In this latter case, the product is in the store (often in the backroom), but it is not available on the shelf when the consumer comes to buy it.

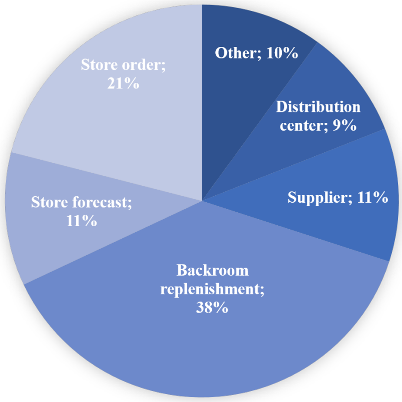

Figure 1.1 – OOS root causes (adapted from Gruen and Corsten (2002)).

To avoid situations like this, over the last few decades, grocery retail companies are striving towards higher operational efficiency (Sternbeck, 2015). One of the factors that highly impacts in-store logistics efficiency is the backroom design and organization (Gruen and Corsten, 2002).

Backroom design is a strategic decision that is part of the strategic outlet planning (please refer to Figure 1.2). Strategic layout planning comprehends deciding the store type, with typical store sizes, and determining the outlet network and locations (Hübner et al., 2013). Moreover, strategic layout planning determines in-store infrastructure and layout for the sales area and backroom. The sales area layout influences consumers' buying decisions and, therefore, should reduce consumer search costs and promote impulse purchases. Additionally, the backroom layout impacts in-store logistic processes and comprise sizing the capacity and infrastructure of the backroom storage (Hübner et al., 2013; Kotzab and Teller, 2005).

Despite being a long term decision that is part of the sales domain, strategic layout planning depends on and impacts other decisions. For instance, the size of the backroom storage departments is highly dependent on the distribution planning, namely the delivery frequencies and time windows, and on the master category planning.

1.2.2 Problem definition

In most retail stores, inventory is held in two locations: retail shelves, in the sales area, and the backroom, our object of study, which is illustrated in Figure 1.3 and highlighted in yellow. Products are stored in the backroom for many reasons but one main factor is the limited shelf space that makes it often impossible to fit a complete replenishment order on

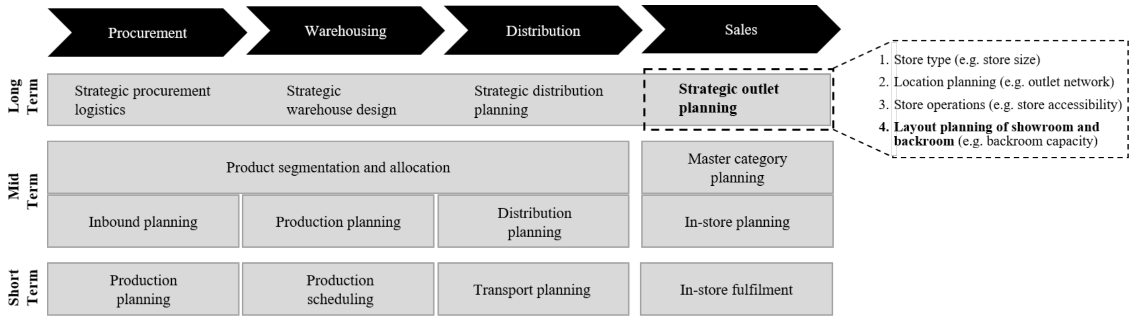

Figure 1.2 – Backroom design is a strategic decision (adapted from Hübner et al. (2013) and Stadtler (2008)).

the allocated shelf space (Eroglu et al., 2013). By storing some inventory in the backroom, shelf space is freed for displaying a wider product assortment, potentially increasing sales (Eroglu et al., 2013; Reiner et al., 2013). Additionally, support activities are performed in the backroom, such as breaking bulk of transportation units to end-user units and keeping additional merchandise of products with high demand. If some of these products were in the sales area they would quickly deteriorate (e.g., fresh fruits and vegetables). Lastly, promotional activities have proven to be a competitive factor in retail, strongly influencing customer's loyalty (Aghazadeh, 2004; Kotzab and Teller, 2005). These promotions, along with modifications in planograms, strongly affect store operations since they require large quantities of merchandise to stock in the backroom (Mckinnon et al., 2007; Van Zelst et al., 2009). However, storing inventory in two separate locations has disadvantages because it requires permanent attention to real-time sales in order to prevent OOS situations and lost sales.

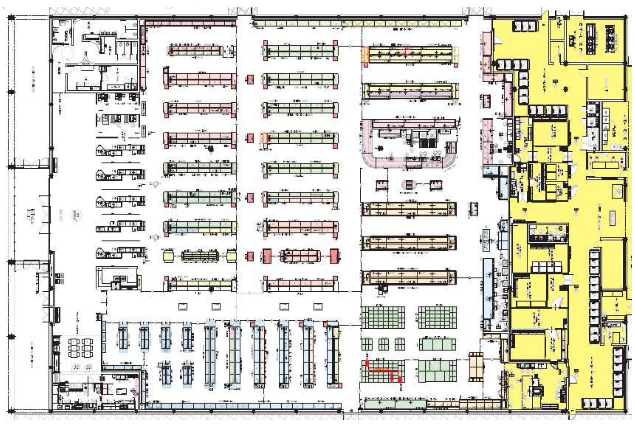

Figure 1.3 – Example of a grocery store layout, with the backroom area in yellow.

The backroom storage area is usually divided into storage and social areas, also called back-office. Storage areas (primary departments) are generally separated into three major departments: food, non-food and chilled areas (frozen and chill departments).

Different types of stores (hypermarkets, supermarkets, or convenience stores) require different backroom departments. For instance, hypermarkets often have their own manufacture of bread, and for this reason need extra areas for ovens and preparation areas. Social areas, also referred as secondary departments in the literature, are intended for the employees of the store and is the space where administrative activities take place. These areas include administrative offices, restrooms, and meeting and living rooms. Additionally, in the backroom there are also technical areas where no products are stored, but that support store activities (e.g., decoration department).

The aim of the backroom design problem is to obtain the backroom size and layout that maximizes store profit. Since this is a very broad and complex problem, it can be divided into three smaller problems: (i) define the backroom departments required, (ii) determine the size of each department and (iii) determine the format and location of each department in the backroom.

Since maximizing the store profit is also a very general objective, two more specific goals were defined, which ultimately lead to the same result. They are (i) minimizing the backroom areas and life cycle costs, and (ii) minimizing the walking distances in the store. The combination of these two objectives help to increase store profitability. On the one hand we minimize the store expenditure and, on the other, we optimize the products flow that, in the end, leads to increased service level and sales.

There are several potential constraints for the backroom design problem, namely the storage requirements, available construction space, architectural constraints (e.g. irregular shapes), sales area layout and storage equipment. Other aspects that impact this decision are the product assortment, services provided (e.g., e-commerce) and stock policies, which also depend on factors such as delivery frequencies.

1.2.3 Case study presentation

Our case study is inspired by a Portuguese chain of supermarkets and hypermarkets, branded *Continente*, that is a part of SONAE MC group.

The importance of the food retail sector in the Portuguese economy is significant, representing a volume of business of 12.298 million euros in 2011 (APED, 2012). The Portuguese retail sector is characterized by modern stores formats (hypermarkets and supermarkets) with an average sales area of 1.154 m^2 (INE, 2015). According to Nielsen (2015a), the Portuguese retail sector is dominated by six commercial brands which are Continente, with the highest market share (27,3%) and penetration rate, followed by Pingo Doce (24,4%), Intermarche (9,9%), Mini Preço (7,2%), Lidl (7,1%) and Auchan (6,4%). Additionally, it is important to notice that the channels for consumption with highest weights are small supermarkets (34,5% of total sales), followed by big supermarkets (30,4%), hypermarkets (26,7%) and traditional stores (8,4%).

Continente stores have become a benchmark in food retail stores in Portugal, offering competitive prices, high product variety, good customer service and regular promotional offers. These are valuable factors for Portuguese customers.

Continente owns a chain with a network of stores distributed across the country, summing up two hundred and twenty-four stores up to this date. In this company, grocery stores are divided in three segments: hypermarkets, supermarkets and convenience stores. The first type of stores includes a total of 47 stores with average sales area of approximately 7.000 m^2 , the second type has the greatest number of stores (128) and an average sales area of approximately 2.000 m^2 and the last, with a total of 100 stores, has an average sales area of approximately 1.000 m^2. For all types of stores the backroom storage areas occupies nearly 36% of the total area of the store.

Regarding demand by category of product, dry grocery is responsible for 38,2% of the total sales, dairy products for 19,6%, health and beauty products for 11,4%, alcoholic drinks for 9,9%, household goods for 8,0%, frozen goods for 6,6% and non-alcoholic drinks for 6,4% of sales (sales figures for the year of 2014). Continente stores are recognized for offering a large number of stock keeping units (SKUs). In terms of the assortment (variety) of products in Continente, hypermarkets hold the largest number of SKUs, summing up a total of around 70.000 products from which 42,28% are food products, 9,79% are fresh and bakery products and the remaining are non-food products. Supermarkets sell an average of 40.000 different SKUs, of which 61,92% are food products, 13,88% are fresh and bakery and the remaining are non-food goods. Finally, convenience stores hold a total of 25.000 products in average, divided in 71,01% for food products, 19,35% fresh and bakery products and 9,64% of non-food products. As expected, smaller types of stores hold a smaller assortment of products, which are predominantly food goods. In Continente, products are grouped (aggregated) by functional activity into the following levels: commercial direction, business unit, category, subcategory, base unit and SKU, with a decreasing aggregation factor. This structure changes from time to time, in order to adapt to the consumers habits and changes in the product assortment. The company works with 6 main commercial directions: grocery, perishables, food and bakery, bazaar, textiles and electronics. In 2014 an average of 16.139 Full Time Employees (FTEs) were working at Continente stores. This corresponds to a monthly average of 186 FTEs by hypermarket, 59 by supermarket and 37 by convenience store.

The company is divided into multiple departments, each of them responsible for a different functional activity. Three main departments interact in the store designing process, which includes both sales and backroom areas. These departments are the operational, construction and space departments. The tendency is for store-related decisions to become more and more centralized. This happens for many reasons, such as removing workload from store personnel in certain activities, such as placing orders, handling the shop decoration, choosing the store assortment and setting planograms. Store design and layout decisions are within the responsibility of the space management department. This department is divided into macro and micro-space management. Macro-space planning is triggered when stores are opened or being renewed. This department is responsible for dividing the construction space throughout the functional areas. On the other hand, in micro-space planning, planograms are generated for each new assortment, considering the store products' assortment. Our project is related to the work carried out by the macro-space layout team.

1.2.4 Current practices

In most companies, including our case study, the design of the backroom areas is mainly established on the perception of the architects and on similar existing stores, when it should be carefully studied based on in-store logistics and operations, volume of expected orders of the regular activity as well as seasonal and promotional activity. As previously referred, in the case study company, the current designing process is performed by the space management department. This team consists of architects and engineers who size and design the store areas, having as reference existing stores they deem to be similar to that being designed. In this task, designers resort to CAD software and spreadsheet tools. What often happens is that stores reflect the subjectivity and preferences of each designer. Therefore, this process is subjective, depending on the designer, and the criteria used to size and allocate the departments is not clear nor standard. Efforts have been made to develop tools to assist designing the sales area, but not the backroom.

Most of the performance problems associated with the backroom storage in the literature are related to constructional defects, inappropriate architecture and the non-existence of standardized guidelines for backroom storage facilities (Kotzab and Teller, 2005; Reiner et al., 2013). In order to improve backrooms design and operations efficiency, architects should rely on formal means to assist the design process, rather than following ad-hoc procedures. With this thesis, we aim to guide retailers in defining the store's backroom areas in an objective and optimized manner.

1.3. Research objectives and methodology

This thesis is motivated by the backroom design challenges arising in food retail. The main objectives of this research project are to draw attention to the backroom's importance to stores and to the overall SC, as well as to contribute to the retail operations academic community with innovative insights and models to support the optimized design of backrooms in practice. To achieve such objective, the aforementioned case-study was used.

The following sections will further address the research questions, the research methodology and the main contributions expected from this project.

1.3.1 Research questions

Three research questions (RQs) were formulated in order to guide the work of this thesis. They concern modelling and formulation issues, derived from the research directions previously mentioned, as well as methodological issues.

The RQs follow the natural path in system analysis, from contextualization to solution development and implementation. Each RQ is divided into several sub-questions that aim to help detailing each RQ.

RQ 1 How should backrooms be designed?

- (a) What are the particularities of backrooms?
- (b) What differentiates the backroom design problem from conventional warehouses design problem?
- (c) What aspects should be considered in the backroom design?

RQ 2 How to formulate the backroom sizing model?

(a) How to determine the backroom requirements?

(b) How to determine the store's expected stock, considering demand fluctuations (e.g., seasonality, promotions)?

(c) Which type of optimization method (approach) is more appropriate to solve the backroom sizing model?

(d) How should the backroom departments dimensions be assessed?

(e) To what extent do these models help retailers reduce backroom space and, therefore, make better use of store space?

RQ 3 How to formulate the backroom layout model?

(a) What should be considered to define the backroom layout?

(b) How can the sales area layout be included in the backroom layout problem?

(c) What are the products' flows in the backroom and what is their influence in the backroom layout?

(d) How should the backroom layout be assessed?

(e) What is the current heuristic used by designers to define the backroom layouts?

The RQs presented are structured hierarchically. We started by addressing RQ 1, which provided the basis for tackling the backroom design problem quantitatively. Then, RQ 2 aims to solve the backroom sizing problem, which results in the size of each backroom department. This information is the basis for the last RQ, with the goal of determining the location of each department in the backroom. Thus, with the last RQ we achieve the final backroom layout.

1.3.2 Methodological approach

The main goal of this section is to briefly explain the overall methodologies used in this research project. We contribute to the current state-of-the art in grocery retail, filling the gap on backroom operations and backroom design. Moreover, we are focused on the practical applications of this research. Therefore, we aim to lay the cornerstones of a Decision Support System (DSS) to assist designers in this challenging task. This is a problem-driven operations research project and is inspired by a case study of a European grocery retail company, already described in Section 1.2.3.

Firstly, an exploratory research was conducted where several retail stores were visited. In these visits, several store employees and store managers were interviewed regarding the flow of products in the store and the most relevant inefficiencies caused by the backroom design. Moreover, architects and engineers responsible for the store design were also interviewed regarding the current backroom design process.

Further in the research, several statistical analysis and data mining techniques were used to predict the expected demand and inventory for a new store's backroom. These techniques include clustering stores with similar demand patterns and multinomial logistic regressions to predict to which cluster a new store belongs. Thus, based on the store characteristics, it is possible to determine the expected storage requirements.

Focusing on the sizing model, different techniques were employed. Firstly, a benchmark analysis, more specifically Data Envelopment Analysis (DEA), provided insights concerning what are the best practices among the existing stores regarding space usage in the backroom. Furthermore, a Mixed Integer Linear Programming (MILP) model was developed to size each of the backroom departments, using a cost minimization approach.

To address the layout problem, we used a MILP model that incorporates the products' flow within a store, the sales area layout as well as the physical and energy constraints. The goal is to minimize the employees' walking distances in the store.

It is important to state that since this is a strategic problem, an exact optimization approach was chosen since optimal solutions are important in this context and larger running times are justifiable. Furthermore, the characteristics of the backroom design problem may differ with the context considered, namely the type of market, company strategy and store environment, among others. Therefore, the developments in this project will be related to the grocery retail industry and all the models and solution approaches will integrate the specific features of the case study considered. Nonetheless, despite the straight link with the case study, all the models are extensible to other food or non-food retailers sharing similar challenges.

1.4. Thesis structure and synopsis

The chapters of this thesis consist of a collection of papers. Each paper (chapter) is aligned with one of the research objectives previously described. This section provides an overview of the main aspects covered by these papers, which are presented in the following chapters.

Chapter 2 introduces the backroom design problem in grocery stores, providing a definition of the problem, which has not been addressed in the literature so far. A literature review on in-store operations and backroom design is presented. Furthermore, we stress the particularities of backroom storage, when compared to conventional warehouses, which support further and separated research. After this analysis we could conclude that the current literature focusing on warehousing is a very small fraction of the overall supply chain papers and backroom design is not discussed. Furthermore, most of the works on retail operations are focused on the sales area, such as shelf planning. Also in this chapter, the results from the exploratory research conducted on the case study are provided, which reveal the current inefficiencies in backroom design. These two research streams allowed to understand the gaps in theory and practice in this topic.

Chapter 3 presents a literature review on backroom design related topics with a major focus on warehouse design. This allowed a further understanding of the gap in the literature regarding the design of backrooms. As a result, a conceptual model for designing the backroom areas was developed. This framework is unique in view of the fact that backroom storage, as a type of warehouse, has never been addressed in the literature. It consists in seven sequential decisions and has the purpose to guide retailers when defining their backroom areas in a standardized and efficient manner. This framework combines the frameworks found in the literature to design conventional warehouses and DCs into one single structured approach that is adapted to the reality of grocery retailing by handling the inefficiencies captured in the exploratory research. This chapter helps to answer the Research Question 1.

Chapter 4 addresses the backroom sizing problem, attempting to answer Research Question 2. A forecasting model and two different models to size the backroom storage departments are presented. This problem consists in determining the size of each storage department in the backroom area. The first formulation is a bottom-up approach that aims to reduce the backroom life cycle costs while the second is a top-down approach based on Data Envelopment Analysis (DEA). The methodology is validated using real data provided by the case study. With both approaches, considerable space savings were achieved.

In Chapter 5 the backroom layout problem is presented, which answers the last research question. In this problem, a set of unequal area rectangular departments with given area requirements have to be placed, without overlapping, on the backroom, which can have regular or irregular shapes. The aim of the problem is to minimize the walking distance made by employees in the store considering physical, operational and energy issues. The methodology is validated using real layouts of stores. By using the proposed model, walking distances in the store are minimized, which contributes to more efficient in-store operations. Besides the original model, a parallel analysis was conducted in order to understand what is the current designing heuristic used by the space management designers to execute current layouts.

1.5. Contributions and future research

This section describes the main contributions of each chapter. Furthermore, a set of future research topics connected to each of the chapters of this thesis is identified.

The contributions of this thesis are aligned in two main directions. On the one hand, we defined the backroom design problem, where backroom storage is introduced as a new type of warehouse. Thus, we enrich the retail and warehouse design literature. On the other hand, we developed innovative mathematical models for designing backrooms that create value to both theory and practice.

Chapter 2 described the backroom design problem and provided a literature review on in-store operations and on the backroom design problem. Besides the literature review, an exploratory research was conducted on a case study company, where we had the opportunity to meet with different departments of the company (for instance, technical, auditing, stock management, logistics and supply chain) and to visit several stores, with the purpose of understanding current inefficiencies and aspects to improve. In Chapter 3, a review on warehouse design approaches was presented. This, together with the managerial insights obtained in Chapter 2, helped build the foundation for the development of a framework to design backroom areas, which is the core of Chapter 3. Succinctly, the first steps have the purpose of characterizing the new store regarding expected demand, products flow, number and type of departments, inventory in each department, necessary resources, among other requirements. These steps appear in the framework as follows: storage requirements, activity profiling, functional requirements and operational strategy. The following steps use the previous information to determine the storage space needed (backroom dimensioning) as well as the warehouse layout (layout preparation), allocating the departments in the warehouse according to the products flow. The final step is the layout assessment considering indicators previously defined with the design and operation teams. In addition to the academic results from this research, we have prepared several technical reports for the company. These documents concern the results from the visits, i.e., the main problems detected in the store backrooms, as well as standard guidelines to design backrooms, for instance, legal issues and recommendations.

From this stream, three main opportunities have emerged. Most importantly, to acknowledge backrooms as a type of warehouse and to conduct further research on how to capitalize from their existence to improve store operations and to support new services, such as e-commerce. Furthermore, there is a need to develop and extend the research on business data mining in order to capitalize on this information by not only presenting the current results, but also capturing tendencies. By doing so, the products and services provided to the customer in the store could be more personalized, which reflects on the space management decisions. Lastly, further research on functional requirements and operational strategy in the light of backrooms is needed. With so many technological developments, studies regarding the best automation level to each backroom are lacking.

From the aforementioned work have resulted one book chapter and one research paper:

- Maria Pires, Pedro Amorim, Jorge Liz and Joaquim Pratas. Design of Retail Backroom Storage: A Research Opportunity?. *In Operations Research and Big Data, Springer International Publishing*, pp. 167-174, 2015.

- Maria Pires, Joaquim Pratas, Jorge Liz and Pedro Amorim. A framework for designing backroom areas in grocery stores. *In International Journal of Retail & Distribution Management*, 45(3), pp. 230-252, 2017.

In Chapter 4 a forecasting model and two sizing models were presented. The forecasting model uses clustering techniques (*k*-means algorithm) and multinomial logistic regressions to determine the storage requirements (storing units) in the backroom. This model is useful to estimate sales profiles of new stores for which there is no historical sales data. The methodology was tested on 50 convenience stores, using real data from the case study. This methodology has demonstrated to be effective on finding and describing patterns in data to build a prediction. The average deviations obtained were 0,4% for net sales and 2,7% for stocks. Furthermore, two optimization models were proposed to size the backroom departments. The sizing models translate the storage requirements (expected inventory) into floor space (m^2). The first is a bottom-up approach, which results in the dimensions and storage heights for each backroom department and has the goal of minimizing the backroom life cycle costs. The second is a DEA inspired model (top-down approach) that aims to reduce the total backroom space by performing a benchmark analysis among existing stores. Both models allow to reduce the backroom total area, in 6% for the bottom-up model and 16% for the top-down model.

In Chapter 4 several research opportunities have emerged, such as analyzing the trade-offs between performing more frequent deliveries to stores and having more backroom space in order to know what would be more profitable when looking at the overall supply chain. Also, it would be interesting to analyze the backroom and sales areas (shelf space) dimensions jointly. By integrating these decisions the total store design could be optimized, instead of optimizing the two separately. This way, it would be possible to evaluate if some of the backroom departments could be reduced, or even excluded, if the assigned space in the sales area was increased. Finally, studying alternative storage systems could contribute to more efficient areas and in-store operations. From the aforementioned work has resulted one paper:

> Maria Pires, Ana Camanho and Pedro Amorim. Solving the grocery backroom sizing problem. *Second review in the International Journal of Production Economics*, 2017.

Chapter 5 described a model to solve the backroom layout problem. In this problem, a set of unequal area rectangular departments with given area requirements have to be placed on the backroom, which can have rectangular or irregular shapes. The aim of this problem is to minimize the walking distance in the stores by the employees. The model was tested on a sample of existing stores. Within the time limit of four hours, optimal solutions were found for six out of the eight instances analyzed. Nonetheless, the instances that did not reach the optimum had a gap of only 2%. The proposed model allows to reduce the walking distance in the store by 30%, which improves in-store operations. Besides the original model, four scenarios were created, each neglecting a different designing aspect. By comparing these scenarios with the real layouts, it was possible to understand what is the current designing heuristic beyond the current layouts. According to this analysis, designers are currently neglecting the replenishment frequencies as well as congestion in I/O points.

As future work in the backroom layout problem, it would be interesting to adapt the model proposed to non-convex shapes, which exist in some urban stores. Furthermore, it would be relevant to test the model in other settings, such as specialized retail and, lastly, to integrate the layouts of the sales and backroom areas. In a more practical/usable perspective, it would be interesting to deliver the layout in a designing software, such as CAD. This way, it would be easier for designers to work on the solution. From the aforementioned work has resulted one paper:

> Maria Pires, Elsa Silva and Pedro Amorim. Solving the grocery backroom layout problem. *Submitted to the European Journal of Operational Research*, 2018.

The sizing and layout models proposed fill a gap in the literature, since the backroom design problem has not yet been tackled quantitatively. Furthermore, they add value in practice since they enable architects to have a systematic and standard methodology to design backrooms, considering in-store operations and products flow. It also allows to decrease the backroom planning times and resources needed for this task. After obtaining the solution of the model, the intervention of the architects and engineers might be necessary to make some final adjustments and define additional technical issues.

Bibliography

Aastrup, J. and H. Kotzab
2010. Forty years of out-of-stock research and shelves are still empty. *The International Review of Retail, Distribution and Consumer Research*, 20(1):147–164.

Aghazadeh, S.-M.
2004. Improving logistics operations across the food industry supply chain. *International Journal of Contemporary Hospitality Management*, 16:263–268.

APED
2012. Plano de atividades 2011. Technical report, Associação Portuguesa de Empresas de Distribuição (APED).

Buttle, F.
1984. Retail Space Allocation. *International Journal of Physical Distribution & Logistics Management*, 14:3–23.

Caplice, C. and L. Das
2017. How back-of-mind backrooms rob retailers of profits. Technical report, Supply Chain Quarterly.

Eroglu, C., B. D. Williams, and M. A. Waller
2013. The Backroom Effect in Retail Operations. *Production and Operations Management*, 22(4):915–923.

Fernie, J., L. Sparks, and A. McKinnon
2010. Retail logistics in the UK: past, present and future. *International Journal of Retail Distribution Management*, 38(11/12):894–914.

Gruen, T. and D. Corsten
2002. Rising to the challenge of out-of-stocks. *ECR Journal*, 2(2):45–58.

Hübner, A. H., H. Kuhn, and M. G. Sternbeck
2013. Demand and supply chain planning in grocery retail: an operations planning framework. *International Journal of Retail Distribution Management*, 41(7):512–530.

INE
2015. Estatisticas do comercio 2015. Technical report, Instituto Nacional de Estatistica (INE).

Kotzab, H. and C. Teller
2005. Development and empirical test of a grocery retail instore logistics model. *British Food Journal*, 107(8):594–605.

Lewison, D. M.
1994. *Retailing*, volume 5th ed. Macmillan College Publishing, New York, NY.

Mckinnon, A. C., D. Mendes, and M. Nababteh
2007. In-store logistics: an analysis of on-shelf availability and stockout responses for three product groups. *International Journal of Logistics Research and Applications*, 10(3):251–268.

Nielsen
2015a. The future of grocery - e-commerce, digital technology and changing shopping preferences around the world. Technical report, Nielsen.

Nielsen
2015b. Scan trends no. 73. Technical report, Nielsen.

Pires, M., P. Amorim, J. Liz, and J. Pratas
2015. Design of retail backroom storage: A research opportunity? In *Operations Research and Big Data*, Pp. 167–174.

Reiner, G., C. Teller, and H. Kotzab
2013. Analyzing the Efficient Execution of In-Store Logistics Processes in Grocery Retailing-The Case of Dairy Products. *Production and Operations Management*, 22(4):924–939.

Stadtler, H.
2008. Supply chain management: an overview. In *Supply chain management and advanced planning*, Pp. 9–36. Springer.

Sternbeck, M. G.
2015. A store-oriented approach to determine order packaging quantities in grocery retailing. *Journal of Business Economics*, 85(5):569–596.

Tompkins
2014. Retail backrooms. Technical report, Tompkins International.

Van Zelst, S., K. van Donselaar, T. Van Woensel, R. Broekmeulen, and J. Fransoo
2009. Logistics drivers for shelf stacking in grocery retail stores: Potential for efficiency improvement. *International Journal of Production Economics*, 121(2):620–632.

CHAPTER 2

Design of retail backroom storage: A research opportunity?

Maria Pires [*] · **Jorge Liz** [†] · **Joaquim Pratas** [†] · **Pedro Amorim** [*]

Adapted from the book chapter published in *Operations Research and Big Data. Studies in Big Data, vol 15. Springer, Cham*, 2015 n Operations Research and Big Data (pp. 167-174). Springer International Publishing.
https://doi.org/10.1007/978-3-319-24154-8-20

Abstract The design of retail backroom storage has a great impact on in-store operations, customer service levels and store life-cycle costs. Moreover, backroom storage in modern retail stores is crucial to several functions, such as acting as a buffer against strong demand lifts yielded by an increasing promotional activity, seasonal peak demand and e-commerce activities. Despite having similar functions to a distribution center, backroom storage facilities have particularities that deserve a distinct analysis. In this paper we aim to draw attention to the lack of research about this topic.

Keywords Backroom design · Retail operations

2.1. Introduction

Warehouses are a key part of modern supply chains and play a vital role in the success or failure of business today (Hackman et al., 2001). Additionally, the large scale retail business is one of the most important supply chain stages both in terms of revenue per year and number of actors and entities involved (Rouwenhorst et al., 2000). It is estimated that the operating costs and capital invested in warehouses represent 22% of logistics costs in USA and 25% in Europe, and that in-store logistics are the most costly part of the retailer's supply chain (Baker and Canessa, 2009; Hübner et al., 2013). The increased competition in the retail industry has required continual improvements in design and operation of the supply chain, which also requires a better performance by the warehouses (Fernie et al., 2010).

Backroom storage, highlighted in yellow in Figure 2.1, is essential in retail stores since the replenishment orders for a given item that arrive at a retail store, coming directly from

[*]INESC TEC, Faculdade de Engenharia, Universidade do Porto, Porto, Portugal
[†]SONAE MC, Porto, Portugal

suppliers or from distribution centers (DCs), may not fit on the allocated shelf space, making this area indispensable (Trautrims et al., 2009; Aastrup and Kotzab, 2010). Moreover, nowadays, backroom storage in retail food stores is becoming more vital to act as a buffer against strong demand lifts yielded by an ever increasing promotional activity, seasonal peak demand for particular categories of products and on weekends, as well as to accommodate other activities such as e-commerce (Fernie et al., 2010; Mckinnon et al., 2007). Promotional activities are a key aspect to retail stores, being a competitive factor, which has a strong influence in the customer loyalty (Kotzab and Teller, 2005). Decisions regarding promotional activities and modification in planograms are often centrally defined and they strongly affect store operations since they require adjustments in the sales area, which is a very time and staff consuming process, and large quantities of merchandise in the backroom (Mckinnon et al., 2007; Berman and Larson, 2004; Van Zelst et al., 2009). Despite having similar functions to a distribution center, backroom storage facilities have particularities that deserve a distinct analysis and which we aim to draw attention to.

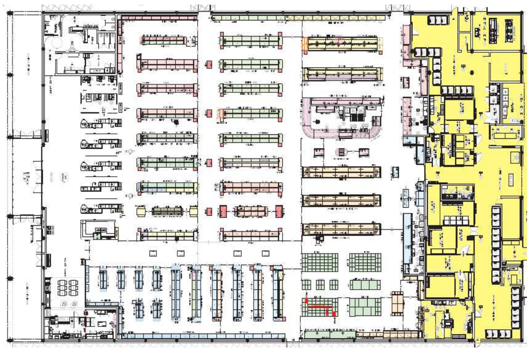

Figure 2.1 – Example of a grocery store layout, with the backroom area highlighted in yellow.

Operations on a retail store level are more complex and unorganized than in DCs (Trautrims et al., 2009). This is largely explained by in-store logistics that includes frequent promotional campaigns, handling the flow of products between shelves, temporary storage areas, promotional areas and backroom areas (Mckinnon et al., 2007; de Koster et al., 2007). Further, on a store level, order packaging units are smaller and more heterogeneous and customers exhibit a higher variability of demand. Moreover, stores stock a high range of products with specific characteristics (such as perishability, sensitivity to temperature and high shelf turnover), and deal with problems such as insufficient and busy staff, receiving errors and inventory shrinkage from theft, spoilage or damage (Van Zelst et al., 2009; Li et al., 2012).

Backroom storage design involves several research areas and it has been overlooked in the literature. The research areas related with the backroom design are very disperse and concern the conventional warehouse design and operations, grocery retailing, store operations, logistics and the facility layout problem. Despite the work undertaken in these distinct areas, a general framework linking these subjects in light of the backroom particularities is missing. For example, the models for designing conventional warehouses and

DCs do not adjust to the necessities of backroom storage facilities, such as accommodating e-commerce operations, being robust against an intense promotional activity stress, and coping with in-store operations (Hassan, 2002).

The remainder of this paper is organized as follows. The next section describes the research approach and methodology. Section 2.3 explains the particularities of backroom areas and Section 2.4 describes the in-store operations within retail stores. Then, Section 2.5 presents the exploratory research conducted on the case study and its findings. Section 2.6 addresses the backroom design and, lastly, Section 2.7 concludes the research paper and proposes future works.

2.2. Research approach

The aim of this paper is to introduce the importance of backrooms in retail supply chains as well as their role at in-store operations and performance. A literature review was undertaken, from May to September of 2014, searching a range of electronic databases, including Science Direct, Google Scholar, Springer and Scopus. These databases were searched using combinations of relevant keywords, such as “backroom”, “back store”, “grocery retail”, “design”, “dimensioning” and “operations”. Relevant papers were then selected based on the abstracts analysis. From this initial selection, the search was extended by accessing relevant books and cited papers. A total of 107 papers were retrieved that met at least one of the search terms. Selected papers date between 1984 and 2014. The literature was then classified into two groups: those that addressed the warehouse design and those that focused on grocery retail operations. It should be referred that no relevant literature existed in design of retail backroom storage areas *per se*.

In parallel with literature review, retail stores of a Portuguese retail company were analyzed. Data was obtained through observation and interviews with the store managers and personnel, when visiting a representative group of stores during January of 2015, as well as extracted from the company historical data. In this company, grocery stores are divided in three segments: hypermarket, supermarkets and convenience stores. The first type of store can be characterized by a total of 40 stores with average sales area of approximately 7380 m^2, the second type has the greatest number of stores (128) and an average sales area of approximately 2093 m^2 and the last, with a total of 42 stores, has an average sales area of approximately 1060 m^2. For all types of stores the backroom storage areas occupies nearly 36% of the total area of the store.

2.3. Backroom particularities

In most retail stores, inventory is held in two locations: retail shelves, in the sales area, and in the backroom, also called back store area. Products are stored in the backroom for many reasons but one main factor is the limited shelf space that makes it often impossible to fit a complete replenishment order on the allocated shelf space. By storing some inventory in the backroom, shelf space is freed for displaying a wider product assortment, potentially increasing sales (Aastrup and Kotzab, 2010; Gu et al., 2010). Additionally, support activities are performed in the backroom, such as break bulk of transportation units to end-user units and additional merchandise of products that have high demand or that in the selling area would quickly deteriorate (such as fruits and vegetables). Storing inventory in two locations has disadvantages because it requires permanent attention to real-time sales in order to prevent out-of-shelf (OOS) situations and lost sales. Furthermore, since in grocery retail store delivery frequencies are high, stock is needed to meet the demand for a short period of time, in contrast with most DCs.

The backroom storage area is divided into two major areas: storage area and social areas also referred as secondary departments in the literature. Storage areas, also called primary departments, are separated in three major departments, depending on the products that are stored: food, non-food and chilled areas. However, in a more detailed level, each department is organized in several sub-departments, with their own layout established. The sub-departments existence depends on the products' category and services performed. For this reason, different types of stores (hypermarkets, supermarkets, or convenience stores) require different sub-departments. An example is that hypermarkets have their own manufacture of bread, and for this reason need extra areas for ovens. Additionally, in the backroom there are technical areas where no products are stored, but that support all the activities of the store. Social areas, such as offices, restrooms and rooms, are intended for the employees of the store in order to provide them the necessary conditions to perform selling, maintenance and administrative activities.

In most companies the design of the backroom areas is mainly established on the perception of the architect and on similar stores, when it should be carefully studied based on in-store logistics, expected orders' volume of the regular activity as well as seasonal and promotional activity. To prevent these situations, designers should also rely on formal means to assist the design process, rather than follow ad-hoc procedures (Vaz et al., 2010).

Most performance problems associated to the design of backroom storage found in the literature are related to the lack of inappropriate architecture and store design. Despite having similar functions to a DC, backroom storage facilities have particularities that deserve a distinct analysis and can be divided in design and operational particularities.

One of the main design differences from DCs is the low and irregular shape caused by the construction space as well as selling area restrictions. These warehouses are integrated in stores which are usually located in residential areas that are more expensive. Additionally, this space coexists with the selling area, which competes for the same space, as shares with it its resources (equipment, personnel, etc.). Another difference between DCs and backrooms is the low level of automation of the latter, which relies in more manual operations.

Logistics processes in retail stores represent 40% of the total working hours and 40% of total retail costs due to manual activities and to the limited possibilities for using technology (Aastrup and Kotzab, 2009). Another important difference is that, although the layout is divided in different areas depending on the category of the products, they all serve the same client, which is the sales area. Thus, it operates as a unit serving one market with the important particularity that orders are not known and specified in advance, as occurs in DCs.

Regarding operational particularities, a big distinction between DCs and backrooms is that the latter are not as organized as the first. The differentiation factor is that personnel in charge of the backroom are the same responsible for replenishment, checkouts and help clients. This causes disorder in the backroom since it is not considered a priority as most of the efforts are attributed to the availability of products in the sales area and assisting clients in purchasing. For these reasons backroom storage areas are often neglected. Finally, backrooms accommodate technical departments, not referred in DCs, with the purpose to support the store activities, as the advertisement of the store. Backroom operational particularities are also associated with in-store operations, which account for the shelf replenishment processes that depend on the store sales and products characteristics. In this process, the personnel travel from the backroom to the sales room, with the products about to miss, or missing, in the shelves (out-of-shelf). In-store logistics consist in the activities that occur in the final stage of the supply chain of a retailer and that will be described in detail in the next section.

2.4. In-store logistics

In-store logistics consist of the activities that occur in the final stage of the supply chain of a retailer. Aastrup and Kotzab (2010) consider this a “hot topic" due to the dominance of store based retailing. Due to the very competitive and global environment in retailing, retail logistics importance has increased, making these activities a key factor impacting on the success of retail business. Raman et al. (2001) showed that poor execution of logistics at the retail outlet level can lead to unsatisfying results in sales. The operational costs associated with delivering items from the backroom to retail shelves can be substantial, accounting for between 38% and 48% of the operational logistics costs in a retail SC (Hübner and Kuhn, 2012). Moreover, more than 40% of the store employee working hours are spent performing in-store logistics tasks (Reiner et al., 2013).

The ultimate goal of in-store logistics is efficiency, which means to offer the quantities of items as requested by customers at the lowest possible price. Thus, the availability of products in shelves is an important key performance as no product available means no purchasing transaction.

In-store logistics can be characterized by a point of destination, which is the point of sales (shelves), a point of delivery, which is the incoming dock of the retail store, usually located in the backroom, and the objects, which are the products (SKUs) and related information. The store is the final moment of truth for most retailers. All aspects of planning, supply chain execution, merchandising, and marketing culminate in the sale and a satisfied customer, which all retailers vie for.

In general, material flow in a conventional warehouse consists in receiving goods, storage, order picking, sorting and shipping. However, operations on a retail store level are more complex and unorganized than in conventional warehouses and DCs (Trautrims et al., 2009; Bruzzone and Longo, 2010). This is largely explained by in-store operations that include handling the flow of products between different locations, such as shelves, temporary storage, promotional and backroom areas (Eroglu et al., 2013; Mckinnon et al., 2007; de Koster et al., 2007). It is estimated that the operating costs and capital invested in warehouses represent 22% of logistics costs in USA and 25% in Europe, and that in-store logistics are the most costly part of the retailer's supply chain (Baker and Canessa, 2009; Hübner et al., 2013).

The store operations include several processes: unloading of the trucks that come from DCs or directly from the suppliers; organizing the goods that need to go to the sales area or to the warehouses; cleaning the store and the shelves; replenishing the shelves; decorating the store for specific seasons or promotions; delivering customized services in specific areas (e.g., delicatessen, meats, seafood); customer assistance, and customer check-out. The tasks performed in store backrooms generally include products transportation, inventory carrying and storing, shelf management, handling and picking, labelling, order management and replenishment. The detailed in-store operations are summarized in Table 2.1.

Table 2.1 – In-store operations (adapted from Reiner et al. (2013) and Kotzab and Teller (2005)).

Backroom operations	Description of operations
Receipt	Products are delivered in stores from DCs or direct suppliers in the unloading dock, according to the delivery windows and frequencies established. Three different types of products are delivered: food, non-food and fresh products.
Inspection	After receiving the merchandise, store personnel inspects the deliveries checking if the delivered products meet the specifications. If not, return activities can take place.
Picking of products	At this stage, products are taken to the temporary storage areas where they are separated by store corridors to facilitate the replenishment process in the sales area.
Transporting products in the sales area	After the products are separated by corridor, they are taken to the sales area and replenished in the shelves or in the promotional areas.
Transporting excess products to backroom storage facilities	Excess stock that could not fit the shelves (overflow inventory) is stored in the backroom.
Replenishment of products in the shelves from the backroom	During the day and according to store sales, products are moved from the backroom to the shelves.
Handling and storing of products on shelves	This process includes all the activities needed to replenish the shelves, such as break bulk of transportation units to end user units, product handling, shelf stacking and product presentation.
Disposal/recycling	This includes both the removal of packaging material and the disposal/recycling of damaged products.

Retailers look for opportunities to optimize operations for better store performance in order to maintain the highest levels of customer service without increasing operational costs.

Figure 2.2 displays a simplified store layout with its main selling areas and the key flows of goods. Also, we intend to demonstrate how irregular the backroom shapes can be. Although it is not the subject of this work, there are also studies which aim to understand the customers flow in the store and which store layout (category positioning) and visual merchandising strategy would maximize the store sales (Mohan et al., 2013; Dhar et al., 2001).

A promising approach that would assist in-store logistics in grocery retail stores is the

Figure 2.2 – Grocery store layout with its main areas and flows (note that T&M correspond to technical and maintenance areas, S&A to social and administrative areas, and ID&CS to information desk and customer service).

RFID (Radio-Frequency IDentification) technology (Piramuthu et al., 2014). RFID advantages in retail are promising such as improving traceability, reducing wastage and "checking and control", reducing inventory and improving the replenishment cycle times (Condea et al., 2012). Nevertheless, despite these operational benefits, it was difficult to identify cost savings at this early stage which would justify the investment in this technology due to the initiation costs.

2.5. Backrooms in practice

In order to complement the theoretical research with real operational knowledge and practical insights, an exploratory work was conducted where several retail stores of international retailers were visited.

This field research allowed us to notice operational inefficiencies related to backrooms as well as to map the products' flow within the stores, which will be the cornerstone for the sizing and layout models to design the backroom area. This qualitative and observational-based information has been translated into flow charts that map the in-store processes since the moment products arrive to the store until they are stocked in the shelves, allowing to differentiate the distinct flows of products. Afterwards, we have combined this information with the legal constraints of the food retail sector in order to establish general guidelines to efficiently design the backroom storage areas.

Generally, stores are divided into sales and backroom areas. Each of these is composed of a number of areas, or departments. The sales area includes the following: books and stationary, apparel/clothes wear, leisure, health and beauty, dairy, fruits and vegetables, frozen food, bakery, delicatessen, take-away, meats and seafood, as well as the supporting checkout and customer service areas. The backroom includes unloading dock(s), food and non-food warehouses, cold rooms (e.g., dairies), frozen rooms (e.g., frozen food), technical and maintenance areas, administrative offices and, lastly, social areas (e.g., changing rooms).

Stores stock a high range of products with different storage temperatures, which influences the number of storage departments. The number of required departments depends not only on the range of products stored, but also on the legal constrains of this sector. For instance, food and non-food products cannot be stored together due to the chemicals present in some products (e.g., home cleaning products). Thus, it is necessary to safeguard the physical separation of these products.

Backrooms are extremely valuable to grocery stores. Without them the operations efficiency, products assortment, services and product availability would be compromised. However, backrooms are costly to the store if they are inadequately sized and allocated. Therefore, the scope of this work involves comprehending the operations in the backroom in order to capture both the space and allocation requirements.

In-store logistics in Continente

The moment when the goods arrive at the store is when more resources are needed (equipment and personnel). After the products are unloaded from the trucks, their arriving conditions are confirmed (transportation temperature and visual confirmation of the products' conditions). If the products do not meet these requirements, they can be returned.

The procedures following the arrival of the products depend on the time of arrival. If it happens before the store opening, less restrictions are applied and products can be carried on pallets directly to the sales area. If the delivery occurs after the store opening, the products are organized in refilling cars and then taken to the sales area. After being transported to the sales area, products are replenished on the shelves following the First-Expired-First-Out (FEFO) policy so that the products that are closest to expire are in the front. Another important factor affecting the flows is that certain products, such as fruits and vegetables, meat or fish require preparation before being put to sales in the sales area. After the products are stored in the shelves, the remaining merchandise is transported to the backroom (double handling of products) where it is organized and stored in racks. Figure 2.3 is an example of a food warehouse. Here, pallets of products are stored according to the business unit (e.g., grocery).

Throughout the day, store employees visually check if there are any missing products in the shelves (OOS situations). If that is the case, then the employee will look for the products in the backroom and refill them on the shelves.

Products flows are organized by their storage temperatures, properties and requirements (e.g., preparation). An example of the products flow map concerning the food and non-food products is presented in Figure 2.4. This is crucial both for product conservation and food safety issues, such as products cross-contamination. In practice this applies, for instance, to poultry (chicken and turkey) which cannot be stored together with other raw meats to avoid cross-contamination of bacteria. As a result of different product streams, the number of departments is defined in such a way that the aforementioned conditions of temperature

Figure 2.3 – Example of a food warehouse at Continente.

and food safety standards are respected.

The number of departments in which the backroom is organized is influenced by the type of store. This is caused by the assortment and volume of stock stored which varies with the type of store. For instance, hypermarkets store higher volumes of delicatessen and take-away products than convenience stores. For this reason they may require one department for each business unit, in order to simplify in-store operations and decrease the wasted energy. On the other hand, convenience stores are able to store these two business units in the same department, since they require the same storage temperature and their sales volume is not enough to require two separate departments. In practice, generally, backrooms of convenience stores are divided into 10 main departments while in hypermarkets backrooms are generally divided into 19 departments. Backroom design includes defining the number of required departments, their sizes and locations. These are strategic decisions that have great influence on in-store and backroom life cycle costs. Once the store is built, it is very unlikely that layout changes will be performed, except in cases of renovations, which are rare.

Main inefficiencies captured in the exploratory study

In this section, the main inefficiencies related to the backroom operations are detailed. In terms of the storage areas, store personnel pointed out the excess of stock, derived from promotional or seasonal campaigns and a wide assortment, as the main cause for backroom operations inefficiency. Furthermore, store employees are responsible for both the sales area and the backroom activities, which often lead to insufficient time to organize the backroom, since it is not considered the priority. Concerning the backroom design, store personnel referred the lack of storage space, that creates congestion and makes employees store merchandise in alternative locations, as the main cause for backroom operations in-

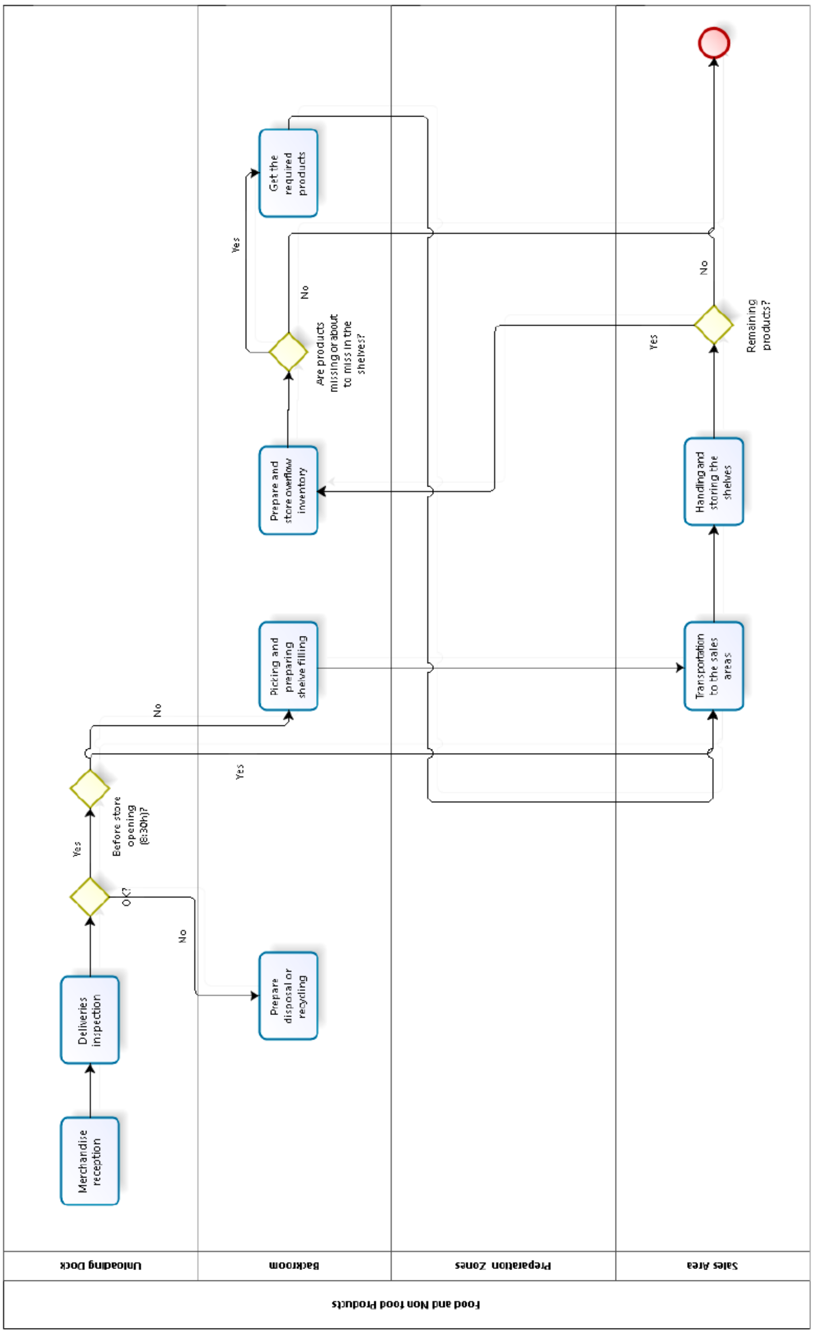

Figure 2.4 – Map of the food and non-food products flow at Continente.

efficiency (please refer to Figures 2.5 and 2.6). This motivated us to tackle the backroom sizing problem, presented in Chapter 4. Furthermore, racks are not always the best solution to store merchandise, especially high racks which are difficult to reach. The lack of appropriate areas to store promotional campaigns hinders finding the products and, therefore, the shelf replenishment process. The inappropriate location of storage departments, i.e, the backroom layout not reflecting the sales area layout, was also referred as a common problem. This aspect challenged us to tackle the backroom layout problem, further detailed in Chapter 5. The nonexistence of chilled and separate departments to store all products was another concern brought up by employees. For instance, some stores did not have chilled areas to store fruits and vegetables, which are very sensitive to temperature and humidity and that easily depreciate at room temperature. Some improving aspects regarding social areas were also pointed out, such as small restrooms and the nonexistence of meeting areas. The lack of appropriate technical areas was also discussed. For instance, the nonexistence of areas to prepare the store decoration, to dispose garbage or to store unused pallets. In terms of external areas, decks are sometimes not properly dimensioned, which difficult unloading merchandise.

New opportunities for improvement were indicated concerning several departments of the company that impact backroom management. In terms of the commercial department, in charge of assortment and buying decisions, it was proposed the review of the (excessive) ordered quantities that cause excess of stock in the backroom as well as the review of the stores' assortment that, in some cases, is inappropriate. Lastly, the implementation of smaller quantity store packs to reduce store stock. Concerning the stock management department, it was proposed to promote campaigns to dispose discontinued products, to improve the overall view of store stock as a whole and to promote inter-store transfer. Lastly, regarding the logistics department, it was discussed improving the pallet assembly process, which causes product breakdowns (mainly cross-docking products), to implement processes for separating products considering the sales area layout, in order to facilitate the picking of products and the replenishment in the store and, lastly, to create processes to return excess campaigns to the DC (inverse logistics).

Figure 2.5 – Excess of stock in the ambient warehouse.

Figure 2.6 – Excess of stock/insufficient storage area in the frozen storage department.

To conclude, it is important to refer that the success of in-store operations depends not only on the correct design of the store areas, but on all departments of the supply chain.

In this way, and to improve customer service, a global view of the retail supply chain is needed.

Besides this analysis, a proposition of best practices to design backrooms was delivered to the company. In this report all legal issues were collected, such as products that cannot be stored together, dimensions of several kinds (door weights or wall heights), among other aspects.

2.6. Backroom design

A backroom, in similarity to a DC, consists of several departments or areas. The warehouse design phase is crucial regarding costs since it is known that warehouse costs are, to a large extent, determined at the design phase (Baker and Canessa, 2009). The design process of DCs is usually described by a sequence of steps. Some authors group the activities within these steps into a hierarchical framework based on a top-down approach, thus identifying strategic, tactical and operational decisions that should be considered in sequence (Vaz et al., 2010). Other authors divide the warehouse design in groups of major decisions, such as: determining the overall structure; sizing and dimensioning the warehouse and its departments; determining the detailed layout within each department; selecting warehouse equipment; and selecting operational strategies (Reiner et al., 2013).

Regarding the overall structure, the main departments of a DC correspond to its major functions such as receiving, storing, packing, sorting and shipping. However, backrooms do not follow this organization since packing and shipping are not equivalent to conventional warehouses. Thus, the overall structure is unique and not a critical aspect in backrooms. Further, equipment selection in backrooms is a very limited decision since the set of equipment to be chosen from is very small and does not vary substantially between different types of stores. Finally, the generality of in-store operations are already reasonably well established and vary little between stores. For these reasons, strategy selection is not a relevant decision. Another point that we would like to stress is that conventional orders do not take place in backroom because the store clients are located in the selling area, choosing their products in the self-service display area and emptying the shelves, which is the trigger for replenishment from the backroom (backroom orders). For this reason, shipping is performed differently since products are picked and arranged in the backroom to be delivered to the sales area to replenish the shelves. Additionally, regular warehouse functions, as value added services, are also generally not performed in backrooms.

Backroom design steps, as in DCs, are interrelated and should interact during the process. Also, operational efficiency and performance are strongly affected by the design decisions. Performance evaluation is important for both warehouse design and operation, and can be assessed in terms of cost, throughput, space utilization and service levels. An alternative for performance evaluation is using Data Envelopment Analysis (DEA) techniques comparing, for instance, service levels, sales and profit of stores (Gu et al., 2007). Using DEA the performance assessment involves a comparison among similar backroom areas located in different stores. This may allow defining targets for different sections and understanding the best warehouse layout practices. Assessing performance provides feedback about how a specific design performs compared with the requirements and how it can be improved. It is also important to state that once these decisions are established and the warehouse areas (and store) are built it can be very expensive or even impossible to make changes.

Backroom sizing and backroom layout are the key stages in the backroom design. Both these stages are influenced by and influence in-store operations and physical constraints. Backroom sizing determine the space allocation among the various departments, according to the storage requirements. Backroom layout corresponds to the detailed configuration within the backroom departments, optimizing the arrangement of departments within the backroom. In order to solve this complex problem, a diversity of methods is described in the literature for both dimensioning and layout. For the dimensioning stage the proposed methods range from linear to nonlinear programming formulations (Baker and Canessa, 2009; Reiner et al., 2013); multi-attribute value functions which capture the trade-offs among different criteria (Reiner et al., 2013); heuristics to find the warehouse size (Singh and Sharma, 2006); integrated optimization-simulation models, which evaluate the storage shortage cost, and optimization models combined with heuristic algorithms to determine the assignment of Stock Keeping Units (SKUs) to storage areas, as well as the size of each functional areas to minimize the total handling and storage costs (Eroglu et al., 2013; Vaz et al., 2010).

Layout problems affect warehouse performances with respect to construction and maintenance costs; material handling costs, handling machinery and energy; storage capacity, which is the ability to accommodate incoming shipments; space utilization and equipment utilization. The most used objective function is the minimization of material handling costs. However, the goals in backrooms can be different from DCs, such as the minimization of OOS, maximization of sales productivity and use of labor. Further, these objectives can be applied together in multi-objective problems. To solve the layout problem several methods are used, such as analytical formulations (Reiner et al., 2013), dynamic programming, non-linear and mixed integer methods (Baker and Canessa, 2009). Additionally, meta-heuristics, such as genetic algorithm, are generally utilized to solve this very complex problem (Eroglu et al., 2013). Simulation is also used to provide a detailed performance evaluation and a clearer view of the products flow for the resulting alternatives (Baker and Canessa, 2009). Additionally, a different approach to this problem is through a facility layout problem that is concerned with finding the most efficient arrangement of finite number of departments with unequal area requirements within a facility (Singh and Sharma, 2006). Thus, this problem can be solved through several methods depending on the objectives and constraints defined.

2.7. Conclusion and future work

This paper draws attention to backroom storage areas and emphasizes their importance. Furthermore, our aim is to stress the particularities of backroom storage when compared to conventional warehouses which support a further and separate research of backrooms. After this analysis we could conclude that the current literature focusing on warehousing is a very small fraction of the overall supply chain papers and backroom design is not discussed. Another important issue that we would like to stress is the evident lack of contributions of practical cases demonstrating potential benefits and application of academic research to real problems. Thus, cross-fertilization between the groups of practitioners and researchers appears to be limited and should be encouraged to face this challenging problem. This discussion will, hopefully, stimulate future research in this very promising area, both from a theoretical and a practical perspective. As future research opportunities we pretend to propose a framework for designing the backroom areas and the development of a decision support system to assist designers in this complex process. Moreover, we also intent to explore what is the best proportion of backroom storage areas within a store.

Bibliography

Aastrup, J. and H. Kotzab
2009. Analyzing out-of-stock in independent grocery stores: an empirical study. *International Journal of Retail Distribution Management*, 37(9):765–789.

Aastrup, J. and H. Kotzab
2010. Forty years of out-of-stock research and shelves are still empty. *The International Review of Retail, Distribution and Consumer Research*, 20(1):147–164.

Baker, P. and M. Canessa
2009. Warehouse design: A structured approach. *European Journal of Operational Research*, 193(2):425–436.

Berman, O. and R. C. Larson
2004. A queueing control model for retail services having back room operations and cross-trained workers. *Computers & Operations Research*, 31(2):201–222.

Bruzzone, A. G. and F. Longo
2010. An Advanced System for Supporting the Decision Process within Large-scale Retail Stores. *Simulation*, 86(0):742–762.

Condea, C., F. Thiesse, and E. Fleisch
2012. Rfid-enabled shelf replenishment with backroom monitoring in retail stores. *Decision Support Systems*, 52(4):839–849.

de Koster, R., T. Le-Duc, and K. J. Roodbergen
2007. Design and control of warehouse order picking: A literature review. *European Journal of Operational Research*, 182(2):481–501.

Dhar, S. K., S. J. Hoch, and N. Kumar
2001. Effective category management depends on the role of the category. *Journal of Retailing*, 77(2):165–184.

Eroglu, C., B. D. Williams, and M. A. Waller
2013. The Backroom Effect in Retail Operations. *Production and Operations Management*, 22(4):915–923.

Fernie, J., L. Sparks, and A. McKinnon
2010. Retail logistics in the UK: past, present and future. *International Journal of Retail Distribution Management*, 38(11/12):894–914.

Gu, J., M. Goetschalckx, and L. F. McGinnis
2007. Research on warehouse operation: A comprehensive review. *European Journal of Operational Research*, 177(1):1–21.

Gu, J., M. Goetschalckx, and L. F. McGinnis
2010. Research on warehouse design and performance evaluation: A comprehensive review. *European Journal of Operational Research*, 203(3):539–549.

Hackman, S. T., E. H. Frazelle, P. M. Griffin, S. O. Griffin, and D. A. Vlasta
2001. Benchmarking warehousing and distribution operations: an input-output approach. *Journal of Productivity Analysis*, 16(1):79–100.

Hassan, M. M.
2002. A framework for the design of warehouse layout. *Facilities*, 20(13/14):432–440.

Hübner, A. H. and H. Kuhn
2012. Retail category management: State-of-the-art review of quantitative research and software applications in assortment and shelf space management. *Omega*, 40(2):199–209.

Hübner, A. H., H. Kuhn, and M. G. Sternbeck
2013. Demand and supply chain planning in grocery retail: an operations planning framework. *International Journal of Retail Distribution Management*, 41(7):512–530.

Kotzab, H. and C. Teller
2005. Development and empirical test of a grocery retail instore logistics model. *British Food Journal*, 107(8):594–605.

Li, Y., B. Cheang, and A. Lim
2012. Grocery perishables management. *Production and Operations Management*, 21(3):504–517.

Mckinnon, A. C., D. Mendes, and M. Nababteh
2007. In-store logistics: an analysis of on-shelf availability and stockout responses for three product groups. *International Journal of Logistics Research and Applications*, 10(3):251–268.

Mohan, G., B. Sivakumaran, and P. Sharma
2013. Impact of store environment on impulse buying behavior. *European Journal of Marketing*, 47(10):1711–1732.

Piramuthu, S., S. Wochner, and M. Grunow
2014. Should retail stores also rfid-tag "cheap" items? *European Journal of Operational Research*, 233(1):281–291.

Raman, A., N. DeHoratius, and Z. Ton
2001. Execution: The Missing Link in Retail Operations. *California Management Review*, 43(3):136–152.

Reiner, G., C. Teller, and H. Kotzab
2013. Analyzing the Efficient Execution of In-Store Logistics Processes in Grocery Retailing-The Case of Dairy Products. *Production and Operations Management*, 22(4):924–939.

Rouwenhorst, B., B. Reuter, V. Stockrahm, G. van Houtum, R. Mantel, and W. Zijm
2000. Warehouse design and control: Framework and literature review. *European Journal of Operational Research*, 122(3):515–533.

Singh, S. P. and R. R. Sharma
2006. A review of different approaches to the facility layout problems. *The International Journal of Advanced Manufacturing Technology*, 30(5-6):425–433.

Trautrims, A., D. B. Grant, J. Fernie, and T. Harrison
2009. Optimizing on-shelf availability for customer service and profit. *Journal of Business Logistics*, 30(2):231–247.

Van Zelst, S., K. van Donselaar, T. Van Woensel, R. Broekmeulen, and J. Fransoo
2009. Logistics drivers for shelf stacking in grocery retail stores: Potential for efficiency improvement. *International Journal of Production Economics*, 121(2):620–632.

Vaz, C. B., A. Camanho, and R. Guimarães
2010. The assessment of retailing efficiency using network data envelopment analysis. *Annals of Operations Research*, 173(1):5–24.

Chapter 3

A Framework for Designing Backroom Areas in Grocery Stores

Maria Pires [*] · **Jorge Liz** [†] · **Joaquim Pratas** [†] · **Pedro Amorim** [*]

Published in *International Journal of Retail & Distribution Management*, 2017
https://doi.org/10.1108/IJRDM-01-2016-0004

Abstract

Purpose: The design of retail backroom storage areas has great impact on in-store operations, customer service level and store life-cycle costs. Moreover, backroom storage in modern retail grocery stores is critical to several functions, such as acting as a buffer against strong demand lifts yielded by an ever increasing promotional activity, stocking seasonal peak demand, and accommodating e-commerce activities. In this paper, we propose a framework to design this crucial area. Furthermore, we aim to draw attention to the lack of literature about this topic, while clarifying the relationship between this promising research stream and the considerable body of research regarding the design and operations of conventional warehouses, as well as retail in-store operations.

Design/methodology/approach: Key literature on backrooms, grocery retail, in-store operations, warehouse design and operations was reviewed. This allowed an understanding of the gap in the literature regarding the design of backrooms. Moreover, a case-study methodological approach was conducted in a Portuguese retailer to extend the literature review.

Findings: Despite having similar functions to conventional warehouses, backroom storage facilities have particularities that deserve a distinct analysis. Thus, we stress these differences and demonstrate how they influence the development of a novel backroom design framework.

Originality/value: This paper fills a gap by proposing a framework to design backroom areas. Furthermore, this research may help practitioners to better design backroom areas, since this process currently lacks a formal and standardized procedure.

Keywords Backroom Design · Grocery Retail · Warehousing

[*]INESC TEC, Faculdade de Engenharia, Universidade do Porto, Porto, Portugal
[†]SONAE MC, Porto, Portugal

3.1. Introduction

The ongoing transformation in the retail industry is significantly impacting its operations, requiring ever greater operational efficiencies, namely regarding the optimization of the store scarce resources, such as the store space (Fernie et al., 2010).

In the retail supply chain (SC) inventory may be placed in several stages. These might be warehouses, distribution centres (DCs), or retail stores (backrooms and sales area). Despite the fact that backrooms have several similar functions to DCs, they have particularities that deserve a distinct analysis (Pires et al., 2015). This link of the SC has been often neglected by academics and practitioners, and it is currently seen as a poorly designed transition point between the DCs and the retail store shelves. However, they are a critical link that is used for much more than just store replenishment (Tompkins International, 2014).

Backroom storage is essential in grocery retail stores since the replenishment orders for a given item that arrives at a retail store, coming directly from suppliers or from DCs, may not fit on the allocated shelf space, making this area indispensable (Buttle, 1984; Eroglu et al., 2013; Aastrup and Kotzab, 2010). Moreover, nowadays, backroom storage in grocery stores is becoming more vital to act as a buffer against strong demand lifts yielded by an ever increasing promotional activity, to stock seasonal peak demand for particular categories of products and also on weekends, as well as to accommodate other activities, such as e-commerce (Fernie et al., 2010; Mckinnon et al., 2007).

Backrooms are part of retail stores that have operations which are more complex and unorganized than in DCs (Trautrims et al., 2009; Bruzzone and Longo, 2010). These operations include handling the flow of products between shelves and storing in temporary, promotional and backroom areas (Eroglu et al., 2013; Mckinnon et al., 2007; de Koster et al., 2007). Furthermore, on a store level, order packaging units are smaller and more heterogeneous, and customers exhibit higher variability in consumer spending. Stores also have to stock a high range of products with specific characteristics (such as perishability, sensitivity to temperature and shelf-turnover), and problems stemming from shrinkage and theft (Van Zelst et al., 2009; Li et al., 2012). Due to the aforementioned reasons, logistics processes in retail stores represent 40% of the total working hours and 40% of total logistics retail costs due to manual activities and to the limited possibilities for using technology (Reiner et al., 2013). In addition to the previously mentioned topics, backroom design faces further challenges, such as the sales area restriction.

In the store designing process, sales area design is the priority since it is the space that creates value to the store. Thus, it should have a regular shape and be attractive to customers. In contrast to the selling area, the remaining space is dedicated to the backroom storage which design is often neglected. Nevertheless, the main problems in grocery stores are related to constructional defects, inappropriate architecture and the non-existence of standardized guidelines for backroom storage facilities, proving the importance of the design of these areas (Kotzab and Teller, 2005; Reiner et al., 2013). Also, retail store shelving and replenishment practices are the causes for about 25% of out-of-shelf (OOS) situations, which reflect inefficient in-store operations that are very influenced by the backroom design (Gruen and Corsten, 2002).

The design of backrooms is a strategic decision that is focused on the last stage of the retail supply chain planning framework (Hübner et al., 2013; Schneeweiss, 2012; Miller, 2012), as illustrated in Figure 3.1. This is a complex decision and both retail literature and practice lack a structured framework to design backroom storage areas. Currently in practice, these complex areas are the result of ad-hoc methodologies, mainly established on the perception of the architect who compares the new store with similar ones.

Therefore, our contribution focuses on answering the following research questions (1) What is the importance of backrooms in grocery retail SC? and (2) What are the main decisions to make when designing a grocery backroom? Answering these questions will help practitioners and researchers to understand what aspects to consider while designing these areas and which methodologies to use when solving this problem. This paper combines knowledge and insights from the literature on backroom design related topics, namely conventional warehouses design, and from an exploratory research conducted on a case study company. This builds the foundation for the development of the framework to design backroom areas.

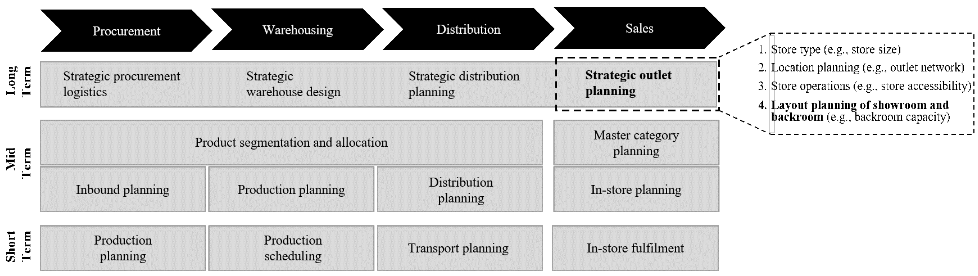

Figure 3.1 – Backroom design in the supply chain design framework (adapted from Hübner et al. (2013) and Stadtler (2008)).

The case study methodological approach was conducted between October 2014 and April 2015 in a Portuguese grocery retail chain, branded SONAE (Voss et al., 2002). SONAE is the leader retailer in Portugal and has 3 segments of stores: convenience stores, supermarkets and hypermarkets. In 2015 this company held a total of 746 grocery stores worldwide and achieved a volume of sales of 3.490 M (SONAE, 2016).

The case study had two phases. Firstly, several retail stores of the Portuguese retail company were visited. These are described in Table 3.1. Our unit of analysis was the in-store operations. This field research allowed us to understand the real context of retail in-store operations as well as to notice operational in-store problems and inefficiencies regarding backrooms. Moreover, with this qualitative and observational-based information we were able to map the products' flow within the stores which is fundamental for the layout definition and department organization within the backroom area. Secondly, non-structured interviews were conducted with 3 members (2 engineers and 1 architect) of the department responsible for designing and managing the stores' space. Our unit of analysis was the store design standard process.

In order to ensure the validity of this study, we have observed the operations of several stores ranging from North to South of Portugal, both in urban and rural areas, thus assuring sample diversity. Moreover, the proposed framework (cf. Section 3.4) was reviewed by

Table 3.1 – Characterization of the stores visited.

Type of stores	Number of stores visited	Stores in Portugal	Avg sales area (m^2)	Avg backroom area (m^2)	Avg number of Stock Keeping Units	Full Time Equivalent
Conventional stores	8	53	1100	660	25000	37
Supermarkets	15	130	2100	1400	40000	59
Hypermarkets	5	40	7500	5400	70000	186

key members of the company.

The remainder of this paper is organized as follows. The next section describes the review of backroom roles, related literature as well as the particularities of backroom storage captured in the exploratory research. Section 3.3 covers the literature review on warehouse design approaches that will help in proposing the framework for designing backroom storage facilities in Section 3.4. Finally, Section 3.5 concludes the research paper and indicates future works and further research areas.

3.2. Backroom role, related literature and backroom particularities

3.2.1 Backroom role

In most retail stores, inventory is held in two locations: retail shelves, in the sales area, and the backroom. Storing inventory in two locations has disadvantages because it requires permanent attention to real-time sales in order to prevent OOS situations and lost sales.

Backroom storage, highlighted in yellow in Figure 3.2, is a requirement in the retail business. Retailers manage these facilities for many reasons. One main factor is the limited shelf space that makes it often impossible to fit a complete replenishment order on the allocated shelf space (Eroglu et al., 2013). By storing some inventory in the backroom, shelf space is freed for displaying a wider product assortment, potentially increasing sales (Eroglu et al., 2013; Reiner et al., 2013). Moreover, backrooms enable retailers to keep stock in anticipation of, or to react to, demand of products. Lastly, backrooms allow a space apart from customers to perform activities such as in-store picking, breaking-bulk of transportation units to end-user units, transforming products before being put to sales, packing, labelling, cross-docking between stores and returning merchandise to the suppliers.

Besides being crucial to retail stores, backrooms impact the whole SC. Firstly, they relieve some of the capacity pressure of DCs by allowing them to (early) transfer stock downstream to the stores. Also, they permit wider delivery windows, which greatly benefit route planning decisions and therefore, transportation costs. Moreover, by providing additional storage space, multiple daily deliveries from the DCs to the stores are avoided which also reduces transportation costs. Backrooms may also play an important role in retail services by enabling new omnichannels needs. For instance, backroom provides retailers with an opportunity to consolidate and fulfill online home-delivery and click-and-collect at the store orders (Aastrup and Kotzab, 2010). Regarding the administrative tasks, backrooms

Figure 3.2 – Example of a grocery store layout, with the backroom area highlighted in grey.

support the link between the stores and the upstream SC departments, enabling sorting and processing of paperwork activities. Finally, backrooms accommodate the social areas, intended to the store employees. For all of the above reasons, backrooms merit attention and focus as they are a key link in the SC and a crucial support to the store.

As mentioned before, backroom storage area is usually divided in two major areas: storage areas and social areas. Storage areas (primary departments) are generally separated in three major departments: food, non-food and chilled areas. In a more detailed level, each department is organized in several sub-departments, with their own layout established. The number of sub-departments is influenced by the type of store (hypermarkets, supermarkets or convenience stores). This happens because the services performed, assortment and volume of stock stored varies with the type of store. Stores have to stock a high range of products with specific and different characteristics, requiring different storage temperatures. Moreover, the number of required departments depend on the legal constraints of this sector.

3.2.2 Related literature

Backroom storage design involves several research areas and it has been overlooked in the literature. The research areas interrelated with the backroom design are very disperse and concern the conventional warehouse design and operations, grocery retailing, store operations, and logistics (Gruen and Corsten, 2007; Raman et al., 2001).

The design and operation of a warehouse comprise many challenging decision problems that have been studied in the literature in many sectors, such as grocery distribution, manufacturing or health care. These problems are usually divided into storage capacity models, warehouse design models and throughput capacity models (Cormier, 2005). Storage capacity models are typically strategic problems that aim to find the optimal warehouse size or else how to maximize space utilization. On the other hand, warehouse design problems deal with questions such as rack orientation, space allocation and overall building configuration. Throughput capacity models are usually in the operational level and comprise order picking policies as well as storage and assignment policies. Furthermore, warehouse performance has also been addressed in the literature, where travel-time models are often used to compare both alternative operating scenarios and warehouse designs.

Despite the research on warehouse design and operations, backroom design has been neglected. Nonetheless, there exists some literature covering backroom design related topics. Eroglu et al. (2013) has looked over in-store operations and has introduced the backroom effect in store operations, which is a consequence of misalignment of case pack size, shelf space, and reorder point. In this paper, the authors assess the impact of the backroom effect on the optimal inventory policy and total costs. This work supports the interconnection between backroom design, upstream SC planning and sales area design. Moreover, Milicevic and Grubor (2015) have analyzed the effect of backroom size on product availability and concluded that in grocery stores, with the increase of backroom size, OOS on a store level decreases while in hypermarkets the opposite was observed, i.e., with the increase of backroom size, OOS increases as well. Therefore, these results opened several issues concerning the differences between smaller and larger stores.

A very important backroom related topic is grocery retailing which allies customers profiling, products profitability (Kumar et al., 2006), category management (Hübner and Kuhn, 2012), store layout (Van Zelst et al., 2009) and shelf management (Dreze et al., 1995). The impact of case pack quantities on the store level has also been addressed in the literature (Van Zelst et al., 2009; Kuhn and Sternbeck, 2013; Waller et al., 2008). Two opposing effects influence the expected levels of backroom activity. While larger case pack sizes increase the probability of excess inventory in the backroom (higher handling and inventory costs), orders will be placed less often and therefore new merchandise will arrive less frequently at the store (lower handling and transportation costs) (Kuhn and Sternbeck, 2013; Waller et al., 2008).

As mentioned before, store operations is a crucial topic to backroom design as it addresses the flow of operations within the store (process chain), and how it affects the backroom area planning (Reiner et al., 2013; Raman et al., 2001). Concerning this topic, the process of replenishing products from the backroom to the sales area (refilling shelves) has been considered by several authors as not efficient, leading to poor service. Corsten and Gruen (2003) have confirmed that between two-thirds and three-fourths of OOS are caused in the store. Also, Kuhn and Sternbeck (2013) have stated that nearly 50% of the entire logistics costs in grocery retailing occur in the retail stores. Some of the raised factors are the incongruence between shelf capacity and replenishment frequencies, large assortment, insufficient staffing, congested backroom and poor design (Waller et al., 2008; Corsten and Gruen, 2003; Fernie, 1994).

The subject of SC planning, which encompasses inventory management (e.g., reorder points), retail supply networks, and delivery patterns, has a significant impact in the overflow inventory in the backroom, affecting its storage requirements (Gudehus and Kotzab, 2012; Teo and Shu, 2004). Kuhn and Sternbeck (2013) have addressed the implications of planning issues such as store delivery arrival times, replenishment lead times and roll-cage sequencing and loading carriers to the store.

Lastly, RFID technology has also been addressed in the backroom context, showing great value for retail in-store operations and a great promise to reduce shelf OOS (Gruen and Corsten, 2007; Condea et al., 2012; Piramuthu et al., 2014). The underlying idea is to automatically monitor inventory in order to trigger replenishments from the backroom to the sales area based on RFID data in real time (Gruen and Corsten, 2007; Condea et al., 2012).

Despite the work undertaken in these distinct areas, the link between these subjects in light of backroom design is missing. For instance, the models for designing conventional warehouses and DCs do not completely adjust to the necessities of backroom storage facilities, such as being robust against an intense promotional activity stress and coping with in-store operations (Aastrup and Kotzab, 2009).

3.2.3 Backroom particularities

The particularities of backrooms *vis-à-vis* DCs can be divided in design and operational particularities. One of the main design differences is the position and function of backrooms and retail stores in the SC. Retailers are positioned in the last stage of the SC while DCs are located upstream. Since retailers operate at the closest point to the client they can serve as an input to the upstream planning areas. Also, the decoupling point that separates planning tasks into forecast driven and order driven is typically located at the store (Hübner et al., 2013; Gudehus and Kotzab, 2012). Another important characteristic is the low and irregular shape of backrooms caused by the construction space as well as selling area restrictions (cf. Figure 3.2). These warehouses are integrated in stores which are frequently located in residential areas that are more expensive. For this reason, the storage capacity of backrooms is more limited. Additionally, backrooms coexist with the selling area, which competes for the same space. Another particularity is the low level of automation of backrooms, which rely on manual operations. Furthermore, the layout organization of backrooms is completely different when compared to DCs. Although the layout is generally divided in different areas depending on the category of the products, they all serve the same client, which is the sales area.

Regarding operational particularities, a significant distinction between DCs and backrooms is that the latter are not as organized as the former. The differentiating factor is that often store personnel are responsible for both backroom and sales area management. This causes disorder in the backroom since it is not considered a priority as most of the efforts are attributed to the availability of products in the sales area and on assisting clients. For these reasons backroom storage areas are often neglected. The in-store operations are summarized in Figure 3.3. In this process, store employees travel from the backroom to the sales area, with the products about to miss, or missing, in the shelves. During this process, employees may interact with the store clients, assisting them if necessary. Since in grocery retail delivery frequencies are high, stock is needed to meet the demand for a short period of time, in contrast with most DCs. Nevertheless, days of inventory in conventional warehouses or DCs are usually shorter than in retail stores. This is caused by several aspects such as the case pack size, excess inventory from promotional campaigns, presentation needs, discontinued products, among others. This is a critical aspect since one may consider that inventory in the stores is more valuable than in DCs because the merchandise was already transported from DCs to stores, which results in additional logistic costs.

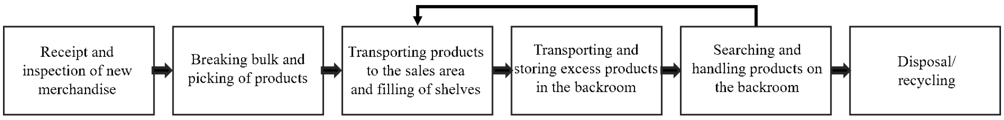

Figure 3.3 – In-store operations (adapted from (Reiner et al., 2013; Kotzab and Teller, 2005).

3.3. Literature review on warehouse design approaches

As previously referred, literature on backroom design is missing. Thus an extensive review on warehouse design was conducted that will later be used on the definition of the backroom design framework, presented in the forthcoming section.

Efficiently designing a warehouse is crucial since it is known that warehouse costs are, to a large extent, determined at this phase. The design process of DCs is usually described by a series of steps. Some authors group the activities within these steps into a hierarchical framework based on a top-down approach, identifying strategic, tactical and operational decisions (Rouwenhorst et al., 2000) . Other authors divide the warehouse design into a set of sequential steps (Hassan, 2002; Baker and Canessa, 2009) and, alternatively, in further approaches warehouse design is presented in non-sequential groups of decisions (Gu et al., 2010).

The literature review on this topic included publications concerning “warehouse design”, being the earliest publication of year 1974 and the most recent of 2016. From the literature review, it was possible to identify three general approaches to design conventional warehouses and DCs. These approaches are summarized in Table 3.2, as well as a description of the methodologies commonly used to tackle the different design stages. In this table, the decision sequence takes place from the left to the right side, as the left-side decisions are previously made and influence the decisions that follow. This table allows the parallel visualization and comparison of the distinct frameworks. From the left to the right side of the table, decisions progress from a lower to a higher detail level.

In the first approach, (Rouwenhorst et al., 2000) define the warehouse design process as a structured approach of decision making at the strategic, tactical and operational levels, representing long (5 years), medium (2 years) and short (1 year) term decisions. In this top-down approach decisions are divided in hierarchical levels which reflect the time horizon. Thus, solutions chosen at a higher level provide the constraints for the lower level decision problems, starting with a rough design that will be refined at the subsequent stages until a final design is defined. At the strategic level, the authors consider decisions that have a long term impact, mostly those concerning high investments. At this level, decisions are made regarding the design of the process flow and the selection of types of warehousing systems. Medium term decisions are made at the tactical design level and generally have a lower impact when compared to strategic decisions. Tactical decisions typically concern dimensioning the resources (such as storage size and number of employees) and the layout definition. At the operational level, processes have to be carried within the constraints settled at the higher levels. The main decisions at this level concern the assignment and control problems of both personnel and equipment. However, in this research we are not tackling the operational level because it is beyond the backroom design problem scope.

In the second approach, Baker and Canessa (2009) propose a framework for the warehouse design by combining the results from the literature review on works such as Rowley (2000), Hassan (2002) and Rushton et al. (2014), as well as warehouse design companies. The proposed framework consists in a set of eleven steps which are organized as follows. The first step consists in defining the system requirements, referring to the overall system, and therefore includes business strategy requirements and relevant constraints, such as planning and environmental issues. The second and third steps involve obtaining and analyzing data, which results in warehouse activity profiling that includes aspects such as customer orders, items characterization and investment profiling. The next step (step 4) consists in establishing unit loads, by taking into account supplier and customer considerations. Step 5 involves the determination of the operating procedures and methods. The authors consider an important part of this step the decision of the zones into which the warehouse should be divided, depending on different product groups, temperature regimes, or Pareto classifications. Step 6 regards the decision of the equipment types and characteristics. Further, step 7 comprises the calculation of equipment types, capacities and quantities. The goals include the development of optimum rack lengths and space utilization. Step 8 consists in defining services and ancillary operations. In step 9 possible layouts are prepared. This is considered by the authors a key and complex step due to the range of different objectives to be optimized. The last steps consist in evaluating and assessing the possible layouts by validating the operational and technical feasibility. The final step involves identifying the preferred warehouse layout by drawing together all of the above elements into a coherent design.

Finally, Gu et al. (2010) present a detailed survey on warehouse design, describing it in five non-sequential major stages: determining the overall structure; sizing and dimensioning of the warehouse and its departments; determining the detailed layout within each department; selecting warehouse equipment; and selecting operational strategies. The overall structure determines the material flow pattern within the warehouse, the specification of functional departments, and the spatial relationship between departments. The warehouse sizing problem determines the warehouse storage capacity. In addition, the warehouse dimensioning problem translates capacity into floor space and determines the space allocation among warehouse departments. This decision has important implications on such costs as construction, inventory holding and replenishment, and material handling. Department layout is the detailed configuration of the warehouse departments. The equipment selection problem's purpose is to determine the appropriate warehouse automation level, and specify equipment types for storage, transportation, order picking, and sorting. The operation strategy selection problem is to determine how the warehouse will be operated, for instance, with regard to storage and order picking.

In this section the literature on warehouse design was reviewed. Conventional warehouses and DCs operate in different conditions from backrooms, which is reflected in the design process. We hereby indicate four areas in which standard frameworks for conventional warehouses differ from those aimed at designing backrooms:

- As opposed to the process of designing conventional warehouses, while designing retail backrooms there are large amounts of data available that are generated with the current stores. It is important that backroom design profits from this information while defining the backroom requirements. Therefore, a step concerning backroom activity profiling should be part of the backroom design process.
- Retail in-store operations can be characterized by a great task complexity, due to the high product assortment as well as the variety of services provided in the store (e.g., counters of "to-be-prepared" products or e-commerce activities) that depend on the store type and influence the backroom departmentalization. Therefore, a step in which the functional requirements are defined is required in the backroom design framework.
- In terms of resources, namely equipment and personnel, backrooms are much more restricted. Actually, backrooms are characterized by a low level of automation, mainly due to budget constraints. For this reason, a step intended to the selection of equipment is not relevant in the backroom design process, as it is in conventional warehouses.
- Finally, backrooms are highly conditioned by the sales area, mostly due to the replenishment operations during the day, and by the physical constraints (irregular shapes and limited space) caused by operating a store in urban areas, for example. Therefore, the definition of the layout as well as its assessment have an enhanced relevance in backroom design.

3.4. Framework for designing the backroom

Backrooms are a very specific type of warehouses and therefore deserve a particular design framework (cf. Section 3.2.3). However, since there is a lack of literature on backroom design and operations, the methodology chosen by the authors consisted on an extensive review of warehouse design (Section 3.3) and adapting it to the backroom design, benefiting from the practical insights described in Section 3.3.

Figure 3.4 presents the framework proposed. It illustrates the design steps sequence as well as the necessary inputs, outputs and external data required for each step. It often occurs that one step requires information from several preceding steps, which is illustrated by dark circles.

In this section we present a framework for the design of backroom areas that consists in a sequence of interrelated steps. In each step of the framework we present the problem description, generically in warehouses and more specifically in the backroom context, the methodologies and techniques applied in the literature to solve each of the individual problems and the tools usually applied in practice. Each subsection ends with the description of the department responsible for this decision in the case study company.

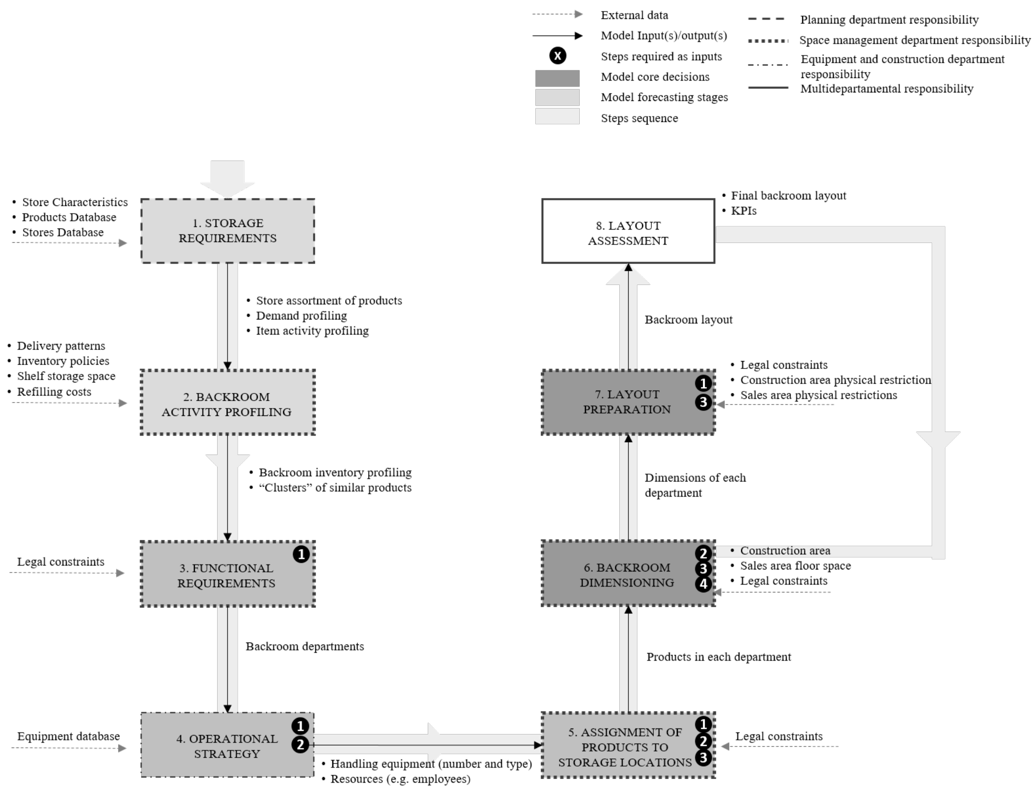

Figure 3.4 – Proposed framework for the backroom design.

Table 3.2 – Comparison between the various approaches (adapted from Baker and Canessa (2009)).

Authors											
Strategic Level	Macro					Strategic Level					Micro
Rouwenhorst et al. (2000)		• Design of the process flow • Selection of types of technical systems						• Equipment selection • Dimensioning of the resources (storage systems, employees, etc.) • Layout design			
Baker et al. (2009)	Define system requirements	Define and obtain data	Analyse data	Establish unit loads to be used	Determine operating procedures and methods	Consider equipment types and characteristics	Calculate equipment capacities and quantities	Define services and ancillary operations	Prepare possible layouts	Evaluate and assess	Identify the preferred design
Gu et al. (2010)		Determine overall structure		Define operational strategy		Select equipment		Sizing and dimensioning		Determination of the layout	
Methodologies used		• Business and supply chain strategy • Scenario analysis • Benchmarking (simulation and data envelopment analysis) • Checklists and spreadsheet models		• Database models • Activity profiling techniques • Warehouse flow charts • Analytic and simulation approaches		• Flexibility frameworks • Spreadsheet models and decision trees • Heuristic, analytic and simulation methods • Checklists		• Multi-attribute value functions • Warehouse relationship activity charts • CAD software (generally used by practitioners)		• Analytic and simulation models • Quantitative (e.g. financial business case) and qualitative (e.g. SWOT analysis) methods • Multi-criteria decision making	

3.4.1 Storage requirements

This step aims to define the general requirements of the backroom. Backrooms are part of retail stores, and for that reason their design is directly related to the type of store. In this step it is important to identify which of the typical types of stores the new store is going to be, i.e., a hypermarket, a supermarket, a convenience store, or another typology (e.g., drugstores, freeze stores or organic POS). Seidel et al. (2016) have analyzed the selling concepts in France and Germany and have defined the sizes of convenience stores to generally be less or equal than 400 m^2, supermarkets between 400 m and 2499 m and hypermarkets dimensions' superior to 2500 m. Moreover, it is worth mentioning that general merchandise stores have historically dedicated about 15 to 20 percent of their store space to the backroom (Dunne et al., 2013). Then, a forecasting analysis should be performed in order to understand the expected levels of store activity, product assortment, sales volume and demand profiling. Usually, practitioners compare the store in project phase with the existing stores in order to provide estimates that will result in the requirements for capacity, throughput, budget and space that the store should meet. The following decisions in the backroom design will be built on these estimates and assumptions.

Data Envelopment Analysis has been used in order to assess retail productivity of outlets in a retail firm (Donthu and Yoo, 1998). Defining the storage requirements of the backroom is interconnected to the forecast analysis of demand, which plays an important role both in manufacturing and retail operations. In that area, there is the work of Kumar and Patel (2010) who has proposed a new method of combining forecasts using the concepts of clustering. Another important decision regards the definition of the product assortment. In this topic, there are works that aim to aid retailers to define which products to stock (product assortment) and how much shelf space to allocate to those (Cachon et al., 2005; Borin et al., 1994; Hariga et al., 2007; Hübner and Kuhn, 2012).

The methods used for this step in practice are scarce and unstructured. Usually ad-hoc database/spreadsheet tools on backroom roles and functions (e.g., storage and treatment zones required) are used (Baker and Canessa, 2009; Gu et al., 2010).

The decision of opening new stores is often the Executive committee's responsibility. Then, the Planning Department performs market studies to predict the characteristics of the store based on available data (e.g., clients profile). This information allows to decide, for instance, the best location for the new store.

3.4.2 Backroom Activity Profiling

Generally, warehouse activity profiling includes topics such as 1) Customer order profiling (e.g., pallet, carton, etc.); 2) Item activity profiling (e.g., item popularity and demand variability distributions); 3) Inventory profiling (e.g., Pareto inventory distribution); 4) Calendar clock profiling (e.g., seasonality and daily activity distributions); 5) Investment profiling (e.g., wage rates and required return on investment); 6) Activity relationship profiling, i.e., importance of certain functions being located near other functions (Baker, 2006). Topics 2, 3, 4 and 6 are especially important in backroom design.

Depending on the product assortment of the store, storage classes can be made, considering the family of products, their demand and characteristics (e.g., sizes, weights, shapes, temperature regimes and expiration dates). Besides the product assortment, the identification of the inventory (topic 3) to store in the backroom takes into account the shelf space of each product in order to assess if it is enough to store the inventory needed to meet the estimated demand. In this decision it should be considered aspects such as product demand forecast, shelf space, inventory policies, delivery patters, and shelf refiling and handling costs of different products. Other important aspect concerns topic 4 and is the seasonality of products, which may affect subsequent steps on space requirements and storage assignment. There are products which demand is relatively low during all year with the exception of one specific period (e.g., summer, Christmas). Another crucial aspect is the promotional campaigns, which can have, for instance, a weekly or biweekly periodicity that influence the sales area and the backroom, as well as the store resources. Finally, regarding topic 6, it is very important to keep in mind the relationship between activities within the backroom in order to better allocate the departments and arrange their location concerning the corresponding sales area. For example, the chilled areas for fish and meat should be near their respective treatment zones (in the backroom) and the attendance service (in the sales area). This is a very important aspect for the efficient and smooth flow of products.

There is some research concerning the topic of in-store operations and inventory management. Lin et al. (2008) have used simulation to investigate shelf replenishment policies used in retail stores. The policies' impact in the efficiency of the retail SC was analyzed and compared. Furthermore, Van Zelst et al. (2009) have developed a conceptual model for shelf stacking in stores, which was derived using the analogy based on order picking models for warehouses. This model demonstrates the impact of the most important drivers for stacking efficiency that are case pack size, number of case packs stacked simultaneously, the filling regime and the working place of the employees. Moreover, benchmark examinations are also used to consider efficient stores as reference to design the new store (Reiner et al., 2013). Within the context of food SC, authors such as Van Donselaar et al. (2006) has studied the design of perishable inventory management systems.

At this step, as well as in the previous, tools used in practice are ad-hoc checklists, flowcharts and spreadsheet (Rushton et al., 2006). Data profiling techniques are used to understand products' details, demand profiles, arrival patterns and site information (Baker and Canessa, 2009).

The data required in this step belongs to several business departments of the company, such as Marketing, Sales and Logistics. However, the data analysis is often the responsibility of the Space Management department that combines the relevant information for defining the backroom activity profile.

3.4.3 Functional requirements

Defining the functional departments consists on determining how many departments will be required in the backroom and their characteristics (e.g., storage temperature). The functional departments are defined based on the zones into which the warehouse should be divided (e.g., zones for different product groups, temperature regimes, or Pareto classifications). This decision is based on the backroom inventory profiling in which the products to store in the backroom were defined. In the specific case of backrooms, items are generally stored in departments depending on their temperatures and categories. Nevertheless, there is a set of common departments to all types of stores (e.g., food warehouse).

Backrooms are generally divided in two major areas: storage areas and social areas. The storage areas include the food and non-food warehouses, chilled and frozen rooms, and technical and maintenance areas (ancillary operations). Additionally, there are important legal constraints to follow regarding food security and hygiene issues (e.g., home cleaning products, which contain chemicals, should not be stored close to food products). In a more detailed level, each department is organized in several sub-departments, with their own internal layout established. Social areas, also referred as secondary departments, are intended for the employees of the store in order to provide them working conditions and areas to perform administrative activities. These areas include administrative offices, restrooms and meeting and living rooms. Furthermore, in some stores there are also external areas including the unloading dock, where products arriving at the store are unloaded.

In warehousing, authors generally consider a warehouse with five functional areas, i.e., receiving, shipping, cross-docking, reserve, and forward areas (Heragu et al., 2005). Furthermore, Le-Duc and De Koster (2005) aimed to determine the optimal number of zones such that the overall (picking and packing) time to finish a batch is minimized using exact and approximate methods.

The set of tools utilized in practice in this step are also empirical and include warehouse flow charts as well as database and spreadsheet models on warehouse roles (e.g., cross-docking) and functions (e.g., storage) (Mantrala et al., 2009; Baker and Canessa, 2009).

These decisions are often taken by the Space Management department. Here, legal constraints are important to make sure that every product is stored in adequate conditions. Nevertheless, suggestions from the Operations department (e.g., store managers) may be taken into consideration.

3.4.4 Operational strategy

Once the main departments and operations are identified, warehouse flow diagrams can be used to describe the daily flows passing through the various zones of the backroom as a basis for the subsequent steps. The selection of the operational strategy is also a high level decision with high impact on backroom life cycle costs and include defining the storage, order picking, material handling systems and personnel.

Regarding storage, it is important to understand what serves better the backroom: dedicated, randomized or class-based storage. Since a quick and efficient service is essential to the quality of shelf-stacking, employees should be familiarized with the location of products in the backroom. For this reason, the strategy usually chosen is dedicated and class-based storage, which also allows the division of the areas by family of products. However, within each sub-department items can be allocated randomly or by their demand (hybrid storage). Further decisions regarding DCs include determining the depth and height of storage, the type and dimensions of unit loads, the type, number and capacity of handling equipment and the assignment of equipment to particular areas of the warehouse. Backrooms are characterized by a low level of automation in storage systems, making use of labour intensive systems (e.g., shelving systems). The common material handling systems include palletizers and truck loaders. In backrooms the simplicity and accessibility of products are crucial requirements for the operation. Moreover, as retailers may have hundreds or thousands of stores, the available financial resources for backroom systems and equipment are very scarce. In addition, there are space constraints which do not allow voluminous systems. In regular retail stores products are generally separated by categories that are assigned to store personnel. For this reason, a common picking strategy in backrooms is zone picking.

An important particularity of backrooms is that pickers per se do not usually exist, since the employees of the store perform activities in both sales area and backroom. It is also important to note that in DCs there exists a list of products to meet a specific order, which tends to be very clear and available at established timetables. However, in backrooms this cannot be assumed because the replenishment from the storage areas is unpredictable and triggered by the absence of products in the sales area (i.e., OOS) and conditioned by the availability of resources. At this decision level, the necessary resources for a smooth store operation should also be calculated, namely the number of employees (full and part time).

In the literature, operational strategy appears divided into storage and order picking strategies (Gu et al., 2007). Berg and Zijm (1999) discussed warehousing systems and presented a classification of warehouse management problems. Regarding storage strategy, Graves et al. (1977) and Schwarz et al. (1978) compared random storage, dedicated storage, and class-based storage using both analytical and simulation models. In respect to order picking strategies, Peterson (2000) simulated five different order-picking policies: single order picking, batch picking, sequential zone picking, concurrent zone picking, and wave picking. Naish and Baker (2004) described a step-by-step approach to equipment evaluation and, lastly, Park and Webster (1989) assumed the functions are given, and select equipment types, storage rules, and order picking policies to minimize total costs. In practice the role of the designer in this process is of great importance and is often supported by checklists with the operational requirements. Nonetheless, the research in this topic considering the backroom's characteristics is very scarce.

The definition of technological requirements, such as store equipment, is decided by the Equipment and Construction department. These decisions are then communicated to the Space Management department that incorporates it in the design.

3.4.5 Assignment of products to storage locations

Once the departments are defined, one needs to determine which items are assigned to each department. As it happens in conventional warehouses, the assignment of items to storage locations is an important step in the design due to its impact on movement time, throughput, productivity of store employees and congestion. Thus, rules for the assignment of items to storage locations have to be carefully defined in order to improve in-store operations.

In the specific case of backrooms these decisions include the assignment of groups of items into storage locations and their arrangement within each location. The assignment decisions rely on information obtained from previous steps concerned with analysis of demand, class formation, backroom departmentalization, legal constraints, and storage systems. For instance, highly demanded items or classes should not be all stored in one place in order to reduce congestion. Thus, highly demanded items are distributed throughout the backroom. As referenced before, zone picking is a common strategy in backrooms. For that reason, effort is made to assign products that are picked in the same route in the same, or adjacent, department.

Regarding the assignment problem, there are some relevant works in the literature. Hackman et al. (1990) solved the problem of which SKUs to assign to the forward area by proposing a heuristic that attempts to minimize the total costs for picking and replenishment activities. Moreover, Frazelle et al. (1994) provided a framework for determining the size of the forward area together with the allocation of products into that area. Finally, Heragu et al. (2005) considered an optimization model and a heuristic algorithm to determine the assignment of SKUs to the different storage areas as well as the size of each functional area in order to minimize the total material handling and storage costs. However, the departmentalization of the warehouse and the complexity of the products stored are not consonant with the reality of backrooms.

In practice, the Space Management department uses the information regarding food safety and legal constraints to guide the products assignment to each department. Usually, no detailed assignment is performed.

3.4.6 Backroom dimensioning

The warehouse dimensioning problem translates capacity into floor space. Space requirements in a conventional warehouse depend on various factors such as inventory levels, storage units, number of aisles, number of storage levels, departmentalization and storage equipment that have already been discussed in earlier steps. Warehouse dimensioning is crucial since it has important implications on construction, inventory holding, and operations costs. Sizing is much related to the inventory policies and decisions, which rely on the forecasting and analysis of demand. This step must be carefully executed because an oversized estimate of space needs could lead to wasted space, while an undersized may lead to crowded conditions.

Assuming that the backroom has little control over inventory, which is often managed centrally by the Commercial and Supply Chain departments, backroom dimensioning determines the appropriate storage capacity in order to cope with the stochastic demand. At this stage, the impact of demand variability may be assessed by organizing several scenarios for space requirements. Moreover, it is important to consider buffers for promotional campaigns and returns to the supplier.

In literature, some authors propose optimization models considering alternative situations: (1) warehouses are responsible for controlling their inventory (Levy, 1974; Cormier and Gunn, 1996) and (2) warehouses that have no control over the inventory policy and are subject to single-product or multi-product deterministic demand (Goh et al., 2001). Heragu et al. (2005) has addressed simultaneously the product allocation and functional area size considering a warehouse with several functional areas resorting to an optimization model and a heuristic algorithm. Simulation models were also applied to understand the effects of inventory control policies on the total required space capacity (Rosenblatt and Roll, 1988).

Lastly, Pliskin and Dori (1982) proposed a method to compare alternative space allocations among different warehouse departments based on multi-attribute value functions. However, none of these models include multi-products with the diversity of storage requirements that backrooms face (e.g., multi-temperature) while considering promotional and seasonal demand and, most importantly, the arrangement of two competing areas such as the backroom and sales area in the same confined space.

This decision is taken by the Space Management department that often makes use of recent and similar stores to use as a reference for the new store.

3.4.7 Layout preparation and assessment

Finally, possible layouts can be prepared and assessed. This step consists in allocating the departments in the backroom by considering several aspects, such as the products flows. This is a complex problem since different objectives can be desired simultaneously, such as the minimization of space, costs related to walking distances, as well as maximization of the products accessibility and resources utilization. However, backrooms have additional goals such as OOS minimization.

Usually, computer-aided design software is used to assist in the layouts drawing (e.g., AutoCAD). Material flow plays an important role in this step since it allows understanding the best organization within the warehouse in order to simplify and streamline the material flow. Designing the backroom layout requires the consideration of several aspects. For instance, the distance between sales area of a specific category of product and its storage space in the backroom should be minimized. Moreover, it is important to consider the adjacencies between the departments, i.e., which department require to be located together due to, for instance, construction issues. Lastly, the backroom area has often irregular shapes which lead to several iterations until the final layout is defined. At this step the designers' know-how and expertise may be very valuable. The final layout is chosen considering the indicators selected to measure the performance of the backroom (e.g., travelled distances).

There is a reasonably robust research literature on the general facility layout problem, which is also a relevant approach to this step and regards the physical organization of the departments. In this area several works were published, including the application of genetic algorithms. For example, Hernandez et al. (2011) used a multi-objective interactive genetic algorithm to support the decision maker's decision. Another example is the work of Amaral (2006), who proposed a mixed-integer linear programming model to the resolution of this problem. Gray et al. (1992) proposed a multistage hierarchical approach that uses simple calculations to evaluate the trade-offs and prune the design space to a few superior alternatives.

The layout definition is usually defined by the Space and Management department. However, it is evaluated by all the stakeholders and modifications are often required.

Despite the sequential manner in which the design steps were presented, a degree of iteration is necessary in order to achieve the best suiting design for a given backroom.

3.5. Conclusions and future research

This paper presents a general framework for the design of backroom storage areas while drawing attention to backrooms and emphasizing their importance to the store and their impact at in-store logistics and customer service level. This framework is unique in view of the fact that backroom storage as a type of warehouse has never been addressed in the literature. Additionally, at each step of the framework a parallel between warehouse and backroom design is established while highlighting the dissimilarities. A limitation of our research concerns the external validity of our framework that was performed using one grocery retail Portuguese (leading) company. Therefore, future research may test the framework on different contexts/companies.

After this analysis we could conclude that the current literature focusing on warehousing is a very small fraction of the overall supply chain papers and backroom design is not discussed. Another important issue that we would like to stress is the evident lack of contributions of practical cases demonstrating potential benefits and application of academic research to real problems in this field. Thus, cross-fertilization between the groups of practitioners and researchers appears to be limited and should be encouraged to face this challenging problem. It was also observed that the design of the backroom areas is mainly established on the perception of the architect and on similar stores, when it should be carefully studied based on in-store logistics and operations, expected orders' volume of the regular activity as well as seasonal and promotional activity. To prevent these situations, designers should also rely on formal means to assist the design process, rather than follow ad-hoc procedures.

In the course of our discussion, we have outlined various aspects that deserve attention but have been barely addressed by retail practitioners, consultants, or academics. Thus, this discussion will, hopefully, stimulate future research in this very promising area, both from a theoretical and a practical perspective, having a strong potential for improving current practices. Further research opportunities lie in performing further empirical studies regarding backroom operations and employ them in quantitative studies concerning backroom design. With the proposed framework we aim to create a basis for discussion around this relevant topic as well as to encourage further research in this topic. The future research opportunities identified were grouped by planning areas, i.e., steps of the framework, and are the following:

- **Storage Requirements and Backroom Activity Profiling** - Retail companies store large-scale data sets in their databases. There is a need to develop and extend the research on business data mining in order to capitalize on this information by not only presenting the current results, but also capturing tendencies. In this research context, companies should be able to determine the new stores' storage requirements based on data regarding, for instance, clients' demand, products' characteristics, inventory policies and store location.

- **Functional Requirements and Operational Strategy** - With so many technological developments, studies regarding the best automation level for backroom storage systems are missing. In confined and constrained spaces, such as backrooms, new systems (e.g., compact storage systems) could allow for an improvement in retail practices. These studies should encompass, for instance, the impact of different transportation and storage units in the retail SC.

- **Assignment of Products to Storage Locations** - The assignment of products within backroom departments has great influence on the in-store operations. Therefore, it would be interesting to study the backroom departments' micro-layout considering aspects such as products characteristics (e.g., volumes, density), replenishment frequency (considering sales area storage capacity and product demand) and promotional and seasonal policies. Allying this research with the potential use of RFID technology would also be very relevant to practice due to the potential improvement in the picking efficiency. By taking advantage of the information provided by the RFID, real time sales, and product location within the backroom departments it would be possible to determine order picking strategies and prevent OOS, increasing sales and, consequently, customer's satisfaction.

- **Backroom Dimensioning** - In the literature, sizing of DCs has been tackled and discussed. However, the number of departments considered and the assortment of products stored do not encompass the complexity of retail operations. Moreover, the backroom sizing needs to consider the sales area as a storage space as well, making this an even more complex problem.

- **Layout Preparations and Assessment** - DCs layout configuration is very different from backrooms. For example, backrooms have irregular shapes caused by the limited construction space in urban areas, which yield a very hard layout problem. Also, backrooms make little use of aisles, as opposed to DCs, since they usually consume valuable storage space, affecting the overall layout. Hence, new layout models and methods are necessary for tackling the overall backroom design problem. Furthermore, the allocation of the departments in the backroom should consider not only the products' flow in the backroom, but also the position of the corresponding products in the sales areas.

The integration of the sizing and layout problems described above is promising. Connecting the capacity allocation among departments with their distribution in the available space is a complex and innovative research direction. Moreover, it would be interesting to extend the mentioned integration with other planning decisions that impact the backroom. These decisions may include not only the inventory and delivery policies to the stores (determining the optimal delivery strategy and inventory levels), but also decisions regarding the sales area space (analyzing the optimal distribution of inventory between the backroom and sales area).

Bibliography

Aastrup, J. and H. Kotzab
2009. Analyzing out-of-stock in independent grocery stores: an empirical study. *International Journal of Retail Distribution Management*, 37(9):765–789.

Aastrup, J. and H. Kotzab
2010. Forty years of out-of-stock research and shelves are still empty. *The International Review of Retail, Distribution and Consumer Research*, 20(1):147–164.

Amaral, A. R.
2006. On the exact solution of a facility layout problem. *European Journal of Operational Research*, 173:508–518.

Baker, P.
2006. Designing distribution centres for agile supply chains. *International Journal of Logistics Research and Applications*, 9(3):207–221.

Baker, P. and M. Canessa
2009. Warehouse design: A structured approach. *European Journal of Operational Research*, 193(2):425–436.

Berg, J. P. V. D. and W. H. M. Zijm
1999. Models for warehouse management: Classification and examples. *International Journal of Production Economics*, 59:519–528.

Borin, N., P. W. Farris, and J. R. Freeland
1994. A model for determining retail product category assortment and shelf space allocation. *Decision sciences*, 25(3):359–384.

Bruzzone, A. G. and F. Longo
2010. An Advanced System for Supporting the Decision Process within Large-scale Retail Stores. *Simulation*, 86(0):742–762.

Buttle, F.
1984. Retail Space Allocation. *International Journal of Physical Distribution & Logistics Management*, 14:3–23.

Cachon, G. P., C. Terwiesch, and Y. Xu
2005. Retail assortment planning in the presence of consumer search. *Manufacturing & Service Operations Management*, 7(4):330–346.

Condea, C., F. Thiesse, and E. Fleisch
2012. Rfid-enabled shelf replenishment with backroom monitoring in retail stores. *Decision Support Systems*, 52(4):839–849.

Cormier, G.
2005. Operational research methods for efficient warehousing. In *Logistics systems: Design and optimization*, Pp. 93–122. Springer.

Cormier, G. and E. A. Gunn
1996. On coordinating warehouse sizing, leasing and inventory policy. *IIE transactions*, 28(2):149–154.

Corsten, D. and T. Gruen
2003. Desperately seeking shelf availability: an examination of the extent, the causes, and the efforts to address retail out-of-stocks. *International Journal of Retail & Distribution Management*, 31(12):605–617.

de Koster, R., T. Le-Duc, and K. J. Roodbergen
2007. Design and control of warehouse order picking: A literature review. *European Journal of Operational Research*, 182(2):481–501.

Donthu, N. and B. Yoo
1998. Retail productivity assessment using data envelopment analysis. *Journal of retailing*, 74(1):89–105.

Dreze, X., S. J. Hoch, and M. E. Purk
1995. Shelf management and space elasticity. *Journal of Retailing*, 70(4):301–326.

Dunne, P. M., R. F. Lusch, and J. R. Carver
2013. *Retailing*. Cengage Learning.

Eroglu, C., B. D. Williams, and M. A. Waller
2013. The Backroom Effect in Retail Operations. *Production and Operations Management*, 22(4):915–923.

Fernie, J.
1994. Quick response: an international perspective. *International Journal of Physical Distribution & Logistics Management*, 24(6):38–46.

Fernie, J., L. Sparks, and A. McKinnon
2010. Retail logistics in the UK: past, present and future. *International Journal of Retail Distribution Management*, 38(11/12):894–914.

Frazelle, E. H., S. T. Hackman, U. Passy, and L. K. Platzman
1994. Optimization in industry 2. chapter The Forward-reserve Problem, Pp. 43–61. John Wiley & Sons, Inc.

Goh, M., O. Jihong, and T. Chung-Piaw
2001. Warehouse sizing to minimize inventory and storage costs. *Naval Research Logistics (NRL)*, 48(4):299–312.

Graves, S. C., W. H. Hausman, and L. B. Schwarz
1977. Storage-retrieval interleaving in automatic warehousing systems. *Management science*, 23(9):935–945.

Gray, A. E., U. S. Karmarkar, and A. Seidmann
1992. Design and operation of an order-consolidation warehouse: Models and application. *European Journal of Operational Research*, 58(1):14–36.

Gruen, T. and D. Corsten
2002. Rising to the challenge of out-of-stocks. *ECR Journal*, 2(2):45–58.

Gruen, T. W. and D. S. Corsten
2007. A comprehensive guide to retail out-of-stock reduction in the fast-moving consumer goods industry.

Gu, J., M. Goetschalckx, and L. F. McGinnis
2007. Research on warehouse operation: A comprehensive review. *European Journal of Operational Research*, 177(1):1–21.

Gu, J., M. Goetschalckx, and L. F. McGinnis
2010. Research on warehouse design and performance evaluation: A comprehensive review. *European Journal of Operational Research*, 203(3):539–549.

Gudehus, T. and H. Kotzab
2012. *Comprehensive Logistics*. Springer, Berlin Heidelberg.

Hackman, S. T., M. J. Rosenblatt, and J. M. Olin
1990. Allocating items to an automated storage and retrieval system. *IIE transactions*, 22(1):7–14.

Hariga, M. A., A. Al-Ahmari, and A.-R. A. Mohamed
2007. A joint optimisation model for inventory replenishment, product assortment, shelf space and display area allocation decisions. *European Journal of Operational Research*, 181(1):239–251.

Hassan, M. M.
2002. A framework for the design of warehouse layout. *Facilities*, 20(13/14):432–440.

Heragu, S. S., L. Du, R. J. Mantel, and P. C. Schuur
2005. Mathematical model for warehouse design and product allocation. *International Journal of Production Research*, 43(2):327–338.

Hernandez, L. G., L. S. Morera, and A. A. Azofra
2011. An interactive genetic algorithm for the unequal area facility layout problem. In *Soft Computing Models in Industrial and Environmental Applications, 6th International Conference SOCO 2011*, volume 87, Pp. 253–262. Springer.

Hübner, A. H. and H. Kuhn
2012. Retail category management: State-of-the-art review of quantitative research and software applications in assortment and shelf space management. *Omega*, 40(2):199–209.

Hübner, A. H., H. Kuhn, and M. G. Sternbeck
2013. Demand and supply chain planning in grocery retail: an operations planning framework. *International Journal of Retail Distribution Management*, 41(7):512–530.

Kotzab, H. and C. Teller
2005. Development and empirical test of a grocery retail instore logistics model. *British Food Journal*, 107(8):594–605.

Kuhn, H. and M. G. Sternbeck
2013. Integrative retail logistics: an exploratory study. *Operations Management Research*, 6(1-2):2–18.

Kumar, M. and N. R. Patel
2010. Using clustering to improve sales forecasts in retail merchandising. *Annals of Operations Research*, 174(1):33–46.

Kumar, V., D. Shah, and R. Venkatesan
2006. Managing retailer profitability: one customer at a time! *Journal of Retailing*, 82(4):277–294.

Le-Duc, T. and M. De Koster
2005. Determining number of zones in a pick-and-pack order picking system.

Levy, J.
1974. The optimal size of a storage facility. *Naval Research Logistics Quarterly*, 21(2):319–326.

Li, Y., B. Cheang, and A. Lim
2012. Grocery perishables management. *Production and Operations Management*, 21(3):504–517.

Lin, C.-C., S.-C. Shieh, Y.-H. Kao, Y.-T. Chang, and S.-S. Chen
2008. The simulation analysis of push and pull shelf replenishment policies for retail supply chain. In *Machine Learning and Cybernetics, 2008 International Conference on*, volume 7, Pp. 3964–3969. IEEE.

Mantrala, M. K., M. Levy, B. E. Kahn, E. J. Fox, P. Gaidarev, B. Dankworth, and D. Shah
2009. Why is Assortment Planning so Difficult for Retailers? A Framework and Research Agenda. *Journal of Retailing*, 85(1):71–83.

Mckinnon, A. C., D. Mendes, and M. Nababteh
2007. In-store logistics: an analysis of on-shelf availability and stockout responses for three product groups. *International Journal of Logistics Research and Applications*, 10(3):251–268.

Milicevic, N. and A. Grubor
2015. Tthe effect of backroom size on retail product availability-operational and technological solutions. *Amfiteatru Economic*, 17(39):661.

Miller, T. C.
2012. *Hierarchical operations and supply chain planning*. Springer Science & Business Media.

Naish, S. and P. Baker
2004. Materials handling-fulfilling the promises. *Logistics and Transport Focus*, 6(1):18–27.

Park, Y. H. and D. B. Webster
1989. Modelling of three-dimensional warehouse systems. *The International Journal of Production Research*, 27(6):985–1003.

Peterson, C. G.
2000. An evaluation of order picking policies for mail order companies. *Production and operations management*, 9(4):319–335.

Piramuthu, S., S. Wochner, and M. Grunow
2014. Should retail stores also rfid-tag "cheap" items? *European Journal of Operational Research*, 233(1):281–291.

Pires, M., P. Amorim, J. Liz, and J. Pratas
2015. Design of retail backroom storage: A research opportunity? In *Operations Research and Big Data*, Pp. 167–174.

Pliskin, J. S. and D. Dori
1982. Ranking alternative warehouse area assignments: A multiattribute approach. *IIE Transactions*, 14(1):19–26.

Raman, A., N. DeHoratius, and Z. Ton
2001. Execution: The Missing Link in Retail Operations. *California Management Review*, 43(3):136–152.

Reiner, G., C. Teller, and H. Kotzab
2013. Analyzing the Efficient Execution of In-Store Logistics Processes in Grocery Retailing-The Case of Dairy Products. *Production and Operations Management*, 22(4):924–939.

Rosenblatt, M. J. and Y. Roll
1988. Warehouse capacity in a stochastic environment. *The International Journal Of Production Research*, 26(12):1847–1851.

Rouwenhorst, B., B. Reuter, V. Stockrahm, G. van Houtum, R. Mantel, and W. Zijm
2000. Warehouse design and control: Framework and literature review. *European Journal of Operational Research*, 122(3):515–533.

Rowley, J.
2000. The principles of warehouse design. *The Institute of Logistics & Transport, Corby*.

Rushton, A., P. Croucher, and P. Baker
2006. *The handbook of logistics and distribution management: Understanding the supply chain*. Kogan Page Publishers.

Rushton, A., P. Croucher, and P. Baker
2014. *The handbook of logistics and distribution management: Understanding the supply chain*. Kogan Page Publishers.

Schneeweiss, C.
2012. *Distributed decision making*. Springer Science & Business Media.

Schwarz, L. B., S. C. Graves, and W. H. Hausman
1978. Scheduling policies for automatic warehousing systems: simulation results. *AIIE transactions*, 10(3):260–270.

Seidel, S., C. Blanquart, and V. Ehrler
2016. Same–same but different? a comparison of food retail and distribution structures in france and germany. *Case Studies on Transport Policy*, 4(1):29–37.

SONAE
2016. SONAE. https://www.sonae.pt/pt/. [Online; accessed 14-May-2016].

Stadtler, H.
2008. Supply chain management: an overview. In *Supply chain management and advanced planning*, Pp. 9–36. Springer.

Teo, C. P. and J. Shu
2004. Warehouse-Retailer Network Design Problem. *Operations Research*, 52(3):396–408.

Trautrims, A., D. B. Grant, J. Fernie, and T. Harrison
2009. Optimizing on-shelf availability for customer service and profit. *Journal of Business Logistics*, 30(2):231–247.

Van Donselaar, K., T. van Woensel, R. Broekmeulen, and J. Fransoo
2006. Inventory control of perishables in supermarkets. *International Journal of Production Economics*, 104(2):462–472.

Van Zelst, S., K. van Donselaar, T. Van Woensel, R. Broekmeulen, and J. Fransoo
2009. Logistics drivers for shelf stacking in grocery retail stores: Potential for efficiency improvement. *International Journal of Production Economics*, 121(2):620–632.

Voss, C., N. Tsikriktsis, and M. Frohlich
2002. Case research in operations management. *International journal of operations & production management*, 22(2):195–219.

Waller, M. A., A. Heintz Tangari, and B. D. Williams
2008. Case pack quantity's effect on retail market share: An examination of the backroom logistics effect and the store-level fill rate effect. *International Journal of Physical Distribution & Logistics Management*, 38(6):436–451.

Chapter 4

Solving the grocery backroom sizing problem

Maria Pires * · **Ana Camanho** * · **Pedro Amorim** *

Under revision in *International Journal of Production & Economics*, 2017

Abstract The grocery retail environment is more dynamic today than ever and competition keeps intensifying. This scenario requires retailers to adapt and develop innovative approaches to face the current challenges. However in both academia and practice, medium-term fresh thinking concerning backrooms is rare. In this paper, we propose a sales forecasting model as well as two mathematical programming formulations to solve the grocery backroom sizing problem. This problem consists in determining the dimension of each storage department in the backroom area. The first formulation is a bottom-up approach that aims to reduce the backroom life cycle costs by determining the optimum floor space and storage height for each department. The second is a top-down approach based on Data Envelopment Analysis (DEA) that determines the efficient level of storage floor space for each backroom department, based on a comparison with the benchmarks observed among existing stores. We also describe the application of the proposed approaches to a case study of a European retailer. The application of this methodology in the designing process demonstrated a substantial potential for space savings. The decrease in the storage areas is significant (6% for the bottom-up model and 16% for the top-down model).

Keywords Backroom Sizing · Grocery Retail · Strategic Planning · Sales Forecasting

4.1. Introduction

The ongoing transformation of retail is impacting every aspect of its operations, requiring ever greater operational efficiency, namely regarding the optimization of the store scarce resources, such as the store space.

There has been a strong development of modern retail and proximity stores have experienced the strongest growth in number of outlets and floor space. Globally, and between 2014 and 2015, while sales in large supermarkets and hypermarkets were flat or declined slightly (+0.3% and -1%, respectively), sales in convenience stores, hard discounters and drug stores grew more rapidly (+2%, +2% and +1%, respectively) (Nielsen, 2015).

Due to the rise of proximity retailing, the future tendency of the brick-and-mortar channel is to open more convenience stores. However, this type of stores is usually located in

*INESC TEC, Faculdade de Engenharia, Universidade do Porto, Porto, Portugal

urban areas, where space is an expensive resource. Therefore, retailers must correctly design their store space in order to leverage its potential for sales and improve customer satisfaction at a reasonable cost.

In most retail stores, inventory is held in two locations: retail shelves, in the sales area, and in the backroom. In the store sizing process, the sales area design is seen as the priority since it is the space that directly creates value. The sales area size is carefully defined considering in-store traffic patterns, shopping behaviour, and expected sales (Lewison, 1994). In contrast to the selling area, the remaining space is dedicated to the backroom storage, whose design is often neglected both by academics and practitioners (Reiner et al., 2013).

Backroom storage is essential in grocery retail stores for many reasons, described in more detail later in the paper, such as to store merchandise that may not fit on the allocated shelf space, to act as a buffer against strong demand lifts yielded by promotional activity or seasonal peak demand and to leverage other activities, such as e-commerce (Fernie et al., 2010; Mckinnon et al., 2007). Backrooms are also essential to in-store performance. Previous research indicates that backroom operations can account for up to 50% of total costs in a retail supply chain and the backroom is responsible for a major portion of those costs (Sternbeck and Kuhn, 2014). Moreover, researchers have also identified that inadequate backroom organization and planning is a major source of OOS, which negatively impacts the store service level (Gruen and Corsten, 2002).

Currently, the design of the backroom areas is mainly established empirically, based on the perception of similar stores by the architect. Hence, there is considerable room for improvement in this process. In particular, it should use information related with in-store logistics and operations, expected orders' volume of the regular activity as well as seasonal and promotional activity (Pires et al., 2015). Designers should also rely on formal means to assist the design process, rather than just follow ad-hoc procedures.

Backroom sizing is a strategic decision that has great influence on in-store and backroom life cycle costs because once the store is built, it is very unlikely that layout changes will be performed, except in cases of refurbishes, which are rare (Hübner et al., 2013).

The scope of this research involves answering the research question of how to effectively size backroom storage areas, focusing on convenience stores. This involves structuring the backroom sizing requirements (e.g., storage needs for permanent, promotional and seasonal demand) using a forecast model and proposing mathematical models in order to help retailers adjust store storage to their necessities. The application of these models to size retail backrooms is illustrated with a case study of a European retailer.

This problem is of considerable practical significance, by providing innovative quantitative tools to size the backroom storage areas. In addition, our findings have a substantial contribution to the literature, since backroom design has not been addressed by academics.

The reminder of this paper is organized as follows. In the next section, we define the grocery backroom sizing problem faced by retailers and in Section 4.3 we present the case study that collaborated in this research. In Section 4.4 we provide the background of our paper and present a brief literature review on related papers. Furthermore, in Section 4.5 we describe the medium-term sales forecasting methodology as well as the optimization models developed to tackle this problem and in Section 4.6 we discuss the results obtained.

In the last section, the conclusions of the research are presented, as well as future research directions.

4.2. Problem framing

In this section, we aim to define the backroom sizing problem and its challenges. The main goal of the backroom sizing problem is to determine the dimensions of the storage departments required in the backroom. This task if often performed by architects and engineers who size and design the store areas, having as reference existing stores they deem to be similar to that being designed. In this task, designers usually resort to ad hoc database/spreadsheet tools and CAD software. What often happens is that stores reflect the subjectivity and preferences of each designer. With this research we aim to guide retailers while defining the store's backroom areas in a standardized, objective and optimized manner.

In this paper we are tackling a conventional grocery store, in which the backroom core operations are stocking merchandise, acting as a buffer, and preparing fresh products (e.g., meat, fruits, bakery) before they go on sale.

Backroom sizing, as in conventional warehouses, depends on various factors, such as inventory levels, storage units and systems used. However, it is also greatly influenced by the type of store and product assortment.

Before sizing the backroom it is crucial to define the backroom departments, i.e., determining the zones into which the backroom should be divided (e.g., zones for different product groups or temperature regimes). This decision is influenced by several aspects, such as operations requirements, category assortment and expected sales. Depending on these aspects, storage classes can be made, considering the family of products, their demand, and characteristics (e.g., sizes, weights, shapes, temperature regimes and expiration dates). Items are generally organized between departments depending on their class of product. Nevertheless, there is a set of common departments to all types of stores (e.g., room-temperature warehouse). However, the number of required departments depends not only on the range of products stored, but also on the legal constrains of this sector. In practice this implies, for instance, that food and cleaning products cannot be stored together due to the chemicals in the cleaning products.

Besides the backroom departmentalization, the identification of the inventory to store in the backroom plays an important part in backroom sizing, since it indicates the storage capacity needed. It takes into account the shelf space of each product in the sales area, in order to assess if it is enough to store the inventory needed to meet the estimated demand. In this analysis, aspects such as product demand forecast, shelf space, inventory policies, delivery patterns, and shelf refiling and handling costs of different products should be considered. Other important aspect concerns the seasonality of products, which affects storage requirements. In addition to seasonality, promotional campaigns also have great influence in the sales area and the backroom.

Regarding the storage policies quick and efficient service is of critical importance in backrooms. In order to provide great quality of shelf-stacking, employees should be familiarized with the location of products in the backroom. For this reason, the strategy usually chosen is dedicated and class-based storage, which also allows the division of the areas by family of products. However, within each sub-department items can be allocated randomly or by their demand (hybrid storage). Another important issue to consider in backroom operations planning is labor. Store salespeople are often responsible for sales area and backroom activities. Thus, during busy high-traffic periods it can be hard for them to replenish merchandise promptly from the backroom.

When designing a store, the first step consists in deciding the sales area size from an available construction space. The remaining space is then assigned to the backroom. The goal is to use this area in the most efficient way. In order to achieve that, several aspects are considered. Usually in backrooms, items are stored in pallets, boxes or rolling cages, varying with the department. The common material handling systems include palletizers and truck loaders. In terms of storage systems, backrooms are characterized by a low level of automation, making use of labour intensive systems (shelving systems, such as racks). Generally racks can have up to three levels of storage, being the upper ones less accessible and therefore used for products with lower rotation. For this reason, the trade-off between products accessibility and space utilization (floor space versus storage height) should be considered. Another important issue has to do with the construction and maintenance costs. In backroom departments there is a considerable diversity of storage temperatures. The lower the storage temperature (e.g., frozen food), the higher the maintenance costs (e.g., energy). Also, the construction costs depend on several aspects such as the storage systems, storage height, materials utilized and, evidently, the floor space utilized.

4.3. Case study

In order to validate the methodology proposed in this research, real data and insights from an European retail chain was used.

In this chain, grocery stores are divided in three segments: hypermarkets, supermarkets and convenience stores. The first type of stores can be characterized by a total of 40 stores with average sales area of approximately 7.000 m^2, the second type has the greatest number of stores (128) and an average sales area of approximately 2.000 m^2 and the last, with a total of 50 stores, has an average sales area of approximately 1.000 m^2. Convenience stores were the ones showing the highest growth in their number. For all types of stores the backroom storage areas currently occupy nearly 36% of the total area of the store.

In terms of the assortment of products, hypermarkets hold the largest number of SKUs, summing up a total of around 70.000 products from which 42,28% are food products, 9,79% are fresh and bakery products and the remaining are non-food products. Supermarkets sell an average of 40.000 different SKUs from which 61,92% are food products, 13,88% are fresh and bakery and the remaining are non-food goods. Finally, convenience stores hold a total of 25.000 products in average, divided in 71,01% for food products, 19,35% for fresh and bakery products and 9,64% for non-food products. As expected, smaller types of stores hold a smaller assortment of products, which are predominantly food goods. The company works with 6 main commercial directions: grocery, perishables, food and bakery, bazaar, electronics and textiles. The grocery section includes non-perishable food and drinks, beauty care and household cleaning products. The perishables section commercializes products such as meat, fish, fruits, vegetables, dairy foods and beverages and bread. Food and bakery comprises bakery, pastry and take-away food. The bazaar section includes household products and books. The electronics section includes household appliances and, lastly, the textiles section sells footwear and clothes for men, women and children. In the year of 2014 the distribution of employees corresponds to a monthly average of 186 FTEs by hypermarket, 59 by supermarket and 37 by convenience stores. We used the information provided by the company regarding all convenience stores, such as sales and stocks per SKU, products profiling, store characteristics (e.g., location, type of client), and inventory policies. The retailer provided store sales and inventory information for all the 50 stores, during the year of 2015.

In this company, all supply chain planning is performed centrally (e.g., store design, planograms and inventory). Designing a store is a complex process that has many intervening parts. The decision of opening new stores is often the executive committee's responsibility. Then, the planning department performs market studies to predict the characteristics of the store based on available data (e.g., the client profile and competitors). This information allows to decide, for instance, the best location and assortment for the new store. The main responsible for designing and remodeling stores is the space management department. They combine the relevant information and design the store, both the sales and backroom areas. They work together with other departments, such as equipment and construction department, which are responsible for the technical aspects (e.g., refrigeration systems). Designers use spreadsheet tools and CAD software to design the sales area (macro layout), and specific proprietary software to design planograms (micro layout). However, as many other retailers, they still do not have any tools to design backrooms. Currently, this is an ad-hoc and subjective process where designers often use recent and similar stores as a reference to design the new store backroom, without any quantitative support. To evaluate different backroom layouts, designers only look at the construction costs. After having a proposition for the store layout, it is sent for evaluation (for instance, by store managers and audit department) and some iterations may occur until the final layout is achieved.

4.4. Literature review

Backroom sizing problem involves several research areas and it has been overlooked in the literature. The research areas interrelated with this problem are very disperse and concern the conventional warehouse design and operations, grocery retailing, in-store operations, and logistics.

This section reviews the literature on the backroom related topics. We start by presenting the importance of backrooms in the retail SC. Then, we tackle the retail operations topics related to this problem as well as the existing techniques for medium-term retail demand forecast. Lastly, we review the approaches to size conventional warehouses and facilities.

4.4.1 Importance of backrooms in the retail SC

Backrooms are crucial to the retail SC for several reasons. They act as a planned buffer when deliveries are uncertain, lead times are long, deliveries are imperfect, there is excess inventory after shelf replenishment, and for some bulky or fast-moving products (Condea et al., 2012; Eroglu et al., 2013). Furthermore, more products can be stored per unit of floor space in the backroom when compared with the sales floor (Condea et al., 2012; Hübner and Schaal, 2017).

By storing some inventory in the backroom, shelf space is available for displaying a wider product assortment, potentially increasing sales (Eroglu et al., 2013; Reiner et al., 2013). Also, they allow a space apart from customers to perform activities such as in-store picking, breaking-bulk of transportation units to end-user units (Kotzab and Teller, 2005).

Backrooms relieve some of the capacity pressure of DCs by allowing them to (early) transfer stock downstream to the stores (Tompkins, 2014). Moreover, backrooms also permit wider delivery windows, which greatly benefit route planning decisions and therefore, transportation costs. Also, by providing additional storage space, multiple daily deliveries from the DCs to the stores are avoided which also reduces transportation costs (Tompkins, 2014).

Omnichannel opportunities are also leveraged by backrooms. For instance, backrooms provide retailers with an opportunity to consolidate and fulfill online home-delivery and click-and-collect at the store. Home delivery of online ordered groceries is becoming more widespread, and one way to do this is to perform the picking and packing and final distribution from existing stores' (Aastrup and Kotzab, 2010; Kotzab et al., 2016). Lastly, backrooms support the link between the stores and the upstream SC departments, enabling sorting and processing of paperwork activities.

4.4.2 Backroom related topics

Mckinnon et al. (2007) analyzed the store service levels, which are often compromised by poor in-store replenishment. Among the pointed reasons are the organization of the backroom, the high level of promotional activity and product packaging. Case pack sizes are addressed in the literature regarding their influence on in-store operations, store inventory and the backroom (Waller et al., 2008; Wensing et al., 2017; Gruen and Corsten, 2002; Van Zelst et al., 2009; Sternbeck, 2015). For instance, Waller et al. (2008) demonstrate that lower case pack quantities mitigate the backroom logistics effect for slow-moving products. Recently, Caplice and Das (2017) pointed out the three main factors that affect backroom space in the food retail context, which are the pack size, profit margin per item and, lastly, its relative importance to the service, for instance an essential ingredient to a product.

Eroglu et al. (2013) introduced the backroom effect as a consequence of a misalignment between case pack size, shelf space, and reorder point. They also quantify the expected amount of backroom inventory and assess the impact of the backroom effect on the optimal inventory policy and total costs. Their results indicate that ignoring the backroom effect leads to artificially high reorder points and higher total costs.

Kuhn and Sternbeck (2013) examined implications of several mid-term planning issues, such as lead time and time windows, in the stores, transportation and the distribution centers. In this work, the authors state the great influence that store delivery patterns have on the utilization of the backroom and on the number of refilling operations. Furthermore, Hübner and Schaal (2017) addressed the effect of in-store replenishment and backroom on retail shelf-space planning, where the authors conclude that if retailers have the opportunity to use backrooms for intermediate storage, they should leverage them, because backroom space allows for more flexibility in planning showroom shelf-space. Milicevic and Grubor (2015) have analyzed the effect of backroom size on product availability and concluded that in grocery stores, with the increase of backroom size, out-of-shelf (OOS) on a store level decreases while in hypermarkets the opposite was observed, i.e., with the increase of backroom size, OOS increases as well. Therefore, these results opened several issues concerning the differences between smaller and larger stores.

The category assortment/management has also been discussed in the light of backrooms where the storage space constraint was considered (Ramaseshan et al., 2009; Hübner, 2011). Furthermore, Ton and Raman (2010) provided empirical evidence that supports that higher product variety and inventory levels lead to an increase of misplaced products, and, therefore, of OOS and defect rates.

In the topic of online retail, backrooms are also mentioned. Aastrup and Kotzab (2010) stated that home delivery of online ordered groceries is becoming more widespread, and one way to proceed is to do the picking and packing and final distribution from existing store backroom facilities.

Lastly, Radio Frequency Identification (RFID) is also a backroom related topic. One of the major RFID applications described for reducing shelf OOS is to understand how much inventory exists in the backroom and its location. This is a very relevant topic since hidden items are a continuing problem for store stockers (Gruen and Corsten, 2007; Condea et al., 2012).

4.4.3 Medium-term retail demand forecast

Forecasting is common in many fields such as finance, economics, meteorology, energy production, sociology, etc. Amongst numerous existing models, we can group them into judgmental and statistical models (Armstrong, 2001). The first ones are based on exploitation of opinions or intentions of people or experts group whereas statistical models exploit historical data.

Sales forecasting is crucial for many retail operations. Companies often need to rely on sales forecasting systems to deal with the customers' requests in order to anticipate production volumes and to stock up items. However, it is highly complex due to the influence of internal and external environments.

In the last decade, several data mining techniques have raised to assist decision makers who manage large volumes of data. These methods are helpful to find and describe patterns in data sets, such as links or associations between sales and descriptive criteria (numeric or nominal). The techniques are vast and have been applied in several sectors.

Concerning the application of data mining techniques to retail datasets, Luxhøj et al. (1996) developed a hybrid econometric-neural network model for forecasting total monthly sales and applied it to a consumer goods producer company. The model builds upon basic concepts of "filtering" forecasts from sequential modeling stages and then "averaging" the outputs from each stage to produce the aggregate forecast. Alon et al. (2001) compared artificial neural networks and traditional methods, such as multivariate regression. The results indicate that, on average, artificial neural networks are favorable in relation to the more traditional statistical methods. In the work of De Andrés et al. (2005) a comparative study of the performance of a number of classification devices, both parametric (LDA and Logit) and non-parametric (fuzzy-rule-based classifiers) is conducted. Thomassey et al. (2005) proposed a forecasting system applied in the textile market, which is composed of several models and performs forecasts for various horizons and at different sales aggregation levels (mid- and short-term horizons). This system is based on soft computing techniques, such as fuzzy logic, neural networks and evolutionary procedures. Another application of a forecasting system in retail is provided by Thomassey and Fiordaliso (2006) who proposed a forecasting methodology, based on clustering and classification tools (decision trees), to perform mid-term forecasting. Doganis et al. (2006) proposed a method that is a combination of two artificial intelligence techniques and a specially designed genetic algorithm. The methodology is applied successfully to sales data of fresh milk provided by a major manufacturing company of dairy products. Furthermore, Taylor (2007) applied forecasting techniques in daily supermarket sales using exponentially weighted quantile regression. Lastly, Thomassey (2010) proposed enhanced forecasting models, which produce more accurate and more reliable sales forecasts than the one published earlier. These models rely on advanced methods such as fuzzy logic, neural networks and data mining.

4.4.4 Sizing models for standard warehouses

Warehouse sizing is a strategic decision which has important implications on warehouse life cycle costs, such as construction, inventory holding, and in-store operations costs (Speh, 2009). Sizing is much related to the inventory policies, which rely on the forecasting and analysis of demand. This step must be carefully executed because an oversized estimate of space needs could lead to wasted space, while an undersized one may lead to crowded conditions (Pires et al., 2016).

In the literature some authors have examined the problem of determining the warehouse size, for fixed and changeable space scenarios, for a single product which minimizes relevant costs over some planning horizon (White and Francis, 1971). Similar problems of determining fixed and changeable warehouse sizes are also discussed by Hung and Fisk (1984) and Rao and Rao (1998) with different cost formulations. Levy (1974), Goh et al. (2001), and Cormier and Gunn (1996) considered warehouse sizing problems in the case where the warehouse is also responsible for controlling the inventory. Therefore, the cost in their models includes not only the warehouse construction cost, but also inventory holding and replenishment cost. Some authors have also performed a trade-off analysis of allocating space among competing departments. Pliskin and Dori (1982) proposed a method to compare alternative space allocations among different warehouse departments based on multi-attribute value functions. Also, Azadivar (1989) proposes an approach to optimally allocate space between two departments: one is efficient in terms of storage but inefficient in terms of operation, while the other is the opposite. Heragu et al. (2005) have addressed simultaneously the product allocation and functional area size considering a warehouse with several functional areas resorting to an optimization model and a heuristic algorithm. Simulation models were also applied to understand the effects of inventory control policies on total required space capacity and to test various warehouse configurations (e.g., bulk floor storage) (Rosenblatt and Roll, 1988; Macro and Salmi, 2002).

4.4.5 Discussion

In the literature review several research gaps were identified:

1. Despite the vast literature in medium-term sales forecasting, models dealing with multi-products with the diversity of storage requirements that backrooms face (e.g., multi-temperature) while considering and distinguishing promotional and seasonal demand have not been addressed.

2. The backroom sizing problem in retail grocery stores has not yet been addressed in the literature. Therefore, the model proposed by Heragu et al. (2005) is adapted to a grocery retail context by including its particularities, namely the objective of minimizing the backroom life cycle costs, which is influenced by the departments' size. Also, the models for designing conventional warehouses and DCs do not completely adjust to the necessities of backroom storage facilities, such as being robust against an intense promotional activity stress.

3. Vaz et al. (2010) applied benchmarking analysis to determine the optimal sales area for the different departments within each store. In this paper, we aim to analyze the backroom storage areas in retail stores. Therefore, the backroom sizing problem is focused on the optimization of the backroom space allocated to each department, based on a comparison with the best practices observed in other stores considered comparable, taking into account their value of net sales. Thus, it is possible to use information from existent stores to design new stores, which is not common in the warehouse design literature.

4.5. Solution methodology

The purpose of the proposed methodology is to determine the size, in terms of area, of the backroom storage areas. This methodology can be employed in new or existing stores. In new stores it provides a size recommendation for each storage department, which is crucial in the design phase. In the case of existing stores, this methodology can be employed to determine the highest priority stores to remodel, i.e., the stores whose backroom areas are not well adjusted to the storage needs, as well as to provide the size recommendations to adjust the non-suited backroom departments.

The first stage of the methodology, which applies only to new stores, consists of a medium-term forecasting model. This step aims to determine the storage requirements, i.e., number of storage units (e.g., pallets) to store in each backroom department of the store under analysis. The second stage aims to transform/translate the storage requirements into backroom space. At this stage two different approaches were followed alongside. The first is a cost driven approach that aims to minimize the life cycle costs of backrooms. This bottom-up approach determines both the size and storage height of each storage department. The second approach is a top-down approach that determines the space required by each department based on a benchmark analysis of operating stores. A general overview of the methodology is presented in Figure 4.1.

4.5.1 Medium-term forecasting model

Knowing the storage requirements is essential to correctly size the backroom space. Thus, we propose a hybrid forecasting system, inspired in the paper by Thomassey and Fiordaliso (2006), where the authors use clustering and classification tools that perform medium term forecasting applied to the textile market. The methodology that we propose also uses clustering techniques, but instead of decision trees, we use multinomial logistic regression models and we apply it to the grocery retail context. The forecasting model aims to estimate the storage requirements for the store being analyzed, based on data from existing stores. It is important to note that this methodology can only be applied to retailers that already have a considerable sample of stores with sales, i.e., it is not suited for new retailers.

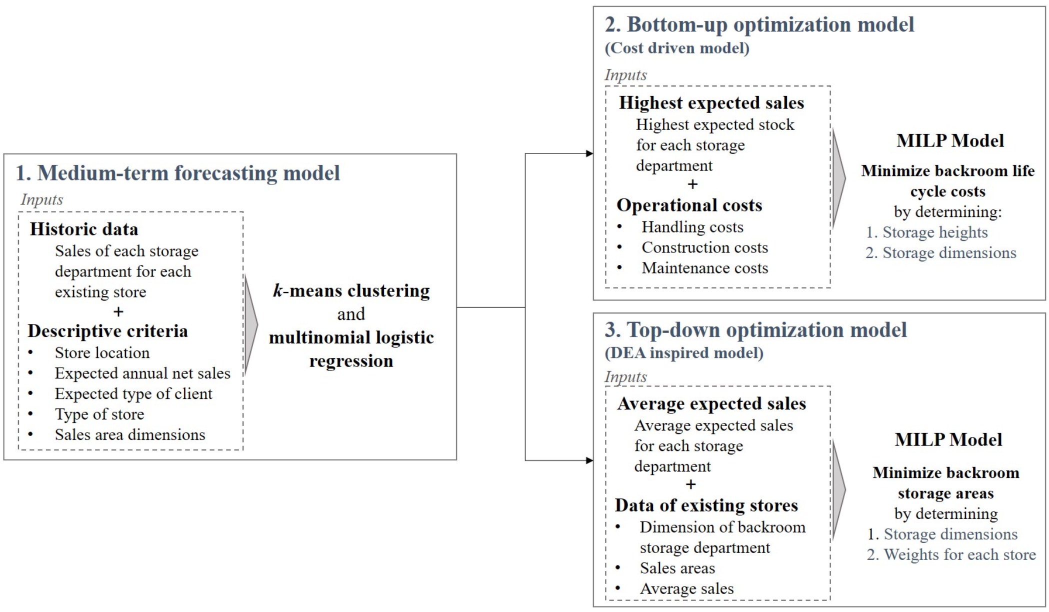

Figure 4.1 – Overview of the solution methodology.

The forecasting model uses some assumptions, namely:

- Product assortment is known.
- The storage systems and units used (e.g., case pack size) in each department are known.
- Presentation stocks, i.e. shelf space, of each store are known.
- Inventory policies, such as delivery policies, are known.
- Historical sales data, including promotions, is known.
- Products flows within the store are known.
- The characteristics of the new store are known.
- Stores have no control over inventory policies.

4.5.1.1 Clustering

The forecasting methodology starts with store clustering, resorting to the *k*-means method.

Since large data sources are usually available regarding the existing stores in a company, it is possible to group stores based on their distribution of sales *per* backroom department. The objective of this phase is to obtain clusters of similar stores in terms of sales profiles in a way such that each cluster has a similar demand pattern.

In order to group similar stores, the global sales of each store are first distributed by backroom storage department, in a way that each department represents a percentage of the store total sales. Therefore, the percentage of sales for each backroom storage department are the variables used for clustering. The *k*-means algorithm achieves exclusive clusters, i.e., each item belongs to only one group, and requires to previously determine the desired number of clusters. Therefore, after normalizing the data, the following step consists on determining the optimal number of clusters (nc^*), which influences the quality of the forecasting model. The clustering procedure, which carries out groups of similar items, enables the forecasting model to reduce noise and complexity, and thus facilitates the next stage of classification (Witten et al., 2016).

4.5.1.2 Multinomial logistic regression

The second stage of the forecasting model aims to assign new stores to existing clusters, based on the known store characteristics. The aim of multinomial logistic regression is to find the best fitting model to describe the relationship between the outcome (dependent or response variable) and a set of independent (predictor or explanatory) variables. For this reason, the multinomial logistic regression technique was selected to carry out understandable links between descriptive store criteria (store characteristics) and the previously computed clusters. Therefore, this regression associates each store (initial design or remodeling) to a cluster according to the known descriptive criteria. These criteria are usually known when opening a new store. Multinomial logistic regression uses a maximum likelihood estimation method and is often employed for analyzing data with categorical outcome variables, in which the log odds of the outcomes are modeled as a linear combination of the predictor variables. Furthermore, this method makes no assumptions on the distribution of the explanatory data. Predictors can be a mix of continuous and categorical variables. The outcome of the model is the probability of an event occurrence (Press and Wilson, 1978).

It is known that parametric models, such as logistic regression, have shown their adequacy for a great number of practical economic classification tasks, such as prediction of financial distress (De Andrés et al., 2005).

The objective of the logistic regression method it to build a model capable of estimating the probability of each store belonging to a certain cluster, based on the store characteristics, i.e, the new store is assigned to the cluster with the highest probability. Once the store is allocated to a cluster, it is possible to infer the expected sales pattern of a new store, based on the sales average of the stores in the same cluster. The expected sales, in euros, are converted to units by using a conversion factor associated to each product category.

4.5.1.3 Backroom inventory estimation

The final stage consists of estimating inventory to be stored in each storage department. The inventory in the store can be obtained by multiplying the expected demand (in units) by the stock turnover, according to the assigned cluster. The inventory stored in the backroom is then the difference between the total inventory and the space assigned to each category in the sales area (shelf storage capacity). Other aspects should be considered, regarding the oscillations in demand, namely the strong promotional activity which differs between categories, and the seasonality of categories along the year.

In grocery stores, permanent stock is generally stored in racks in defined and fixed locations by product class (e.g., rice), while promotional merchandise is usually stored in the ground in order to facilitate handling and the in-store operations. For this reason, the permanent storage space should be calculated for peak sales. On the other hand, since promotional stock is stored on the ground, the various categories in promotion compete for the same space, which requires an aggregated analysis by department of the maximum total space required.

In Figure 4.2 we provide an illustrative example of the forecasting methodology for a new store.

4.5.2 Sizing models

In this section, two approaches to determine the backroom dimensions will be detailed. The first model is a bottom-up approach that aims to reduce the backroom life cycle costs while the second is a top-down approach that performs a benchmark analysis among existing stores. Both these models may be fed by the forecasting methodology previously described and their output serves as a base for further detailed backroom sizing.

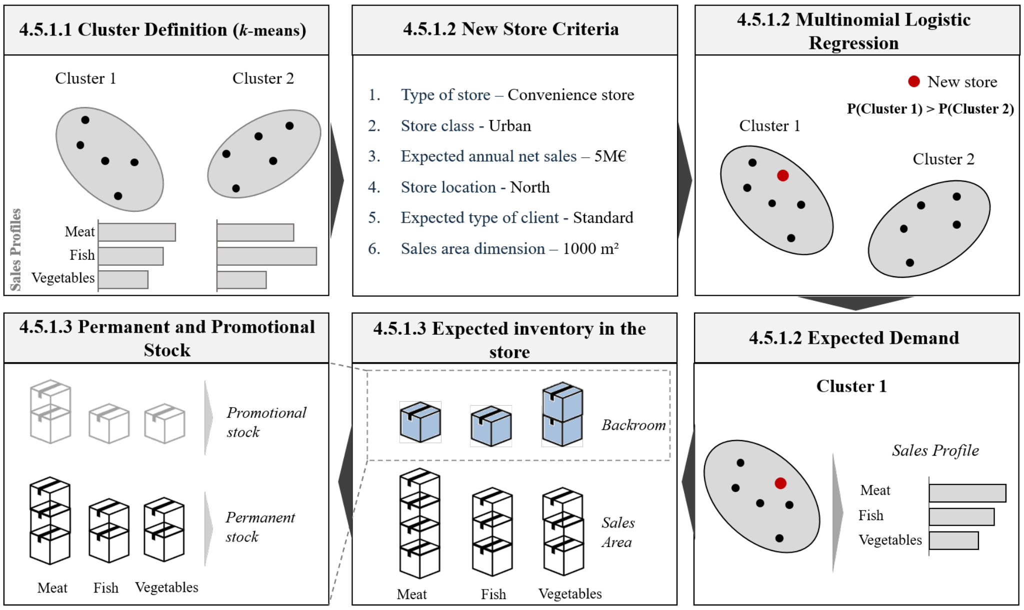

Figure 4.2 – Illustrative example of the forecasting methodology.

4.5.2.1 Bottom-up approach

The mixed-integer linear programming (MILP) model presented is a bottom-up approach that aims to determine the size and storage height of each backroom department by minimizing the backroom life cycle costs. This model requires as input information the highest expected storage needs (i.e. stock) for each backroom storage department as well as the construction and operational costs for each type of storage (e.g., frozen, chilled or ambient temperature). Since this model does not require the existence of historical information, it can also be referred as a single-store approach that can be used by new retailers.

This model is inspired in the work of Heragu et al. (2005) who developed a model to determine the functional area sizes for a warehouse. However, this model was developed for conventional warehouses with three departments (reserve, forward and cross-docking areas). Furthermore, the goal of this model is to minimize the total material handling costs whereas in the backroom sizing problem the goal is to minimize the total backroom life cycle costs. Since the existent models in the literature are not applied to this context and, therefore, do not provide accurate solutions for backroom sizing, we have adapted the model proposed by Heragu et al. (2005) to the backroom context by incorporating its particularities, such as the consideration of different costs, promotional areas within each department and also deciding the storage height for each department.

This model assumes the following:

- Inventory to be stored in each department is known (determined in the forecasting stage).
- Available construction space for the backroom is known.

- Shelf space is known. Then, based on the expected demand and the shelf space, the picking frequencies in each department are determined.
- Costs of handling products, maintaining the backroom departments and constructing the infrastructure are given.
- Storage policies and material-handling equipment are known (these affect the unit handling and storage costs).

Indexes, parameters and variables

The appropriate nomenclature used in the models is herein presented.

Index sets:

D - Set of backroom departments.
L - Set of storage levels.
T - Interval of time considered (period of an operating backroom, until it is renewed).

Parameters:

H_{dl} - Cost of handling products in department d in storage level l .
F_d - Picking frequency in department d per day.*
r - Discount rate.
CC_d - Cost of constructing a unit of space in department d.
TS - Available construction area for the backroom.
E_{dl} - Cost of an equipment (i.e. storage systems, such as racks) for department d with l levels.
SUP_d - Storage units to use in department d to satisfy promotional demand.
$ASUR_{dl}$ - Blocks of pallets required (on the floor), in department d if using l levels.
M_d - Maintenance cost of department d.
A_d - Area occupied by the storage units used in department d.
MS_d - Lower bound (minimum required space, in percentage) for department d.

Decision Variables:

X_{dl} - Binary variable takes value of 1 if department d has l storage levels, 0 otherwise.
S_d - Proportion of total backroom space assigned to department d.

*Picking frequency in department d per day is determined by the maximum ratio between $\frac{demand}{presentationstock}$ of all the categories stored in department d

Objective Function

$$\text{Minimize} \sum_{d}\sum_{l}\sum_{t}\frac{H_{dl}\times F_d\times X_{dl}}{(1+r)^t}+\sum_{d}\frac{M_d\times TS\times S_d}{(1+r)^t}+\sum_{d}CC_d\times TS\times S_d$$
$$+\sum_{d}\sum_{l}E_{dl}\times ASUR_{dl}\times X_{dl} \quad (4.1)$$

Equation 4.1 defines the objective function. All costs are expressed in the time period when the decision is made, i.e., if it is a cost that occurs repeatedly over time, it has a factor r associated, whereas if it only occurs once (as is the case of the construction cost), it is only considered once in the objective function. The main goal of this model is to minimize the backroom life cycle costs that are composed of four different costs: handling costs, equipment costs, construction costs and maintenance costs. The handling costs (first parcel of the objective function) represent the costs of picking products in the backroom, namely the time required to perform this task. These costs depend on the accessibility of the products, necessity of using specialized handling equipment, picking frequency of a certain category of products, among others. The higher the storage height, the greater the handling costs. The maintenance costs (second parcel of the objective function) depend on the floor space and type of products stored. These costs include insurance, energy, cleaning services and occasional repairs. These costs are dependent on the space occupied by each department.

Lastly, the construction and equipment costs are also considered. This costs occur only once, when the store structures are being built and the equipment acquired. Despite not being operational costs as the previous, these are very relevant in the ownership perspective, considering that the payback period of these stores can be very high. These costs depend on the floor space, storage height, and the type of products stored which indicate the width required. At this point it is important to notice that usually only regular stock is stored in racks. Promotional stock is stored on the floor in order to be more accessible.

Constraints

$$\sum_{l}X_{dl}\times(ASUR_{dl}+SUP_d)\times A_d\leq S_d\times TS, \forall d \quad (4.2)$$

$$\sum_{l}X_{dl}=1, \forall d \quad (4.3)$$

$$\sum_{d}S_d\leq 1 \quad (4.4)$$

$$S_d\geqslant MS_d, \forall d \quad (4.5)$$

$$X_{dl} \in \{0,1\}, \forall d,l \tag{4.6}$$

Equation 4.2 ensures that the size of each department is defined in order to accommodate the dynamic (promotional campaigns or seasonal demand) and current/regular demand, depending on the storage height defined (X_{dl}) and the storage units used (pallets, boxes, etc.).

Equation 4.3 attributes only one height to each department, determining that the storage height is homogeneous among the same department.

Equation 4.4 ensures that the total space required for storage must be less or equal to the total available construction space for the backroom.

Equations 4.5 and 4.6 define the domain of the decision variables, in which a minimum area for each department is guaranteed.

4.5.2.2 Top-down approach

DEA has been used in several studies concerning performance assessment in a variety of settings and contexts, such as health, education and banking (Charnes et al., 2013).

Nevertheless, the number of studies focusing specifically on the store level is quite limited and the backroom sizing problem has not yet been addressed.

The top-down model aims to determine the optimal storage dimensions based on direct comparisons with peers (stores considered efficient), whose linear combination define the best-practices that should be considered for estimating the size of the department under analysis. In this model, we are looking for the optimal size for each backroom department of a new store based on the design characteristics and attributes of the existing stores.

As opposite to the previous approach to size backroom storage departments, this approach requires the existence of historical data (e.g., backroom and sales area dimension) for existing stores. Thus, this is a multi-store data approach, suitable for well-established retailers.

This model assumes the following:

- Characteristics of the new store are known, such as sales, available construction area and sales area storage capacity.
- The new store being designed cannot be more efficient that the existing stores. This means that the optimal standards are defined based on what was actually observed in the retail chain. The distinction between efficient and inefficient levels of operation is determined by the optimization model when constructing the efficient frontier enveloping the data corresponding to the operating data (inputs and outputs) of each store.

Indexes, parameters and variables

The appropriate nomenclature used in the models is herein presented.

Index Sets:

D - Set of backroom departments.
J - Set of stores.

Parameters:

S_{dj} - Dimension of department d in store j.
$Sales_{dj}$ - Sales of department d in store j.
$Sales_{d0}$ - Sales of department d of the store under analysis.
$Costs_j$ - Overall backroom costs (considering construction and maintenance costs) of store j .
$Costs_0$ - Overall backroom budget costs of the store under analysis.
TS_0 - Total available construction space for the backroom for the store under analysis.
PS_{dj} - Presentation stock of the products belonging to department d in the sales area of the store j .
PS_{d0} - Presentation stock (storage capacity in the sales area) of the store being sized.
MS_d - Lower bound (minimum required space) for department d.

Decision Variables:

S_{d0} - Space assigned to department d in the store under analysis.

λ_j - Variable that defines the contribution of each peer (efficient store) to the optimal value proposed by the model for the backroom space to be assigned to the store under assessment.

Objective Function

$$\text{Minimize} \sum_d S_{d0} \tag{4.7}$$

The objective function is described by Equation 4.7. The model aims to minimize the space required for each department by a comparison with a point on the production frontier that corresponds to a linear combination of the efficient stores. Note that one linear programming model must be run for each store under assessment.

Constraints

$$Sales_{d0} \leq \sum_j \lambda_j \times Sales_{dj}, \forall d \tag{4.8}$$

$$S_{d0} \geq \sum_j \lambda_j \times S_{dj}, \forall d \tag{4.9}$$

$$Costs_0 \geq \sum_j \lambda_j \times Costs_j \tag{4.10}$$

$$PS_{d0} \geq \sum_j \lambda_j \times PS_{dj}, \forall d \tag{4.11}$$

$$\sum_d S_{d0} \leq TS_0 \tag{4.12}$$

$$S_{d0} \geq MS_d, \forall d \tag{4.13}$$

$$\lambda_j \geq 0, \forall j \tag{4.14}$$

The production frontier corresponds to piece-wise linear segments connecting efficient stores in the sample. The variables λ_j are the coefficients used in the construction of this linear combination. The targets for each department correspond to a point on the production frontier.

Equation 4.8 certifies that the linear combination of the peers (corresponding to the efficient stores identified by the optimization model) must have the same or higher sales than the store under analysis. Equation 4.9 defines that the dimension of the department being sized (S_{d0}) cannot be smaller than the linear combination of the efficient stores, i.e., the stores that define the production frontier. The same happens with Equation 4.10, which implies that the overall costs in the new store cannot be smaller than the one observed in the existing stores. Equation 4.11 imposes that the comparison only occurs between stores with the same, or smaller, storage space in the sales area (presentation stock). Otherwise, we could be considering a store more efficient than other because it had similar sales with less backroom area when actually it had more space assigned in the sales area. Moreover, the sum of all the department areas cannot be bigger than the available construction area assigned for the backroom (Equation 4.12). Lastly, Equations 4.13 and 4.14 define the domain of the decision variables, in which a minimum area for each department is guaranteed.

4.5.2.3 Models comparison

The bottom-up model aims to minimize the backroom life cycle costs. This model determines the floor space and storage height for a given storage requirement (inventory to store). It considers the trade-off between less space (lower construction and maintenance costs) and higher storage height (higher handling and equipment costs) in order to find an optimal solution. Because this model does not use any design information of the existing stores, it is impartial to the designer's judgments. Nonetheless, it requires several delicate information, such as construction costs, that is data generally very hard to obtain.

On the other hand, the top-down model is an empirical method that requires few assumptions. It has the advantage of not requiring complex data, namely detailed costs, such as handling costs, which are generally very difficult to acquire in practice. Since this methodology is based on a benchmark analysis, it requires the existence of a reasonable sample of stores to compare (multi-store retailers). The bottom-up approach, however, does not have this requisite and can be used by new retailers.

The DEA-inspired model has the objective of minimizing the size of each department for a new store by performing a benchmark analysis among the existent comparable stores. This allows to find the outlets that, for each department, with similar outputs (sales) were able to use less inputs (backroom storage space, presentation stock and costs). Therefore, the required data consists in design information of existing stores which could be easily obtained. However, this approach has the disadvantage that if the stores in the sample are poorly designed, the model results will lead to targets that can be further improved. Note that the empirical nature of DEA means that the reference for the specification of targets is not a "theoretical" maximum, but what was actually observed in the other stores of the retail chain. For that reason, the sample of stores used should be carefully defined such that appropriate references are included in the sample, including all relevant stores considered comparable and removing outliers.

4.6. Computational experiments

In this section the computational results for each model will be presented. This section starts with the results obtained with the forecasting and sizing models. The validation methodology applied is also described.

The retailer provided a complete and granular dataset concerning all of its 50 convenience stores during 2015. These data include daily information about transactions and inventory levels for each of the categories available in the stores. It also includes information about store attributes (e.g., store location and type of clients). Moreover, it comprises several costs, such as construction and handling costs. Table 4.1 describes all of the variables that are included in the dataset. Due to confidentiality reasons we are not able to disclose further information.

4.6.1 Forecasting model results

4.6.1.1 Clustering results

To group stores into clusters, we used the sales related to each backroom department. To define the appropriate number of clusters (nc^*), we analyzed the influence of this parameter in within groups sum of squares. This value stabilized at $nc^* = 6$, as can be verified in Figure 4.3. Theoretically, the suitable maximum number of clusters can be estimated as

Table 4.1 – Description of the real data used in the computational experiments.

Data	**Data description**
Sales	Daily sales (in euros and units) for each product category and store during the time period considered
Inventory	Daily inventory for each category and store during the time period considered
Costs	Construction, equipment, maintenance and handling costs verified in operating stores
Store dimensions	Dimensions of both the sales area and backroom departments (e.g., ambient storage, frozen chamber.)
Store characteristics	Characteristics of each store, such as expected annual net sales, store location and type of client

the square root of the sample size ($\sqrt{50}$) which results in a $nc^* \approx 7$ (Thomassey, 2010). Thus, the sales profile of the 50 stores can be summarized by the 6 cluster centres.

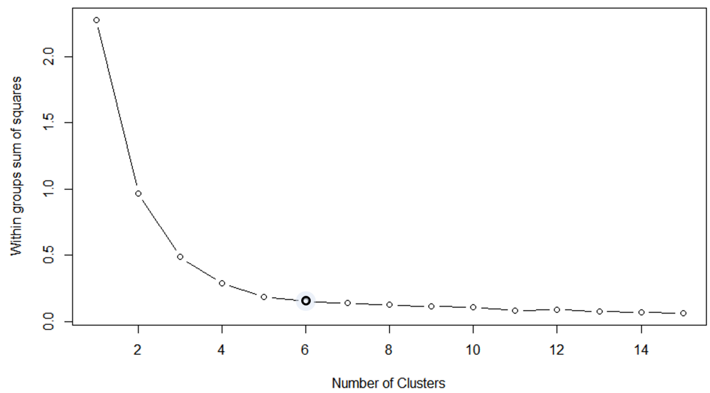

Figure 4.3 – Plot of the within groups sum of squares by number of clusters.

Table 4.2 shows the number of stores included in each cluster, which ranges from 4 to 13.

From the clustering analysis it is possible to infer interesting insights regarding the purchase and consumption habits. In Appendix A we detail the cluster centers for the 6 store groups found. For instance, clients from stores in cluster 3 show preference for fresh products, such as fruits and vegetables, meat and fish. On the other hand, they show very low preference for ambient products. This store segmentation is a crucial starting point towards inferring the buying preferences for a new store without sales historical data.

Table 4.2 – Number of stores in each cluster.

Cluster No.	Stores
1	12
2	9
3	13
4	7
5	5
6	4

4.6.1.2 Multinomial logistic regression results

The logistic regression allows to predict a sales profile (cluster) of a new store based on its characteristics. The store descriptors (independent variables) used to characterize each store are detailed in Table 4.3 and consist on a mix of continuous and categorical variables.

- Expected annual net sales - Generally the marketing department is able to project annual expected sales for new stores.
- Store location - Depending on the store location, consumption habits and patterns vary.
- Sales area dimension - When a store is being projected, a sales area dimension (in square meters) is defined *a priori*.
- Expected type of client - The marketing department is able to estimate the type of client that will shop at the store (standard, economic or quality) based on existing nearby stores.
- Store class - Stores can be located in rural or urban areas. The main difference between the two is that rural stores offer a wider range of non-food products, which impact the backroom space requirements.

Before the models were built the variables were tested, concerning correlation, covariance and collinearity. For instance, the variable *Cafeteria*, which indicates if the store offers cafeteria services (similar to a coffee shop), is collinear with the predictor variable *Sales Area*. This happens because only bigger stores provide this service. Therefore, the variable *Cafeteria* was removed from the model. Furthermore, the significance of all variables was tested using the Wald test, which evaluates the significance of the relation between the independent variable and the outcome within the logistic model therefore. If the Wald test is not significant, the independent variable should be discarded from the model. The aim of this model is to estimate the probability of a store belonging to a certain cluster, c. The model consists in a set of 5 equations, each of them providing a probability of a store belonging to a cluster. Table 4.3 presents the coefficients of the model, except for cluster 1 which is considered as the base, i.e., the probability of a store being assigned to cluster 1 ($c = 1$) is $1 - \sum_{c=2}^{6} p(c)$. Each row corresponds to a model equation. For instance,

Table 4.3 – Multinomial logistic model coefficients.

Cluster	(Intercept)	Net Sales	Loc: South	Sales Area	Client: Quality	Client: Standard	Store: Urban
2	-791.05	4.54e-04	-257.27	-0.96	66.29	-282.50	-348.76
3	532.85	1.49e-04	-55.91	-0.40	80.44	-181.22	-344.01
4	773.49	8.80e-05	-47.32	-0.40	43.45	-211.25	-329.81
5	-784.20	3.64e-04	-239.98	-0.50	244.84	-83.93	-208.49
6	-223.15	2.55e-04	-79.91	-0.27	74.34	-247.85	-172.60

Note: In terms of store location (Loc), *South* is considered the base/reference location. In terms of client type (Client), *Quality* and *Standard* are the references. Lastly, *Urban* stores are the reference for store class (Store).

Table 4.4 – Multinomial logistic model prediction results.

Cluster	1	2	3	4	5	6
1	4	0	0	1	0	1
2	0	12	0	0	0	0
3	0	0	7	0	0	0
4	1	0	0	10	0	0
5	0	0	0	0	7	0
6	0	0	0	0	0	7

the first row is comparing $Cluster = 2$ to the baseline $Cluster = 1$ and the second row is comparing $Cluster = 3$ to the baseline $Cluster = 1$. The store is then assigned to the cluster with highest probability.

The multinomial logistic model showed a proportion of correct cases of 94%, with only three misclassified stores, as showed in Table 4.4. Regarding the importance of the independent variables, Table 4.5 shows that they are all significant in at least one cluster ($p = 0,02$), which demonstrates their importance in store classification, i.e., in assigning a store to the correct cluster.

Table 4.5 – p-values for each predictor.

Store characteristic	2	3	4	5	6
Net sales	0.128	0.178	0.020	0.001	0.494
Loc: South	0.324	0.006	0.219	0.032	0.231
Sales Area	0.043	0.182	0.139	0.000	0.022
Client: Quality	0.279	0.094	0.030	0.001	0.206
Client: Standard	0.716	0.016	0.011	0.000	0.000
Store: Urban	0.042	0.349	0.493	0.001	0.160

4.6.1.3 Overall forecast model results

In order to validate the results obtained with the forecasting methodology, the projected sales (in euros and units) and projected stocks, were compared with the real data for the year of 2015. However, since the partition of the backroom space is not homogeneous/uniform, only the common departments to all stores were considered.

The average deviations obtained for each department using this methodology are exhibited in Table 4.6. As it is possible to confirm, the errors obtained are low, proving the effectiveness and validity of the proposed approach.

Table 4.6 – Average deviations for the 8 analyzed storage departments.

Department	Sales	Quantities	Stock
Ambient Storage	-0,3%	-0,3%	-0,1%
Bakery	1,9%	0,2%	6,2%
Dairy	-1,4%	-3,8%	-3,1%
Delicatessen	-0,2%	-0,3%	1,1%
Fresh Fish	-0,6%	1,7%	3,4%
Frozen Bakery	-0,2%	12,1%	11,6%
Frozen Food	-1,1%	-1,7%	-0,6%
Meat	-1,6%	-1,8%	3,1%

4.6.2 Sizing models results

4.6.2.1 Validation methodology

To validate the results obtained by the sizing models we have conducted a survey that was sent to the managers of the existing convenience stores where they were asked to give their opinion on the actual backroom space. Answers were discretized in excess space, lack of space and sufficient space. Thus, we intend to find out if the current dimensions are the most appropriate. This way, we were able to confirm that the dimensions and storage heights suggested by the models are meeting the real needs of stores. However, it should not be neglected that different employees may have different interpretations and opinions regarding this topic. Moreover, we have defined an upper limit to the backroom space in the models according to the available construction space, defined by the company. Table 4.7 presents a summary of the answers obtained by the stores and considering all the departments.

Table 4.7 – Survey responses to each pair store-department.

Answers	Response	Percentage
Sufficient space	155	60,5%
Lack of space	99	38,7%
Excess space	2	0,8%

The analysis shows that the success rate of the ad-hoc approach used by the company is approximately 61%. It also shows that stores rarely consider having excess storage space (only 2 cases and both referring to ambient storage). The proposed model was validated in 50 stores.

In order to interpret the model performance, the results obtained were compared with the actual/real dimensions of the stores as well as with the answers provided by the survey sent to stores. The rules used to assess the model are the following:

(1) If the survey answer is “Sufficient space" it is assumed a correct result if the model shows an absolute deviation from the real dimensions up to 20%.

(2) If the survey answer is “Lack of space" it is assumed a correct result if the storage dimension proposed by the model is greater than the real dimension in at least 20%.

(3) If the survey answer is “Excess of space" it is assumed a correct result if the storage dimension proposed by the model is lower than the existing dimension in at least 20%.

4.6.2.2 Bottom-up approach results

The first model is a bottom-up approach that aims to minimize the backroom life cycle costs.

The model showed a success rate of 69%. In Table 4.8 are the deviations obtained when the conditions mentioned above are not verified (NOK cases, i.e., cases (2) and (3)).

Table 4.8 – Average deviation (in m^2) for inaccurate cases in the bottom-up model.

Backroom department	Deviation for NOK cases (m^2)
Ambient Storage	-10,98
Bakery	-4,68
Dairy	-2,70
Delicatessen	6,96
Fresh Fish	-3,32
Frozen Bakery	-1,72
Frozen Food	2,09
Meat	1,08

As it can be observed the optimization model generally recommends inferior areas to the ones implemented in stores. The *NOK* cases were verified when store managers consider the storage space sufficient and the model indicates inferior dimensions.

Sensitivity analysis

So far, our analysis was limited to a base case that was defined by a number of model parameters assumed to be constant. However, the results obtained are (highly) correlated with the expected demand given by the forecasting model, i.e. with the storage units to

Table 4.9 – Sensitivity analysis results for each backroom department.

Department	S1	S3
Ambient Storage	-3,3%	3,2%
Codfish	-0,3%	0,2%
Delicatessen	-6,2%	5,9%
Frozen	-7,9%	7,7%
Fruits and Vegetables	-10,9%	6,4%
Dairy	-2,6%	3,9%
Frozen Bakery	-8,8%	14,0%
Bakery	-2,0%	2,6%
Fresh Fish	-3,1%	12,2%
Meat	-2,3%	2,2%

keep in the backroom. For this reason, this section investigates the impact of changes in the expected demand.

In order to perform a sensitivity analysis we compiled two sets of parameters that correspond to two distinct scenarios: S1 - lower limit, given by the cluster center minus the average distance between the stores of each cluster and the cluster center, d_{sc}, S2 - cluster center, given by the average sales (in %) of each cluster, and S3 - upper limit, given by the cluster center plus the average distance between stores the cluster center, as illustrated in Figure 4.4. Thus, S3 represents the scenario with the highest sales (conservative scenario) and S1 is the scenario with the lowest sales. This analysis is performed for all the stores, assigned to one of the six clusters.

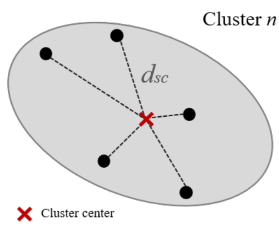

Figure 4.4 – Methodology used to define the intervals in the model parameters.

The influence of changing the expected demand parameters have an influence ranging from -4,7% to +5,8% in the required backroom space. Considering that backrooms represent an average percentage of 30% of grocery stores, which in convenience stores is equivalent to around 500 m^2, these deviations represent approximately -24 m^2 to +29 m^2 of the total backroom area.

Table 4.9 shows the impact of demand alterations on the storage departments areas. If retailers are unsure of the demand and chose a more conservative scenario, they should opt for scenario 3.

The departments with the highest deviations are the delicatessen, frozen food, fruits &

Table 4.10 – Average deviation (in m^2) for inaccurate cases in the top-down model.

Backroom department	Deviation for NOK cases (m^2)
Ambient Storage	-70,10
Bakery	-10,50
Dairy	-5,55
Delicatessen	-4,22
Fresh Fish	-6,65
Frozen Bakery	-7,29
Frozen Food	-8,50
Meat	-9,37

vegetables and frozen bakery. For these departments, more conservative approaches should be employed in order to avoid lack or excess of space.

4.6.2.3 Top-down model results

The second proposed approach is a DEA inspired model that provides dimensions for the backroom storage departments based on a benchmark analysis using existing stores. The objective is to occupy the minimum space possible with backroom areas.

The model showed a success rate of 74%. In Table 4.10 are the deviations obtained when the conditions described in the previous section are not verified. As opposed to the bottom-up model, the *NOK* cases occur when the survey responses indicate insufficient storage space and the model recommends similar or even lower areas than those observed in stores.

The stores more frequently used for benchmarking, i.e. those with the best practices, are often urban stores, that are generally smaller stores. Another interesting conclusion is that the peers (efficient stores) were the ones with the highest proportion of Full Time Equivalent (FTE) *per* store unit of area (approximately 0.1 FTE/m^2). This is very interesting because FTEs highly impact in-store operations and service levels. Lastly, rented stores/spaces are less efficient than stores built from scratch.

4.6.2.4 Overall sizing models results

The mean absolute percentage error (MAPE) results obtained for the two models are presented in Figures 4.5 and 4.6. The values in the graphics are related to the differences between the results obtained from the models and the real areas in stores.

In both models, larger differences are observed in the ambient storage, fresh fish and frozen departments. This means that these are the departments in which the higher disparity between the results from the models and the real areas are observed. Thus, these are the departments where we can expect better improvements regarding store design.

Furthermore, it is important to note that both models point in the same direction, indicating that these areas are not adequate to the real needs of the stores, which is supported by the survey results, where the areas with the highest dissatisfaction rates are the ambient storage, frozen bakery and frozen food.

To conclude, both models lead to less backroom areas. On the one hand, in the 61% of the cases where stores consider having appropriate storage areas, sizing models provide similar or lightly inferior areas. On the other, in the remaining 39% of cases where stores consider insufficient backroom areas, models converge to similar or superior areas.

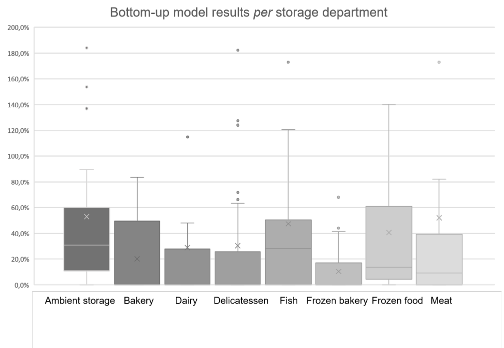

Figure 4.5 – Bottom-up model results.

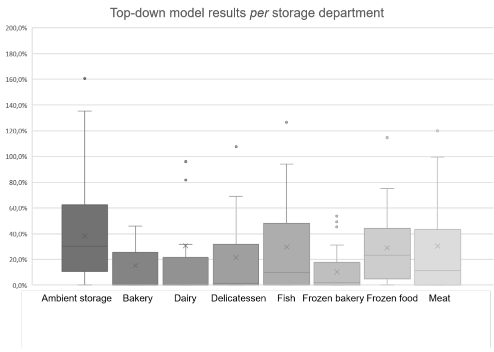

Figure 4.6 – Top-down model results.

4.7. Conclusions and future research

In this paper, we have focused on the backroom sizing problem to which little attention has been paid so far by both academics and practitioners. We propose a forecast model and two alternative optimization models to solve the backroom sizing problem. The methodology was tested on 50 convenience stores, using real data from an European retailer. The forecasting model is based on a clustering technique (k-means algorithm) and multinomial logistic regressions. This methodology is useful to estimate sales profiles of new stores for which there is no historical sales data. The clustering procedure groups similar stores in terms of sales profiles. The logistic regression links up descriptive criteria of historical data with store clusters. These methodology has demonstrated to be effective to find and describe patterns in data to build a prediction. The average deviations obtained were -0,4% for net sales and 2,7% for stocks. Furthermore, two optimization models were proposed. The first is a bottom-up approach which results in the dimensions and storage heights for each backroom department by considering the highest storage requirements and by minimizing the backroom life cycle costs. The second is a DEA inspired model that aims to reduce the total backroom space by performing a benchmark analysis among existing stores.

Both models were tested and validated by comparing the obtained results with the responses from a survey sent to store managers concerning backroom areas.

The survey allowed concluding that the ad-hoc procedures conducted by the company to size the backroom areas could be improved since the percentage of cases where the backroom space was sufficient is 60%. The bottom-up and top-down models showed performance levels of 69% and 74%, respectively.

Therefore, this methodology allows an overall increase of the accuracy of long-term forecasting as well as better adjusted storage areas.

There are several interesting future research goals, such as analyzing the trade-off between performing more frequent deliveries to stores and having more backroom space in order to know what would be more profitable when looking at the overall supply chain. Also, it would be interesting to analyze the backroom and sales areas (shelf space) dimensions jointly. By integrating these decisions the total store design could be optimized, instead of optimizing the two separately. This way, it would be possible to evaluate if some of the backroom departments could be reduced, or even excluded, if the assigned space in the sales area was increased. Furthermore, it would be a very fruitful future work to analyze the interaction among logistic parameters, such as the case pack size and lead times in the backroom dimensions, as well as the impact of departments size on OOS. Studying alternative storage systems could also contribute to more efficient areas and in-store operations. Finally, future work may include replicating this methodology in other store types and retailers, namely electronics retail.

4.8. Acknowledgements

This work is financed by the North Portugal Regional Operational Programme (NORTE 2020), under the PORTUGAL 2020 Partnership Agreement, and through the European Regional Development Fund (ERDF), within the project «NORTE-01-0145-FEDER-000020».

Bibliography

Aastrup, J. and H. Kotzab
2010. Forty years of out-of-stock research and shelves are still empty. *The International Review of Retail, Distribution and Consumer Research*, 20(1):147–164.

Alon, I., M. Qi, and R. J. Sadowski
2001. Forecasting aggregate retail sales:: a comparison of artificial neural networks and traditional methods. *Journal of Retailing and Consumer Services*, 8(3):147–156.

Armstrong, J. S.
2001. *Principles of forecasting: a handbook for researchers and practitioners*, volume 30. Springer Science & Business Media.

Azadivar, F.
1989. Optimum allocation of resources between the random access and rack storage spaces in an automated warehousing system. *The International Journal of Production Research*, 27(1):119–131.

Caplice, C. and L. Das
2017. How back-of-mind backrooms rob retailers of profits. Technical report, Supply Chain Quarterly.

Charnes, A., W. W. Cooper, A. Y. Lewin, and L. M. Seiford
2013. *Data envelopment analysis: Theory, methodology, and applications*. Springer Science & Business Media.

Condea, C., F. Thiesse, and E. Fleisch
2012. Rfid-enabled shelf replenishment with backroom monitoring in retail stores. *Decision Support Systems*, 52(4):839–849.

Cormier, G. and E. A. Gunn
1996. On coordinating warehouse sizing, leasing and inventory policy. *IIE transactions*, 28(2):149–154.

De Andrés, J., M. Landajo, and P. Lorca
2005. Forecasting business profitability by using classification techniques: A comparative analysis based on a spanish case. *European Journal of Operational Research*, 167(2):518–542.

Doganis, P., A. Alexandridis, P. Patrinos, and H. Sarimveis
2006. Time series sales forecasting for short shelf-life food products based on artificial neural networks and evolutionary computing. *Journal of Food Engineering*, 75(2):196–204.

Eroglu, C., B. D. Williams, and M. A. Waller
2013. The Backroom Effect in Retail Operations. *Production and Operations Management*, 22(4):915–923.

Fernie, J., L. Sparks, and A. McKinnon
2010. Retail logistics in the UK: past, present and future. *International Journal of Retail Distribution Management*, 38(11/12):894–914.

Goh, M., O. Jihong, and T. Chung-Piaw
2001. Warehouse sizing to minimize inventory and storage costs. *Naval Research Logistics (NRL)*, 48(4):299–312.

Gruen, T. and D. Corsten
2002. Rising to the challenge of out-of-stocks. *ECR Journal*, 2(2):45–58.

Gruen, T. W. and D. S. Corsten
2007. A comprehensive guide to retail out-of-stock reduction in the fast-moving consumer goods industry.

Heragu, S. S., L. Du, R. J. Mantel, and P. C. Schuur
2005. Mathematical model for warehouse design and product allocation. *International Journal of Production Research*, 43(2):327–338.

Hübner, A.
2011. *Retail category management: decision support systems for assortment, shelf space, inventory and price planning*, volume 656. Springer Science & Business Media.

Hübner, A. and K. Schaal
2017. Effect of replenishment and backroom on retail shelf-space planning. *Business Research*, Pp. 1–34.

Hübner, A. H., H. Kuhn, and M. G. Sternbeck
2013. Demand and supply chain planning in grocery retail: an operations planning framework. *International Journal of Retail Distribution Management*, 41(7):512–530.

Hung, M. and J. C. Fisk
1984. Economic sizing of warehouses: A linear programming approach. *Computers & Operations Research*, 11(1):13–18.

Kotzab, H. and C. Teller
2005. Development and empirical test of a grocery retail instore logistics model. *British Food Journal*, 107(8):594–605.

Kotzab, X. B., H. Christoph Teller, A. Hübner, H. Kuhn, and J. Wollenburg
2016. Last mile fulfilment and distribution in omni-channel grocery retailing: a strategic planning framework. *International Journal of Retail Distribution Management*, 44(3):228–247.

Kuhn, H. and M. G. Sternbeck
2013. Integrative retail logistics: an exploratory study. *Operations Management Research*, 6(1-2):2–18.

Levy, J.
1974. The optimal size of a storage facility. *Naval Research Logistics Quarterly*, 21(2):319–326.

Lewison, D. M.
1994. Retailing (5” ed).

Luxhøj, J. T., J. O. Riis, and B. Stensballe
1996. A hybrid econometric—neural network modeling approach for sales forecasting. *International Journal of Production Economics*, 43(2):175–192.

Macro, J. G. and R. E. Salmi
2002. Warehousing and inventory management: a simulation tool to determine warehouse efficiencies and storage allocations. In *Proceedings of the 34th conference on Winter simulation: exploring new frontiers*, Pp. 1274–1281. Winter Simulation Conference.

Mckinnon, a. C., D. Mendes, and M. Nababteh
2007. In-store logistics: an analysis of on-shelf availability and stockout responses for three product groups. *International Journal of Logistics Research and Applications*, 10(3):251–268.

Milicevic, N. and A. Grubor
2015. Tthe effect of backroom size on retail product availability-operational and technological solutions. *Amfiteatru Economic*, 17(39):661.

Nielsen
2015. The future of grocery. Technical report, Nielsen Company.

Pires, M., P. Amorim, J. Liz, and J. Pratas
2015. Design of retail backroom storage: A research opportunity? In *Operations Research and Big Data*, Pp. 167–174.

Pires, M., P. Amorim, J. Liz, and J. Pratas
2016. A framework for designing backroom areas in grocery stores. *International Journal of Retail Distribution Management*, 45(3).

Pliskin, J. S. and D. Dori
1982. Ranking alternative warehouse area assignments: A multiattribute approach. *IIE Transactions*, 14(1):19–26.

Press, S. J. and S. Wilson
1978. Choosing between logistic regression and discriminant analysis. *Journal of the American Statistical Association*, 73(364):699–705.

Ramaseshan, B., N. Achuthan, and R. Collinson
2009. A retail category management model integrating shelf space and inventory levels. *Asia-Pacific Journal of Operational Research*, 26(04):457–478.

Rao, A. and M. Rao
1998. Solution procedures for sizing of warehouses. *European Journal of Operational Research*, 108(1):16–25.

Reiner, G., C. Teller, and H. Kotzab
2013. Analyzing the Efficient Execution of In-Store Logistics Processes in Grocery Retailing-The Case of Dairy Products. *Production and Operations Management*, 22(4):924–939.

Rosenblatt, M. J. and Y. Roll
1988. Warehouse capacity in a stochastic environment. *The International Journal Of Production Research*, 26(12):1847–1851.

Speh, T. W.
2009. Understanding warehouse costs and risks. In *Ackerman Warehousing Forum*, volume 24.

Sternbeck, M. G.
2015. A store-oriented approach to determine order packaging quantities in grocery retailing. *Journal of Business Economics*, 85(5):569–596.

Sternbeck, M. G. and H. Kuhn
2014. An integrative approach to determine store delivery patterns in grocery retailing. *Transportation Research Part E: Logistics and Transportation Review*, 70:205 – 224.

Taylor, J. W.
2007. Forecasting daily supermarket sales using exponentially weighted quantile regression. *European Journal of Operational Research*, 178(1):154–167.

Thomassey, S.
2010. Sales forecasts in clothing industry: The key success factor of the supply chain management. *International Journal of Production Economics*, 128(2):470–483.

Thomassey, S. and A. Fiordaliso
2006. A hybrid sales forecasting system based on clustering and decision trees. *Decision Support Systems*, 42(1):408–421.

Thomassey, S., M. Happiette, and J.-M. Castelain
2005. A global forecasting support system adapted to textile distribution. *International Journal of Production Economics*, 96(1):81–95.

Tompkins
2014. Retail backrooms. Technical report, Tompkins International.

Ton, Z. and A. Raman
2010. The effect of product variety and inventory levels on retail store sales: A longitudinal study. *Production and Operations Management*, 19(5):546–560.

Van Zelst, S., K. van Donselaar, T. Van Woensel, R. Broekmeulen, and J. Fransoo
2009. Logistics drivers for shelf stacking in grocery retail stores: Potential for efficiency improvement. *International Journal of Production Economics*, 121(2):620–632.

Vaz, C. B., A. Camanho, and R. Guimarães
2010. The assessment of retailing efficiency using network data envelopment analysis. *Annals of Operations Research*, 173(1):5–24.

Waller, M. A., A. Heintz Tangari, and B. D. Williams
2008. Case pack quantity's effect on retail market share: An examination of the backroom logistics effect and the store-level fill rate effect. *International Journal of Physical Distribution & Logistics Management*, 38(6):436–451.

Wensing, T., M. G. Sternbeck, and H. Kuhn
2017. Optimizing case-pack sizes in bricks-and-mortar retailing from an instore perspective. Working paper.

White, J. A. and R. L. Francis
1971. Normative models for some warehouse sizing problems. *AIIE Transactions*, 3(3):185–190.

Witten, I. H., E. Frank, M. A. Hall, and C. J. Pal
2016. *Data Mining: Practical machine learning tools and techniques*. Morgan Kaufmann.

Appendix A

Table 4.11 – Cluster centers.

Cluster	Ambient	Dairy	Deli	Fruits&Veg	Bakery	Fish	Codfish	Meat	F. food	F. bakery
1	53,98%	6,49%	10,74%	9,49%	2,37%	2,68%	1,86%	4,88%	6,33%	1,18%
2	50,96%	6,66%	10,65%	8,52%	2,64%	3,80%	2,48%	6,16%	6,79%	1,22%
3	49,89%	5,98%	10,26%	10,25%	2,15%	3,08%	1,71%	7,59%	6,86%	1,51%
4	53,47%	5,18%	9,24%	6,30%	2,53%	3,42%	4,29%	6,42%	6,75%	1,38%
5	52,50%	5,36%	9,75%	7,50%	2,78%	3,59%	3,00%	6,88%	6,57%	1,28%
6	51,08%	6,19%	11,30%	11,53%	2,45%	2,78%	1,23%	4,97%	6,55%	1,57%

CHAPTER 5

Solving the backroom layout problem

Maria Pires [*] · **Elsa Silva** [*] · **Pedro Amorim** [*]

Submitted to *European Journal of Operational Research*, 2018

Abstract

The retail stores' backroom storage layout has structural differences when compared to other warehouses and distribution centers which are more traditionally studied in the literature. This paper presents a mathematical optimization approach for an unequal area facility layout problem (UA-FLP), which is applied in designing the backroom layout in the grocery retail context. In this problem, a set of rectangular facilities (backroom departments) with given area requirements has to be placed, without overlapping, on a limited floor space (backroom area), which can have a regular or an irregular shape. The objective is to find the location and format of the storage departments, such that the walking distances in the store are minimized. The proposed approach is tested in a European grocery retailer. In this analysis, several real store layouts are compared with the ones suggested by the proposed model. The decrease in the walking distances is, on average, 30 percent.

In order to understand what the current designers strategy is, a set of scenarios was created and compared with the real layouts. Each scenario ignores a characteristic of the problem. The goal is to understand what aspect designers are currently discarding. The findings indicate that, currently, designers neglect the different replenishment frequencies of storage departments.

Keywords Backroom Layout Problem · Grocery Retail · Strategic Planning · Mixed Integer Programming

5.1. Introduction

Retailers primary deal with finished goods inventory. In most cases, retailers stock products in anticipation of customer demand, following a "make-to-stock" strategy. For that reason, backrooms, which occupy on average 20 percent of retail stores space, have a major importance in retail (Dunne et al., 2013).

Retail companies may attempt to avoid keeping backroom inventory and favor "one-touch replenishment" policies, where the products go from the unloading dock directly to the sales area. Nevertheless, there are a number of reasons why retailers continue to keep backroom inventory, such as (i) storing more products per unit of floor space in the

[*]INESC TEC, Faculdade de Engenharia, Universidade do Porto, Porto, Portugal

backroom compared with the sales floor, (ii) having a backroom inventory that can act as a buffer when deliveries are uncertain or imperfect and when demand forecasts are not accurate, (iii) coping with some bulky or fast moving products where the shelf space available may not be sufficient to unload all products directly into the sales floor, (iv) storing and preparing perishable products, which in the sales area would quickly deteriorate, and (v) offering new opportunities for omnichannel retailing.

Previous studies indicate that backroom operations can have a significant impact on the overall store costs. In-store operations can account for up to 50 percent of total costs in a retailer supply chain and backrooms are responsible for a significant share of these costs (Van Zelst et al., 2009; Kuhn and Sternbeck, 2013). Despite this fact, research concerning backrooms has been rare. Researchers have been focused on the optimization of processes between the Distribution Centres (DCs) and stores as well as on designing the layouts of warehouses and sales area (Drira et al., 2007; Anjos and Vieira, 2017). Despite of the importance of layout design in several sectors, most of the previous research has been focused on manufacturing and distribution. Furthermore, the sales area layout has also been studied due to its direct impact on store sales (Aloysius and Binu, 2013; Turley and Chebat, 2002; Ozgormus, 2015).

In practice, when designing the layout of their stores, retailers understandably pay closer attention to the sales area, i.e. the place that creates direct value to the store. Backrooms, on the other hand, tend to attract less attention and are not as well understood, especially regarding their impact on store performance. Hence, the design of the backroom areas is mainly established empirically, based on the perception of the architect of similar stores. To prevent these situations, designers should also rely on formal means to assist the design process, rather than follow *ad-hoc* procedures (Pires et al., 2016).

The scope of this research involves answering the research question of how to effectively design the layout of backroom storage areas. This involves structuring and proposing mathematical models to help retailers adjust backroom layouts to their needs.

In this paper we propose an effective analytic method for designing backroom layouts considering walking distances, departments adjacency, sales areas layout and other physical constraints. Moreover, the application of this method to design retail backrooms is illustrated with a case study of a European retailer.

Due to the existing lack of literature in this research topic, our problem has relevance and contribution in two existing streams of the literature: facility layout and retail operations.

The remainder of the paper is organized as follows. The next section provides a description of the Backroom Layout Problem (BLP). Section 5.3 reviews the literature concerning the BLP related topics. Section 5.4 describes the mathematical model used to tackle this problem. Then, the results obtained and their implications are discussed in Section 5.5. Lastly, Section 5.6 concludes the paper and provides insights into possible future works.

5.2. Problem framing

The backroom layout problem is a strategic decision that consists on positioning the storage departments in the best possible location of the backroom in order to minimize the walking distances in the store, i.e. between the backroom and sales area. An example of a store layout is presented in Figure 5.1. The BLP is challenging, due to backroom particularities. Backrooms coexist with the sales area, which makes them a unique type of warehouses. In this problem, the walking distances made between storage departments (in the backroom) and the sales area departments/zones depend on the shelf replenishment frequencies. Departments with higher rotation or bulkier products will more likely need to be replenished more often during the day. For that reason, these departments should be nearer to the input/output (I/O) points (i.e. backroom doors). However, they should not be located all together in order to avoid congestion.

Space constraints on backrooms depend heavily on the type of store. Larger stores located far from city centers have fewer space constraints, one reason being the cheaper cost per unit area. However, when it comes to convenience stores located in urban centers, and often in buildings, the constraints related with space (available construction space) and architectural aspects (e.g., irregular shapes) are tighter.

Products in grocery stores are generally separated into storage departments, depending on the product segment (category) and storage requirements (temperature and humidity). Products that require different storage temperatures should be placed in different departments, for instance frozen (-18 to -35 C) and chilled (1-4 C) products. Also, to ensure food safety, some products should be separated. For instance, white and red meat should be apart to avoid food contamination. The same happens with raw and cooked food.

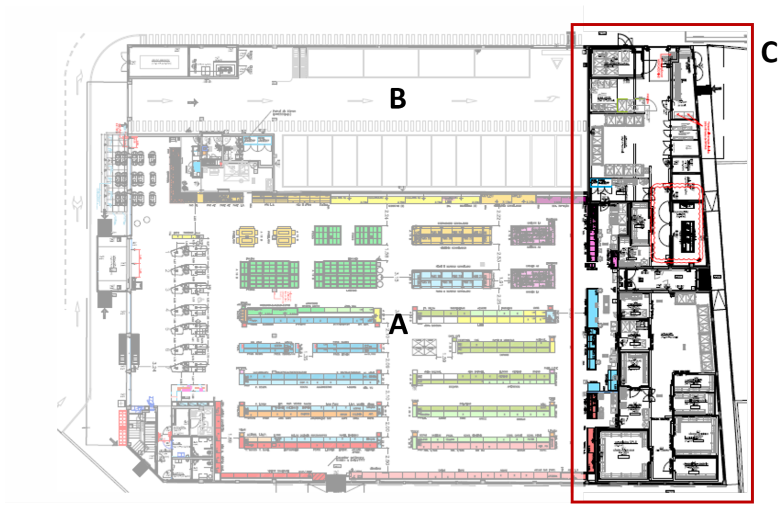

Figure 5.1 – Backroom of an existing store. “A" represents the sales area, “B" the unloading dock and “C" is the backroom.

In addition to storage departments, service counters and preparation areas are located in the backroom. Here, products are prepared before going to the sales area or according to customers’ requests. These areas should be located near the corresponding departments in the sales area and backroom. When locating departments, it is also necessary to consider energy efficiency aspects. For instance, refrigerated temperature departments (frozen and chilled) should be together, in order to avoid heat loss. Another important decision concerns the aisles design that consume valuable space. In practice, the aisles connect all the storage departments, i.e. all departments should be accessible. Furthermore, since the aisles are not refrigerated, it is common to use this space as storage for the food and non-food products, which do not require temperature control. Thus, it is required that the area that links all the refrigerated departments is a single undivided polygon with enough width to move the pallet truck and that also has enough space to store the food and nonfood stock.

Lastly, other important particularity is the disposition of the departments. In practice, designers tend to allocate the departments in the perimeter of the backroom in order to allow a larger space in the middle, for ambient products, promotions and buffers.

In conclusion, the goal of the BLP is to allocate the departments in the perimeter of the backroom in order to minimize the distances within the store. In this problem, there are five types of departments: (i) storage departments at ambient temperature (which are located in the middle area of the backroom), (ii) refrigerated storage departments, (iii) frozen storage departments, (iv) preparation departments and, lastly, (v) technical departments. With the exception of storage departments at ambient temperature, all other departments are separate departments. In addition, with the exception of technical departments, all other departments depend on the sales area and, therefore, use the I/O points.

5.3. Literature review

The BLP is related to two research streams: Retail operations and facility layout. In this section, we will address the existing literature concerning these research topics, while we draw parallels with the BLP.

5.3.1 Backroom related topics in retail operations

Grocery stores are usually arranged into two main areas: sales area and backroom. Whereas the sales area is dedicated to customers, the backroom supports the in-store operations.

In-store operations in grocery stores are complex. Generally, products flow into the store through a receiving area/unloading dock in the backroom before being placed on shelves. Store employees then unload and inspect products arriving from upstream distribution centres and/or suppliers and carry out activities such as stocking and replenishing store shelves. In the sales area, customers view and select products from shelves and exit the store after payment (Fisher, 2004; Pires et al., 2015). Items delivered to the retail store by internal distribution centres and/or external suppliers that cannot immediately fit in dedicated retail shelves are typically stocked in a backroom and replenished into the retail shelves when shelf inventory reaches a threshold or has run out (out-of-shelf).

The literature on retail store operations is vast and includes both operational execution and service improvement topics (Mou et al., 2017). Some of the most researched topics in this field include “Inventory management" (Bijvank and Vis (2011); Chandra and Grabis (2008)) and “Assortment and display" (Hübner and Kuhn (2012)). Store operations also includes the physical layout of a retail store, which is closely linked with backroom layout planning. However, the literature concerning grocery stores layout is still limited (Inglay and Dhalla, 2010).

The revenue of a grocery store depends on the clients purchases (type and quantity of products), which are highly influenced by the store design (Cil, 2012). The impulse purchases, i.e. the unplanned purchases, are the ones that are more influenced by the store layout (Mohan et al., 2013). Adjacency plays an important part in the customer's propensity to purchase items related to the ones that he/she had already planned to buy, but that were not in the shopping list. Thus, there is a trade-off between stimulating impulse purchases and increasing a customer's path length, which should be considered while designing a store.

Surjandari and Seruni (2010) unveiled category association rules by analyzing market basket data, and then used this information to determine a product placement layout. The sizes of the departments (product category areas) in this paper are fixed in a way that only the locations of products are chosen. Peng (2011) addressed the store layout problem by maximizing impulse purchases. The author first defines the must-have items in a grid layout store and then uses an algorithm to distribute these items across the store to increase impulse purchases. The generated layout is improved by using a simulated annealing (SA) metaheuristic. The size of the departments is also assumed to be fixed and equal. Cil (2012) examines the layout strategy in relation to supermarket retail stores by using buying association measures to create a category correlation matrix. The size of the departments considered in this work is also fixed. A model and solution approach was developed by Yapicioglu and Smith (2012), using tabu search, for the design of the block layout of a store with a racetrack aisle network. Aloysius and Binu (2013) presented an approach to product placement in supermarkets that aims to maximize impulse purchases by using market basket data analysis. The authors used data mining techniques to explore frequent patterns in the shopping lists of customers. A mixed integer mathematical model allied with both tabu search and genetic algorithm (GA) was proposed by Ozcan and Esnaf (2013) to design a bookstore layout. Pinto et al. (2015) combined regression models and a Particle Swarm Optimization metaheuristic to optimize space allocation with the goal of maximizing the predicted sales.

Pizzi and Scarpi (2016) researched the effect of different shelf visual layouts on decision satisfaction and perceptions of the retailer assortment. More recently, Altuntas and Altuntas (2017) proposed a two-step approach based on utility mining to derive store layout. Furthermore, the authors conducted a case study in a supermarket to illustrate the approach.

Generally, the objective function in the store layout problem is to maximize the revenue, either by increasing impulse purchases or by the client satisfaction regarding departments and adjacency (Botsali, 2007). Also, the sizes of the departments are generally fixed, and sometimes assumed equal sized, so only the locations of products are chosen. In terms of the methods applied, approximated methods are the most used, motivated by the difficulty in solving models to optimality. The heuristic algorithms that researchers are most interested in are simulated annealing and population based methods.

5.3.2 Facility layout

Facility layout problems (FLPs) are a general class of operations research problems concerned with finding the optimal arrangement of a given number of non-overlapping indivisible departments within a given facility (Anjos and Vieira, 2017). This is a challenging combinatorial optimization problem encountered in many service and manufacturing organizations. The aim is to determine the most effective department arrangement within a facility. In this problem several objectives may be considered, such as minimizing the material handling costs or maximizing space utilization. The costs considered are commonly represented by the sum of the products of the weighted rectilinear distance and the material-handling flow between the centroids (Paes et al., 2017).

The FLP is NP-hard in general, so solving it to global optimality in reasonable time is often difficult. Indeed the restricted version where the dimensions of the departments are all equal and fixed, and the optimization is taken over a fixed finite set of possible locations for the departments, is already an NP-hard problem. The constraints of the basic FLP problem encompass the department shape and location requirements. The department shape requirements include the required area and dimensions (height and width). The department location requirements include the non-overlap of departments within the facility.

There are three main classes of FLPs. The row layout problems, unequal-areas FLPs, and multi-floor FLPs. One-dimensional facilities lead to row FLPs. The goal of this problem is to assign departments to rows and to position them within the row. The Unequal-Areas FLP is concerned with finding the optimal arrangement of a given number of departments with varying areas so as to minimize the total expected cost of flows inside the facility. Unlike in the row FLPs, the dimensions of each department are optimized (subject to the area requirement) (Armour and Buffa, 1963). The multifloor FLP involves finding the optimal arrangement of departments in a facility with multiple floors. The problem tackled in this paper relates to the unequal-areas FLPs (UA-FLPs).

Various methods and procedures have been proposed to solve the UA-FLP and can be classified into exact methods, heuristics and meta-heuristics, and math-heuristics.

Most of the proposed approaches are two-stage methodologies, where the first stage determines the relative location of the departments, and the second stage obtains the final layout via a mathematical optimization model. The main differences between different approaches are in the first-stage algorithms.

Kim and Kim (2000) developed a MIP model for the layout planning problem with the objective of minimizing the sum of rectilinear distances weighted by flow amounts between input and output points of the facilities. Furthermore, Barbosa-Povoa et al. (2001) proposed a MILP where binary variables are introduced to characterize topological choices (e.g. equipment orientations) and continuous variables describe the distances and locations involved.

Wu and Appleton (2002) presented a method to solve the layout and aisle structure problems simultaneously by a slicing floorplan. The method decomposes the problem into two stages. The first stage minimizes the material handling cost with aisle distance, and the second stage optimizes the aisle structure. A representation of slicing floorplan is introduced for the optimization by genetic algorithms. Lee and Lee (2002) proposed a shape-based block layout approach using a hybrid genetic algorithm in which the objective function minimizes the total material handling cost and maximizes the space utilization. Osman et al. (2003) integrated the graphical capabilities of computer-aided design (CAD) with a genetic algorithm. Later, Wang et al. (2005) presented a study that combines a GA with analysis of variance (ANOVA). The experimental results showed that this approach is more feasible in addressing facilities layout problems in the real world. By reformulating the FLP with a sequence-pair representation, Meller et al. (2007) were able to solve problems with up to eleven facilities. Also, Konak et al. (2006) modeled the facility area constraints exactly using a set of linear constraints derived from the structure of the flexible bay structure representation. They report solving problems having up to fourteen facilities. Liu and Meller (2007) proposed a GA combining the sequence-pair representation with a mixed integer programming (MIP) model. For a given sequence-pair, the corresponding layout is determined in this hybrid approach using the linear programming relaxation of the MIP model.

A tabu search algorithm for solving fixed and flexible facilities in UA-FLPs was proposed by Scholz et al. (2009). Their tabu search incorporated four types of neighborhood moves to find better solutions. An ant colony system was proposed by Wong et al. (2010) to solve the UA-FLP using several types of local search to improve its search performance. Later, Kulturel-Konak (2012) proposed a tabu search approach that used linear programming to determine department shapes and their locations within the bays. The proposed approach was used to solve 13 instances of different sizes from the literature and it results equaled the best results to that date. Bozer and Wang (2012) developed an hybrid approach where linear programming is used to determine the exact location of each facility and a simulated annealing algorithm is used to search for new layouts based on the graph-pair representation. Furthermore, Kulturel-Konak (2012) proposed a probabilistic tabu search (PTS) approach to solve the facility layout problem (FLP) with unequal area departments.

Gonçalves and Resende (2015) proposed a biased random-key genetic algorithm with a decoder, which combines a placement strategy and a linear programming model to find the location and the dimensions of the facilities, such that the sum of the weighted distances between the centroids of the facilities is minimized. A mathematical programming model to solve the UA-FLP was developed by Tari and Neghabi (2015). In this study a new version of adjacency, which provides a more flexible layout design, is proposed. Chae and Regan (2016) proposed a MIP to solve the layout design problem with two types of department. A department's shape is given in either flexible or specified dimensions, which are denoted as Types A and B. Paes et al. (2017) introduced two algorithmic approaches to address this problem: a basic GA, and a GA combined with a decomposition strategy via partial solution deconstructions and reconstructions. Lastly, Palomo-Romero et al. (2017) proposed, for the first time, an Island Model Genetic Algorithm to solve the UA–FLP.

Table 5.1 presents the main characteristics of the various methods and procedures that have been proposed to solve the UA-FLP since the year 2000 Each model can be classified into several aspects: the type of variables representing the departments location, the decisions about the dimensions of the departments and the main considerations, such as irregular departments and facilities, department rotation, objective function and, lastly, solution method.

Table 5.1 – Review of UA-FLP approaches in the literature.

Author	Var.	Dimens.	Irr.dep.	Irr.fac.	Rotation	O.F.	Sol.
Kim and Kim (2000)	C	-	-	-	✓	DB	H
Barbosa-Povoa et al. (2001)	C	✓	-	-	✓	CB	E
Wu and Appleton (2002)	C	✓	-	-	-	DB	H
Lee and Lee (2002)	D	✓	-	-	-	DB+SUB	H
Osman et al. (2003)	D	✓	-	✓	-	DB	H
Wang et al. (2005)	D	✓	-	-	-	DB	H
Konak et al. (2006)	D	✓	-	-		DB	E
Meller et al. (2007)	D	✓	-	-	-	DB	E
Liu and Meller (2007)	C	✓	-	-	-	DB	MH
Scholz et al. (2009)	C	✓	-	-	✓	DB	H
Wong et al. (2010)	C	✓	-	-	-	DB	MH
Bozer and Wang (2012)	C	✓	-	-	-	DB	MH
Kulturel-Konak (2012)	C	✓	-	-	-	DB	MH
Gonçalves and Resende (2015)	C	-	-	-	-	DB	H
Tari and Neghabi (2015)	C	-	-	-	-	AB	E
Chae and Regan (2016)	D	✓	-	-	-	DB	E
Paes et al. (2017)	C	✓	-	-	-	DB	MH
Palomo-Romero et al. (2017)	C	✓	-	-	-	DB	H
This paper	C	(✓)	-	✓	-	DB	E

Caption:
Var. - Type of decision variables: C - Continuous or D - Discrete; Dimens. - Dimension; Irr. depart - Irregular departments; Irr. facility - Irregular facility; O.F. - Objective function: DB - Distance-based, CB - Connectivity-based, AB - Adjacency-based or SUB - space utilization based; Sol. - Solution: E - Exact, H - Heuristic or MH - Matheuristic;

In terms of the layout representation, both continuous (slicing tree and the flexible bay structure) and discrete variables have been used. Each of these have advantages and disadvantages. For instance, the allocation of the departments is less constrained in the continuous representation. However, for irregular backroom shapes, discrete representation is more advantageous, namely in non-convex backroom shapes where the space definition is more complex using continuous variables. Nonetheless, this increases significantly the number of binary variables and, therefore, the computational time. Furthermore, apart from Osman et al. (2003), all authors consider regular facilities. In terms of the objective function, UA-FLP models generally look at minimizing the costs or flows in the facility. It is also important to notice that recent contributions in the UA-FLP field have focused in new approaches to solve the problem more efficiently rather than in extending the mathematical formulations.

5.3.3 Literature review discussion

Analyzing the overall grocery retail literature, there are several papers concerning sales area layout. However, they have significant limitations, such as considering the store solely as a grid layout (i.e., in a rectangular arrangement of displays along parallel aisles) when actually they have more complex layouts. Additionally, the dimensions of the departments are often assumed equal sized in the literature when, in reality, it is often not the case. Moreover, if literature on sales area design is limited, literature on backroom layout design is non-existent. To the best of our knowledge, there are no papers tackling the backroom layout problem.

The class of facility layout problems is well-known, and there are numerous papers published since the 1950's. The literature on facility layout has focused on manufacturing enterprises and, specially, on material handling systems. In this paper, we contribute by extending the FLP to service industry, more specifically, to grocery retail store backrooms.

Establishing a parallel between the UA-FLP and the BLP, in terms of the layout representation, generally backrooms can have up to 30 departments and 1000 m^2. For this reason, using the discrete alternative would make the problem extremely complex, which would be reflected in the computational times. In terms of the objective function, the goal in the BLP resembles the FLP since it aims at minimizing the total walking distances in the store. However, we also consider the sales area layout, the I/O flows between sales area and the backroom, as well as the fact that some departments should be positioned together (grouped).

Lastly, the formulation proposed adds physical and operational constraints, such as a specific distribution of the storage departments in the perimeter of the backroom and the existence of a connected polygonal area linking all departments (for aisles and ambient departments).

More recent research has focused on metaheuristic methods, such as local search. Several studies have addressed the UA-FLP using GA and SA. However, a disadvantage of applying local search methods is the possibility of becoming trapped in a local optimum.

To the best of our knowledge, the best results so far using a MIP approach were obtained by Konak et al. (2006) that reported solving optimally problems having up to 14 facilities. In this paper, the authors decided the dimensions (width and height) and the position for each department. The model that we propose is able solve optimally problems with 29 departments. However, the decisions regarding the dimensions, specifically, are decoupled from the original model. The model decides the format of each department (with associated widths and heights) instead, as well as its position.

5.4. Model development

The solution methodology used to solve the BLP is divided in two sequential phases: preprocessing followed by the optimization model. This methodology was chosen to simplify the optimization model and it is based on cutting and packing problems, where a set of pieces should be placed in one (or more) large object without overlapping. In this type of problems, the set of pieces to be positioned in the big object is already defined, namely regarding its geometric dimensions. Based in this approach, we first define the size (m^2) of each department and the possible formats (with corresponding widths and heights). Then, the mathematical model selects the best format and location for each department. In summary, the methodology proposed is divided in the following two phases:

1. The pre-processing phase aims to discriminate the possible backroom department formats, assuming always rectangular shapes and no rotation.

2. The optimization model aims to allocate the departments in the backroom space.

Moreover, the approach uses the following assumptions:

- Backroom department dimensions are known.
- Available backroom construction area is defined, i.e. the architectural plan.
- Product flows in the backroom are known.
- Position of the categories in the sales area is known.
- Position of the access points (doors) between the sales area and backroom are known.

To describe the BLP, we consider $K = \{1,...,k\}$ to be a set of unequal area departments to be placed, without any overlap, on a rectangular floor space with dimensions (W, H) along the x- and y-axis, respectively, and total area of A. Furthermore, let $F_k = \{1,...,f_k\}$ be a set of formats for each department with area A_{fk} and dimensions $w_{fk} \cdot h_{fk}$.

5.4.1 Pre-processing

The first phase of the model aims to define the possible formats for each backroom department.

Since the optimal department sizes are assumed to be known, the first stage defines all the possible formats for each department. Departments must have a usable shape that allows personnel to move in the department. Therefore, we added a constraint that defines the subset of feasible formats. An adequate aspect ratio is required for each department, which is defined as a maximum allowed value of $AR_{max} \geq \frac{max\{height,width\}}{min\{height,width\}}$. Furthermore, it is admissible some slack (θ) in the department size ($\frac{A_{fk}-A_k}{A_k} \leq \theta$), where A_k is the target area of the department. Algorithm 1 describes the methodology used to define the formats for each department.

Algorithm 1: Pre-processing algorithm.

Input: Let K be a set of departments with target area A_k (m^2).
Output: F_k - set of all admissible formats for department k.

begin
  for $w_{fk} = 1$ **to** A_k **do**
    for $h_{fk} = A_k$ **to** *1* **do**
      Aux = $w_{fk} \times h_{fk}$
      if $Aux \geq A_k$ ***and*** $\frac{Aux - A_k}{A_k} \leq \theta$ ***and*** $\frac{max(w_{fk}, h_{fk})}{min(w_{fk}, h_{fk})} \leq AR_{max}$ **then**
        Add w_{fk} and h_{fk} to F_k ;
      end
    end
  end
end

Figure 5.2 presents the possible formats for an area with $8m^2$. The allowed formats are the ones that satisfy the minimum (pre-defined) area (in this case $8m^2$) while having admissible aspect ratio values. For instance, formats 1 and 3 satisfy the minimum area, however their aspect ratio values are above the admissible upper limit defined (we considered $AR_{max} = 4$). On the other hand, the remaining shapes are admissible. Also, as exemplified in shape 6, formats with areas greater than the minimum required are allowed, within the slack θ (in this case $\theta = 25\%$).

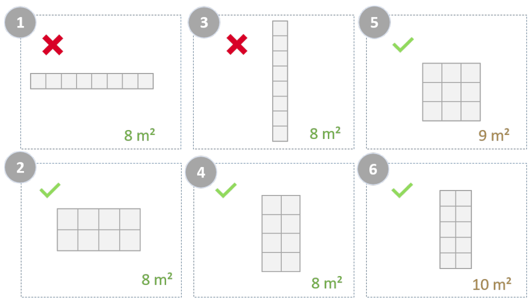

Figure 5.2 – Representation of the possible formats for a $8m^2$ department.

5.4.2 Optimization model

The second phase of the solution approach consists on the optimization model. The proposed model is inspired in the two dimensional knapsack problem developed by Pisinger and Sigurd (2007). The objective is to find the location and the dimensions (format) of the departments such that the total distance is minimized. We start by describing the simplest case, which is the regular (rectangular) backroom. Nonetheless, we also show how to adapt this model to irregular backroom shapes. In this model, we will use the superscript x, y to denote the dimensions along the x and y axis, respectively, considering that the overall building has its origin in its southwest corner.

Each department is characterized by its replenishment frequency, rf_k, which corresponds to the number of times that, in average, the shelf space is replenished from the backroom during the day. Let KC be a subset of K that only includes frozen departments and KT be a subset of K that only includes technical departments (i.e. that do not require I/O points). Furthermore, the backroom layout has a set of doors $D = \{1, ..., d\}$. Each door is characterized by its position (d^x_d, d^y_d) and by the maximum flow of products allowed to go through them *per* day, fm_d, in order to avoid congestion. Furthermore, the distance from door d to each department in the sales area is denoted as ds^x_{kd} and ds^y_{kd}, in x and y respectively.

In order to ensure that all departments are accessible and that pallet carriers can reach all departments, a minimum distance (s) is guaranteed between departments. Moreover, a minimum area (ma) in the center of the backroom should be left unoccupied to store ambient-temperature merchandise, such as groceries and beverages. Lastly, we ensure that departments are leveled in the x and y-axis, using Δ as the maximum allowed difference in the departments widths, or heights, to avoid extra walls between the departments.

To formulate the BLP, we use decision variables χ_{kf}, γ_{kd}, x_k, y_k, α_{ki}, δ_{ki}, σ^x_k, σ^y_k, ξ^x_k and ξ^y_k to characterize the backroom departments. Binary variables χ_{kf} are used to assign a format f to a department k, whereas variables γ_{kd} are used to assign departments k to doors d. Continuous variables x_k and y_k define the position of departments in the x and y-axis, respectively. Continuous variables σ^x_k (σ^y_k) indicate the minimum distance in the backroom from department k to door d in the x-axis (y-axis). Moreover, continuous variables ξ^x_k (ξ^y_k) indicate the sum of the interdepartmental distances in the x-axis (y-axis) between department k and the remaining. Binary variables a_k, b_k, c_k and d_k indicate in which of the four backroom edges the department is. For instance, if $a_k = 1$ department k is in $y = 0$ and so on, sequentially in the clockwise direction. To describe the relative position of the departments, auxiliary binary variables, α_{ki} and δ_{ki}, indicate if department k is to the left or below department i. Continuous variables v^x_{kd} (v^y_{kd}) indicate the distance from departments k to door d in x (in y). Also, continuous variables ω^x_{ki} (ω^y_{ki}) indicate the horizontal (vertical) distance between departments k and i. Lastly, binary variables ψ^x_{ki} (ψ^y_{ki}) indicate if departments k and i have a gap in the x-axis (y-axis).

5.4.2.1 Regular backroom

The proposed formulation for the regular BLP reads as follows:

$$\text{Minimize} \sum_{k \in K \setminus \{KT\}} (\sigma^x_k + \sigma^y_k + \sum_{d \in D} (ds^x_{kd} + ds^y_{kd}) \cdot \gamma_{kd}) \cdot rf_k + \sum_{k \in KC} (\xi^x_k + \xi^y_k) \tag{5.1}$$

Equation (5.1) represents the objective function. The goal is the minimization of the walking distance, measured using the manhattan distance, of handling products in the store, considering both the distances in the backroom and sales area. Furthermore, it aims at minimizing the construction distance between the frozen departments. This model is subjected to the following constraints:

Master layout constraints

$$\alpha_{ki} + \alpha_{ik} + \delta_{ki} + \delta_{ik} \geq 1, \forall i,k \in K : i < k \tag{5.2}$$

$$\alpha_{ki} + \alpha_{ik} \leq 1, \forall i,k \in K : i < k \tag{5.3}$$

$$\delta_{ki} + \delta_{ik} \leq 1, \forall i,k \in K : i < k \tag{5.4}$$

$$\sum_{f} \chi_{kf} = 1, \forall k \in K \tag{5.5}$$

$$x_k + \sum_{f} w_{fk} \cdot \chi_{kf} \leq x_i + W \cdot (1 - \alpha_{ki}), i,k \in K : i \neq k \tag{5.6}$$

$$y_k + \sum_{f} h_{fk} \cdot \chi_{kf} \leq y_i + H \cdot (1 - \delta_{ki}), i,k \in K : i \neq k \tag{5.7}$$

$$x_k \leq W - \sum_{f} (w_{fk} \cdot \chi_{kf}), \forall k \in K \tag{5.8}$$

$$y_k \leq H - \sum_{f} (h_{fl} \cdot \chi_{kf}), \forall k \in K \tag{5.9}$$

$$\sum_{k} \sum_{f} \chi_{kf} \cdot A_f \leq A \tag{5.10}$$

$$A - \sum_{k} \sum_{f} \chi_{kf} \cdot A_f \geq ma \tag{5.11}$$

$$\Delta \geq |x_k + \sum_{f} \chi_{kf} \cdot w_{fk} - (x_i + \sum_{f} \chi_{fi} \cdot w_{fk})| - M \cdot (2 - b_i - b_k), \forall k,i \in K : i \neq k \tag{5.12}$$

$$\Delta \geq |x_k - x_i| - M \cdot (2 - d_i - d_k), \forall k, i \in K : i \neq k \tag{5.13}$$

$$\Delta \geq |y_k + \sum_f \chi_{kf} \cdot h_{fk} - (y_i + \sum_f \chi_{fi} \cdot h_{fk})| - M \cdot (2 - a_i - a_k), \forall k, i \in K : i \neq k \tag{5.14}$$

$$\Delta \geq |y_k - y_i| - M \cdot (2 - c_i - c_k), \forall k, i \in K : i \neq k \tag{5.15}$$

Equations (5.2) to (5.4) enforce that all selected formats are arranged to the left and/or below one another. Equation (5.5) ensures that each department k is assigned to one format f. Equations (5.6) and (5.7) ensure that departments do not overlap each other. Equations (5.8) and (5.9) ensure that each department k is within the backroom space. Equation (5.10) makes sure that the chosen formats do not exceed the available backroom space. Equation (5.11) ensures that a minimum area is left for storing merchandise at ambient temperature. Lastly, Equations (5.12) and (5.13) guarantee that the departments are leveled, not exceeding a deviations in x greater than Δ, to avoid extra walls. Equations (5.14) and (5.15) have the same purpose, but now considering the y-axis.

Door-selection constraints

$$\sum_d \gamma_{kd} = 1, \forall k \in K \tag{5.16}$$

$$\nu^x_{kd} = |d^x_d - (x_k + \sum_f w_{fk}/2 \cdot \chi_{kf})|, \forall k \in K \backslash \{KT\}, d \in D \tag{5.17}$$

$$\sigma^x_k \geq \nu^x_{kd} - M \cdot (1 - \gamma_{kd}), \forall k \in K \backslash \{KT\}, d \in D \tag{5.18}$$

$$\nu^y_{kd} = |d^y_d - (y_k + \sum_f h_{fk}/2 \cdot \chi_{kf})|, \forall k \in K \backslash \{KT\}, d \in D \tag{5.19}$$

$$\sigma^y_k \geq \nu^y_{kd} - M \cdot (1 - \gamma_{kd}), \forall k \in K \backslash \{KT\}, d \in D \tag{5.20}$$

$$\sum_k \gamma_{kd} \cdot rf_k \leq fm_d, \forall d \in D \tag{5.21}$$

Equation (5.16) ensures that each department has one door assigned. Equations (5.17) and (5.18) define the absolute distance from departments to doors, in the x-axis. Equations (5.19) and (5.20) define the distance to doors, in the y-axis. Lastly, Equation (5.21) defines a limit for products flow passing through each door d, in order to avoid congestion.

Energy constraints

$$\omega^x_{ki} = |x_k - x_i|\,, \forall i,k \in KC : k \neq i \tag{5.22}$$

$$\xi^x_k \geq \sum_i \omega^x_{ki}\,, \forall k \in KC \tag{5.23}$$

$$\omega^y_{ki} = |y_k - y_i|\,, \forall i,k \in KC : k \neq i \tag{5.24}$$

$$\xi^y_k \geq \sum_i \omega^y_{ki}\,, \forall k \in KC \tag{5.25}$$

Constraints (5.22) to (5.25) define the distance between the frozen departments, which is a parcel of the objective function that should be minimized. Thus, Equations (5.22) and (5.24) calculate the distances in the x and y axis respectively, while Equations (5.23) and (5.25) fix the highest value. This ensures that these departments are placed together, reducing the construction costs.

Backroom perimeter constraints

$$a_k + b_k + c_k + d_k \geq 1\,, \forall k \in K \tag{5.26}$$

$$H \cdot (1 - a_k) \geq y_k\,, \forall k \in K \tag{5.27}$$

$$W \cdot (1 - b_k) \geqslant x_k\,, \forall k \in K \tag{5.28}$$

$$y_k + \sum_f \chi_{kf} \cdot h_{fk} \geqslant c_k \cdot H\,, \forall k \in K \tag{5.29}$$

$$x_k + \sum_f \chi_{kf} \cdot w_{fk} \geqslant d_k \cdot W\,, \forall k \in K \tag{5.30}$$

As previously mentioned, departments should be located in the perimeter of the backroom area. Thus, Equations (5.27) to (5.30) ensure that all departments are being allocated to the edges of the backroom. Variables a_k, b_k, c_k and d_k correspond to one edge of the backroom.

Store operation constraints

$$x_k \leqslant x_i - \sum_f \chi_{kf} \cdot w_{fk} - s + M(1 - \psi^x_{ki}), \forall i,k \in K : k \neq i \tag{5.31}$$

$$y_k \geqslant y_i + \sum_f \chi_{if} \cdot h_{fi} + s - M(1 - \psi^y_{ki}), \forall i,k \in K : k \neq i \tag{5.32}$$

$$\psi^x_{ki} + \psi^y_{ki} \geqslant a_i + b_k - 1, \forall i,k \in K : k \neq i \tag{5.33}$$

These last constraints make sure that all departments are connected and that there is enough space (aisle width), s to move merchandise around the backroom. Thus, since all departments are in one edge of the backroom, the opposite edge should be free. In the case of a rectangular backroom, there exist four combinations of two for these constraints. In Equations (5.31) to (5.33), we represent the case where one department is located in $y = 0$ and other in $x = 0$.

Variables domain

$$\chi_{kf}, \gamma_{kd}, \alpha_{ki}, \delta_{ki}, \psi^x_{ki}, \psi^y_{ki}, a_k, b_k, c_k, d_k \in \{0,1\} \tag{5.34}$$

$$x_k, y_k, v^x_{kd}, v^y_{kd}, \sigma^x_k, \sigma^y_k, \xi^x_k, \xi^y_k, \omega^x_{ki}, \omega^y_{ki} \in \mathbb{R}^+ \tag{5.35}$$

5.4.2.2 Irregular backroom

In case of having irregular backroom shapes, constraints (5.6)-(5.9) and (5.26)-(5.33) would have to be adapted to the new shape. In Figure 5.3, an example of an irregular backroom is illustrated. In this layout, the top edge is inclined, as an example. This section describes how to cope with the irregular shape presented in Figure 5.3.

When one, or more, of the edges has a slope different than zero, it affects the “admissible region". The area in which the departments can be allocated is defined by former Equations (5.8) and (5.9). In this example, former Equation (5.9) is adapted to Equation (5.36) to cope with the irregular shape illustrated in this example. Here, m is the slope of the wall, that previously was zero, and b is the intersection in the y-axis.

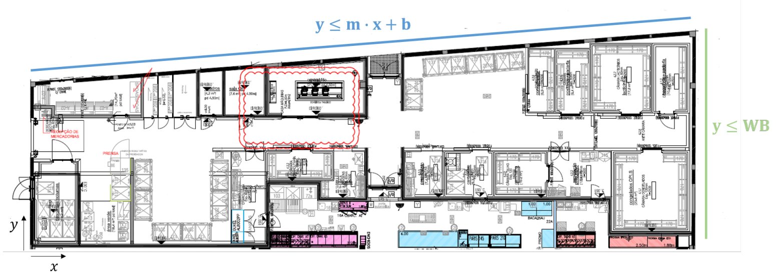

Figure 5.3 – Example of an irregular backroom.

$$y_k + \sum_f \chi_{kf} \cdot h_{fk} - m \cdot x_k - b \leq 0, \forall k \quad (5.36)$$

Furthermore, since the departments should be allocated in the perimeter of the backroom, former Equation (5.29) is now transformed into Equation (5.37), that copes with this irregularity. Here it is important to notice that, since the slope of the line is positive, the reference vertex that should be in contact with this line is the top-left vertex. However, if the slope was negative, it would have been the top right vertex instead.

$$y_k + \sum_f \chi_{kf} \cdot h_{fk} \geqslant (b + m \cdot x_k) - M \cdot (1 - c_k), \forall k \quad (5.37)$$

5.5. Computational experiments

This section presents the numerical results of our optimization approach and provides managerial insights regarding the BLP. First, we present the instances used to test the model proposed to solve the BLP. Then, we quantify the savings obtained by using the model proposed when compared to a baseline solution (provided by the case study retailer). Afterwards, we test four different models in order to unveil the heuristic beyond the current design process. Lastly, we provide an illustrative example of the methodology followed.

All numerical tests were conducted on Intel Xeon E5-2687 @3.100GHz CPU and 64 GB of physical memory.

5.5.1 Experimental set-up

To evaluate the performance and the capabilities of the model proposed, we performed a series of computational experiments. As smaller store formats (proximity stores) are growing more rapidly, they are the focus of our study (Nielsen, 2015). The data to build our instance set was provided by a large food retailer operating in Europe. The model was tested using eight layouts of existent convenience stores, which were provided by the case

Table 5.2 – Instance characterization.

Store	# Dpts	# Frozen dpt	# Ref dpt	# Doors	# Formats	Irregular	N.R. area	Area (m^2)
Store A	14	2	12	1	26	yes	15%	1843
Store B	15	2	7	1	43	-	29%	1247
Store C	17	2	10	1	41	yes	50%	1332
Store D	17	3	13	2	52	-	39%	1794
Store E	20	3	12	1	41	-	28%	1177
Store F	20	3	13	2	50	-	27%	2115
Store G	26	2	13	2	73	yes	45%	2269
Store H	29	3	13	2	10	-	20%	2722

study company. The sample of stores represents all convenience stores in a way that it includes several locations, backroom sizes and shapes.

The characterization of the instances is presented in Table 5.2. The main instance characteristics are the number of departments (total, frozen and refrigerated departments), number of doors (I/O points), number of possible formats, the shape of the backroom (regular or irregular), the non-refrigerated area (in %) and, lastly, the store total area (in m^2). In terms of departments, there are three different types: storage, preparation and technical departments. From these, only storage and preparation departments influence the walking distance in the store. However, since all departments must be placed in the backroom, technical departments add computing complexity. The non-refrigerated area (in %) corresponds to the quotient between the free area - available space (in m^2) left when the required storage area is removed from the total backroom area - and the total backroom area.

5.5.2 General results

Table 5.3 summarizes the results for applying the approach described on Section 5.4 to the several instances. This table describes the number of variables, number of constraints, objective function (O.F.), running time (in seconds), gap (for the cases when the model could not find the optimal solution within the time limit) for each store, the objective function of the stores' actual layout and, lastly, the deviation between the two objective functions. As it is possible to conclude, the results depend on the combination of the number of departments, possible shape formats and I/O points, that directly impact the number of variables. As these increase, the complexity and solving time of the problem increases as well. As opposed to the previous, when the non-refrigerated area (in %) increases, the simpler the problem becomes since there is more flexibility to allocate the departments in the backroom. Furthermore, the irregularity of the backroom also adds complexity to the problem, as shown in the running times.

The time limit was set for four hours (1440 seconds), which is appropriate since this is a strategic problem. Within the time limit of four hours, optimal solutions were found for six out of the eight instances analyzed. Nonetheless, these instances had a gap of only 2%.

Table 5.3 – Computational results for the original model.

Store	#Variables	#Constraints	Model O.F.	Time (s)	Gap (%)	Real O.F.	Deviation (%)
Store A	3465	5124	2236,7	14400	1,8%	3014,5	25,8%
Store B	4694	6280	2130	20	0,0%	3504,5	39,2%
Store C	5837	7367	3012,9	5520	0,0%	3797,5	20,7%
Store D	6738	9682	2091	368	0,0%	4227	49,6%
Store E	7822	10947	3533,1	14400	2,1%	4662,3	24,2%
Store F	8781	10971	3323,9	6960	0,0%	4632,6	28,2%
Store G	14477	19445	2901,5	370	0,0%	4283,9	32,3%
Store H	8781	10971	2502	4840	0,0%	4147,7	39,7%
Avg regular shapes				5317,2	0,4%		36,4%
Avg irregular shapes				6763,3	0,6%		26,2%

The model proposed allows the decrease of the walking distances by 30% in average, which creates better conditions for the store employees as well as an opportunity to create better service (lower out-of-shelf situations) to customers. Ultimately, this might result in higher store sales, customer satisfaction and lower personnel costs.

Looking in more detail, it is possible to see that the model is able to create more improvements for regular stores than for irregular stores. The store with the largest deviation is store D, with a 49,6% deviation between the current solution and the one proposed by the model. This happens because the store departments with higher replenishment frequencies are located far from the I/O points in the real layout.

5.5.3 Unveiling the practitioners heuristics

Currently, the design of the backroom areas is mainly established empirically, based on the perception of similar stores by the architect. What often happens is that stores layouts reflect the subjectivity and preferences of each designer. Hence, the criteria used to allocate departments in the backroom is not clear. In this analysis we attempt to grasp the heuristic behind the design process currently followed in practice, i.e., what are the current objective and constraints being used besides the space (physical) constraints. Thus, four variations of the model previously defined were also tested (scenario 1 to 4). Each of these variations/scenarios neglects one important aspect considered in the original model. These aspects were selected based on our perception of what was being neglected when discussing the problem with the company's designers. The four scenarios are:

- Scenario 0: The first scenario corresponds to the original model proposed that considers all the aspects neglected in the scenarios presented below.

- Scenario 1: The second scenario does not consider the location of the product categories in the sales area in the objective function. Therefore, it only aims at minimizing the distance within the backroom.

- Scenario 2: The third scenario does not consider energy efficiency issues. Therefore, it does not aim at minimizing the distance between frozen departments.

- Scenario 3: The fourth scenario ignores replenishment frequencies for the different storage departments. Thus, in this scenario, all departments are considered similar in terms of how many times they are visited daily by an employee.
- Scenario 4: The fifth and last scenario neglects the flow in the doors, i.e., the solution of this model ignores the congestion in the doors and, therefore, does not attempt to distribute the flow of merchandise as it is actually desired in practice.

Scenarios 1, 2 and 3 are obtained by modifying the objective function whereas the last one is achieved by removing Equation (5.21), that ensures flow balance in the doors by setting a limit. Appendix A provides further detail on how to achieve each of these scenarios.

These scenarios have the goal of understanding what is currently the design strategy of the case study company, by finding the one with the closest objective function value to the real layout. Thus, it is possible to understand the aspects that designers are considering and what they are neglecting. With this analysis, we aim to provide managerial insights to help designers make more structured decisions in the future.

5.5.3.1 Comparison results

These results were obtained by comparing the objective function of the real backroom layout with the objective function of the solution obtained in each scenario. In terms of model efficiency, it can be observed that when the replenishment frequencies and sales area locations are removed from the objective function, the models perform worse.

Table 5.4 presents the results for each pair scenario-store analyzed. When aggregating the results in Table 5.4 by scenario, we realize that the mean deviations are, in ascending order, 23,8% for Scenario 3, 26,9% for Scenario 4, 29,6% for Scenario 2, 32,6% for the original model and, lastly, 58,3% for Scenario 1. Thus, it is plausible to conclude that the closest scenario to the real layout is Scenario 3 (which does not consider replenishment frequencies), followed by Scenario 4 (does not consider congestion at the I/O points). Also, Scenario 1 is the one that is furthest from the real layout. The combination of scenarios 3 and 4 was also tested, but the results obtained were worse than for scenario 3. These results are relevant from a practical point of view, since they indicate what has been considered and ignored when designing backrooms. Designers have been neglecting the replenishment frequencies and door assignment, and have been considering the location of the departments in the sales area. This can occur for several reasons, namely the lack of the architects' knowledge in relation to in-store operations (e.g., products flow, replenishment frequencies).

5.5.3.2 Illustrative example

In this section we illustrate the methodology used and the results obtained for Store G in the previous section (original model and hypothetical scenarios). Store G is characterized

Table 5.4 – Scenario analysis results.

Scenario	Store	O.F.	Time	Gap (%)	Real O.F.	Deviation
S1	Store A	673	14400	7,1%	1197,7	43,8%
	Store B	536	18	0,0%	2113,8	66,6%
	Store C	556,5	5519	0,0%	1152	51,7%
	Store D	634,9	14400	1,2%	1717,7	61,0%
	Store E	1058,5	14400	13,0%	2190,7	46,7%
	Store F	728,1	14400	5,6%	2041,5	64,3%
	Store G	711,7	14400	8,5%	2049,9	63,3%
	Store H	640,5	8940	0,0%	1998,5	68,0%
Avg						58,3%
S2	Store A	2490	14400	1,8%	3014,5	17,4%
	Store B	2130	20	0,0%	3707,8	42,6%
	Store C	3005,5	4800	0,0%	3492,2	13,9%
	Store D	2083,35	288	0,0%	4127,2	44,5%
	Store E	3521,6	14400	2,3%	4660,1	24,4%
	Store F	3321	987	0,0%	4628,7	28,3%
	Store G	2897,5	468	0,0%	4249,9	31,8%
	Store H	2478,5	940	0,0%	3629,1	31,7%
Avg						29,9%
S3	Store A	285	14400	13,3%	287,8	1,0%
	Store B	155,5	2	0,0%	261,1	37,4%
	Store C	317,4	14400	2,7%	390,8	18,8%
	Store D	260	14400	4,1%	460,1	37,5%
	Store E	331,2	14400	10,0%	399,94	17,2%
	Store F	295,3	14400	3,7%	388,5	24,0%
	Store G	340,8	14400	1,7%	390,8	12,8%
	Store H	350,3	3280	0,0%	602	37,8%
Avg						23,8%
S4	Store A	2490	14400	1,8%	3014,5	17,4%
	Store B	2130	19	0,0%	3707	37,5%
	Store C	3012,95	5160	0,0%	3504,5	14,0%
	Store D	2291	432	0,0%	4002,5	38,8%
	Store E	3533	14400	1,8%	4662,3	24,2%
	Store F	3136,9	6480	0,0%	4147,2	24,4%
	Store G	2633,5	359	0,0%	3681,8	28,5%
	Store H	2283,5	6480	0,0%	3409,1	33,0%
Avg						26,9%

by 26 departments of which 2 are departments to store frozen goods, 8 are departments to store refrigerated goods, 3 are preparation areas and 13 are technical departments. Further details regarding this store are provided in Appendix B.

Figure 5.4 – Real layout of the backroom.

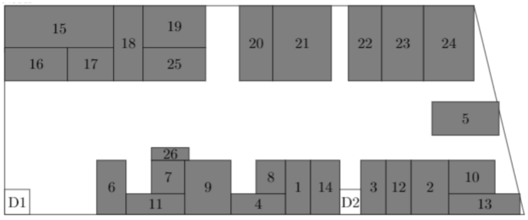

Figure 5.5 – Abstraction of the real layout.

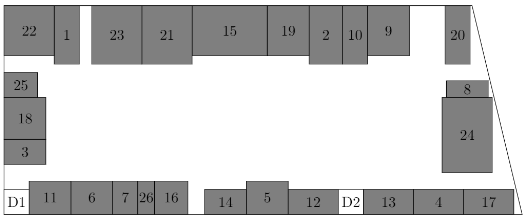

Figure 5.6 – Solution for Scenario 0.

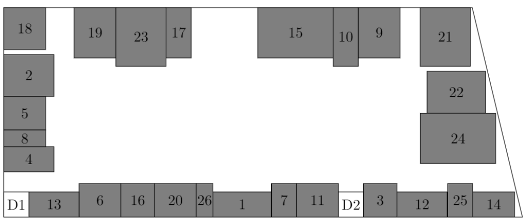

Figure 5.7 – Solution for Scenario 1.

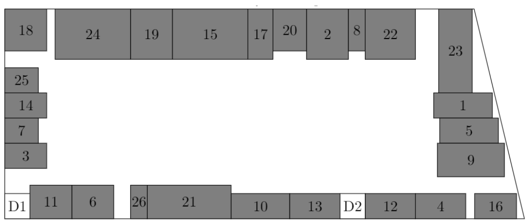

Figure 5.8 – Solution for Scenario 2.

The original model places the departments in a way that minimizes the total walking distance in the store, considering the sales area location, replenishment frequencies, sales area layout and energy aspects (Figure 5.6). Departments around door 1 (door to the left) are departments located in the left part of the sales area. The same happens with departments around door 2 (right part of the sales area). Furthermore, departments 3, 4, 6, 11, 12 and 13 are the ones with the highest replenishment frequencies and that is the reason why they are close to the doors, these are meat, fish, fruits & vegetables and preparation areas. By analyzing the real layout (Figure 5.5), we can conclude that this aspect has not been considered in the actual backroom layout. Furthermore, we can see that in the real layout departments are not as close to door 1 as they should, in order to minimize the walking distance. Thus, product flows are not balanced, as 75% of products flows are assigned to door 2. Moreover, frozen departments 9 and 10 are next to each other in order to minimize heat

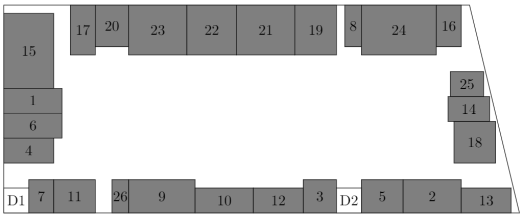

Figure 5.9 – Solution for Scenario 3.

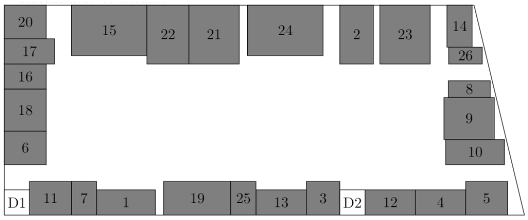

Figure 5.10 – Solution for Scenario 4.

loss. The departments that were positioned in the top of the backroom are the technical and social departments, that do not require to be near the sales area.

In the first scenario (without considering the location of the product categories in the sales area) the model only considers the distances in the backroom (Figure 5.7). Therefore, the backroom layout presents a different arrangement of departments. The departments that before were closer to the corresponding locations in sales area are now in other positions. Therefore, the replenishment frequencies only affect the walking distances within the backroom. Thus, departments with higher replenishment frequencies remain next to the doors. Furthermore, frozen departments remain together. In the scenario where frozen departments are not obliged to be positioned adjacent to each other (scenario 2), we see in the solution (Figure 5.8) that departments 9 and 10 are, in fact, separate which would lead to an increase in the energy costs. The remaining aspects are still considered. In the scenario where replenishment frequencies were neglected, we see a different arrangement from all the above (Figure 5.9). Here, the departments are allocated to the right doors, however, the order in which the departments are located does not represent the frequency in which departments are visited by employees during the day. For instance, departments 6 and 13 are not as close to the doors as in the other solutions. In the fourth scenario, the flow passing through each door is not considered (Figure 5.10). Therefore, we see that door 2 (in the right) has more departments assigned than door 1 (in the left), which would cause congestion. As Table 5.4 indicates, Scenario 3 is the one that best represents the heuristic used by designers to design backrooms. In the specific case of store G, the deviation is of 12,8%.

5.6. Concluding remarks

In this paper we present a mathematical programming model for the BLP, applied to the grocery retail context. In this problem, a set of unequal area rectangular facilities with a given area requirements have to be placed, without overlapping, on the backroom, which can have rectangular or irregular shapes. The aim of the problem is to minimize the walking distances in the stores. The model is tested on a sample of existing stores. Besides the number of departments and possible formats (decision variables), the model is sensible to the irregularity of the backroom, taking longer running times.

The BLP is a strategic problem, which admits long running times. Within the time limit of four hours, optimal solutions were found for six out of the eight instances analyzed.

Nonetheless, these instances had a gap of only 2%. Since the BLP is a strategic problem, if an optimal solution is required, running times should be increased. By using the model proposed, the walking distance in the store decreases approximately 33%.

Besides the original model, four scenarios were created, each neglecting a different designing aspect. By comparing these scenarios with the real layouts, it was possible to estimate what is the current designing heuristic beyond the current layouts. According to this analysis, designers are currently neglecting the replenishment frequencies as well as congestion in I/O points.

The proposed model fills a gap in the literature, since this problem has not yet been tackled. Furthermore, it adds value in practice since it enables architects to have a systematic and standard methodology to design backroom layouts, considering in-store operations and products flow. It also allows to decrease the backroom planning times and resources needed for this task. After obtaining the solution of the model, it might be necessary the intervention of the architects and engineers to make some adjustments and define additional technical issues. Nonetheless, it frees them of the greater task of allocating the departments, which usually takes days. Stores may also benefit from the new proposed layouts in terms of increasing customer service. Shorter walking distance lead to less out-of-shelf situations (since employees are more willing to replenish the shelves from the backroom), additional time for employees to perform other tasks (e.g., supporting customers) and, lastly, provides better conditions to employees (e.g., less injuries caused by carrying heavy merchandise for long distances).

Although the findings are encouraging, there are still limitations to overcome in the future. First, this study was conducted in an experimental setting and as such the results presented have a straight link to the case study. Secondly, the sample of stores was limited and, ideally, should be increased.

As future work, it would also be interesting to adapt the model to non-convex shapes, which exist in urban stores, test the model in other settings, such as consumer electronics retail and, lastly, integrate the layouts of the sales and backroom areas.

Acknowledgements

This work is financed by the North Portugal Regional Operational Programme (NORTE 2020), under the PORTUGAL 2020 Partnership Agreement, and through the European Regional Development Fund (ERDF), within the project «NORTE-01-0145-FEDER-000020».

Bibliography

Aloysius, G. and D. Binu
2013. An approach to products placement in supermarkets using prefixspan algorithm. *Journal of King Saud University-Computer and Information Sciences*, 25(1):77–87.

Altuntas, S. and S. Altuntas
2017. A novel approach based on utility mining for store layout: a case study in a supermarket. *Industrial Management & Data Systems*, 117(2):304–319.

Anjos, M. F. and M. V. Vieira
2017. Mathematical optimization approaches for facility layout problems: The state-of-the-art and future research directions. *European Journal of Operational Research*.

Armour, G. C. and E. S. Buffa
1963. A heuristic algorithm and simulation approach to relative location of facilities. *Management Science*, 9(2):294–309.

Barbosa-Povoa, A., R. Mateus, and A. Novais
2001. Optimal two-dimensional layout of industrial facilities. *International Journal of Production Research*, 39(12):2567–2593.

Bijvank, M. and I. F. Vis
2011. Lost-sales inventory theory: A review. *European Journal of Operational Research*, 215(1):1–13.

Botsali, A. R.
2007. *Retail facility layout design*. PhD thesis, Texas A & M University.

Bozer, Y. A. and C.-T. Wang
2012. A graph-pair representation and mip-model-based heuristic for the unequal-area facility layout problem. *European Journal of Operational Research*, 218(2):382–391.

Chae, J. and A. C. Regan
2016. Layout design problems with heterogeneous area constraints. *Computers & Industrial Engineering*, 102:198–207.

Chandra, C. and J. Grabis
2008. Inventory management with variable lead-time dependent procurement cost. *Omega*, 36(5):877–887.

Cil, I.
2012. Consumption universes based supermarket layout through association rule mining and multidimensional scaling. *Expert Systems with Applications*, 39(10):8611–8625.

Drira, A., H. Pierreval, and S. Hajri-Gabouj
2007. Facility layout problems: A survey. *Annual Reviews in Control*, 31(2):255–267.

Dunne, P. M., R. F. Lusch, and J. R. Carver
2013. *Retailing*. Cengage Learning.

Fisher, M.
2004. To me it's a store. to you it's a factory. *International Commerce Review: ECR Journal*, 4(2):9.

Gonçalves, J. F. and M. G. Resende
2015. A biased random-key genetic algorithm for the unequal area facility layout problem. *European Journal of Operational Research*, 246(1):86–107.

Hübner, A. H. and H. Kuhn
2012. Retail category management: State-of-the-art review of quantitative research and software applications in assortment and shelf space management. *Omega*, 40(2):199–209.

Inglay, R. S. and R. S. Dhalla
2010. Application of systematic layout planning in hypermarkets. In *Proceedings of the 2010 international conference on industrial engineering and operations management*, Pp. 9–10.

Kim, J.-G. and Y.-D. Kim
2000. Layout planning for facilities with fixed shapes and input and output points. *International Journal of Production Research*, 38(18):4635–4653.

Konak, A., S. Kulturel-Konak, B. A. Norman, and A. E. Smith
2006. A new mixed integer programming formulation for facility layout design using flexible bays. *Operations Research Letters*, 34(6):660–672.

Kuhn, H. and M. G. Sternbeck
2013. Integrative retail logistics: an exploratory study. *Operations Management Research*, 6(1-2):2–18.

Kulturel-Konak, S.
2012. A linear programming embedded probabilistic tabu search for the unequal-area facility layout problem with flexible bays. *European Journal of Operational Research*, 223(3):614–625.

Lee, Y. H. and M. H. Lee
2002. A shape-based block layout approach to facility layout problems using hybrid genetic algorithm. *Computers & Industrial Engineering*, 42(2):237–248.

Liu, Q. and R. D. Meller
2007. A sequence-pair representation and mip-model-based heuristic for the facility layout problem with rectangular departments. *IIE transactions*, 39(4):377–394.

Meller, R. D., W. Chen, and H. D. Sherali
2007. Applying the sequence-pair representation to optimal facility layout designs. *Operations Research Letters*, 35(5):651–659.

Mohan, G., B. Sivakumaran, and P. Sharma
2013. Impact of store environment on impulse buying behavior. *European Journal of Marketing*, 47(10):1711–1732.

Mou, S., D. J. Robb, and N. DeHoratius
2017. Retail store operations: Literature review and research directions. *European Journal of Operational Research*.

Nielsen
2015. The future of grocery - e-commerce, digital technology and changing shopping preferences around the world. Technical report, Nielsen.

Osman, H. M., M. E. Georgy, and M. E. Ibrahim
2003. A hybrid cad-based construction site layout planning system using genetic algorithms. *Automation in construction*, 12(6):749–764.

Ozcan, T. and S. Esnaf
2013. A discrete constrained optimization using genetic algorithms for a bookstore layout. *International Journal of Computational Intelligence Systems*, 6(2):261–278.

Ozgormus, E.
2015. *Optimization of Block Layout for Grocery Stores*. PhD thesis.

Paes, F. G., A. A. Pessoa, and T. Vidal
2017. A hybrid genetic algorithm with decomposition phases for the unequal area facility layout problem. *European Journal of Operational Research*, 256(3):742–756.

Palomo-Romero, J. M., L. Salas-Morera, and L. García-Hernández
2017. An island model genetic algorithm for unequal area facility layout problems. *Expert Systems with Applications*, 68:151–162.

Peng, C.-C.
2011. *Optimizing the layout of a grocery/convenience store to maximize revenue from impulse items*. State University of New York at Buffalo.

Pinto, F., C. Soares, and P. Brazdil
2015. Combining regression models and metaheuristics to optimize space allocation in the retail industry. *Intelligent Data Analysis*, 19(s1):S149–S162.

Pires, M., P. Amorim, J. Liz, and J. Pratas
2015. Design of retail backroom storage: A research opportunity? In *Operations Research and Big Data*, Pp. 167–174.

Pires, M., P. Amorim, J. Liz, and J. Pratas
2016. A framework for designing backroom areas in grocery stores. *International Journal of Retail Distribution Management*, 45(3).

Pisinger, D. and M. Sigurd
2007. Using decomposition techniques and constraint programming for solving the two-dimensional bin-packing problem. *INFORMS Journal on Computing*, 19(1):36–51.

Pizzi, G. and D. Scarpi
2016. The effect of shelf layout on satisfaction and perceived assortment size: An empirical assessment. *Journal of Retailing and Consumer Services*, 28:67–77.

Scholz, D., A. Petrick, and W. Domschke
2009. Stats: a slicing tree and tabu search based heuristic for the unequal area facility layout problem. *European Journal of Operational Research*, 197(1):166–178.

Surjandari, I. and A. Seruni
2010. Design of product placement layout in retail shop using market basket analysis. *Makara Journal of Technology*, 9(2):43–47.

Tari, F. G. and H. Neghabi
2015. A new linear adjacency approach for facility layout problem with unequal area departments. *Journal of Manufacturing Systems*, 37:93–103.

Turley, L. W. and J.-C. Chebat
2002. Linking retail strategy, atmospheric design and shopping behaviour. *Journal of Marketing Management*, 18(1-2):125–144.

Van Zelst, S., K. van Donselaar, T. Van Woensel, R. Broekmeulen, and J. Fransoo
2009. Logistics drivers for shelf stacking in grocery retail stores: Potential for efficiency improvement. *International Journal of Production Economics*, 121(2):620–632.

Wang, M.-J., M. H. Hu, and M.-Y. Ku
2005. A solution to the unequal area facilities layout problem by genetic algorithm. *Computers in Industry*, 56(2):207–220.

Wong, K. Y. et al.
2010. Solving facility layout problems using flexible bay structure representation and ant system algorithm. *Expert Systems with Applications*, 37(7):5523–5527.

Wu, Y. and E. Appleton
2002. The optimisation of block layout and aisle structure by a genetic algorithm. *Computers & Industrial Engineering*, 41(4):371–387.

Yapicioglu, H. and A. E. Smith
2012. A bi-objective model for the retail spatial design problem. *Engineering Optimization*, 44(3):243–266.

Appendix A

The methodology used to develop each of the scenarios described in Section 5.5.3 is presented in this appendix.

To develop the first scenario (S1), which does not consider the distance to the sales area, the objective function needs to be adjusted. Thus, the parcel concerning the location of the departments in the sales area is removed from the objective function (please refer to equation A). To develop the second scenario (S2), which does not consider the energy efficiency issues, the parcel concerning the distance between the frozen departments is removed from the objective function (S2 in equation A). Scenario 3 (S3), that ignores the different replenishment frequencies of departments, is obtained by removing rf_k from the objective function A. Lastly, scenario 4 (S4) is attained by removing the equation B.

$$\text{Minimize} \sum_{k \in K \setminus \{KT\}} (\sigma_k^x + \sigma_k^y + \underbrace{\sum_{d \in D} (ds_{kd}^x + ds_{kd}^y) \cdot \gamma_{kd}) \cdot \overbrace{rf_k}^{\text{S3}}}_{\text{S1}} + \overbrace{\sum_{k \in KC} (\xi_k^x + \xi_k^y)}^{\text{S2}} \tag{A}$$

$$\overbrace{\sum_k \gamma_{kd} \cdot rf_k \leq fm_d}^{\text{S4}}, \forall d \in D \tag{B}$$

Appendix B

Table 5.5 – Characterization of store G.

# Dept	Function	Size (m^2)	R.F.	# Formats
1	Store dairy	21	1	2
2	Store delicatessen	28	2	4
3	Store fruits and vegetables	15	19	3
4	Store fish	17	16	2
5	Store bakery	20	2	4
6	Store meat	20	18	4
7	Store poultry	12	5	2
8	Store codfish	10	4	2
9	Store frozen food	30	2	4
10	Store frozen bakery	21	2	2
11	Prepare meat	19	25	2
12	Prepare take-away	17	25	2
13	Prepare bakery	18	25	2
14	Washing area	15	-	3
15	Machine room 1	50	-	5
16	Machine room 2	15	-	3
17	Machine room 3	18	-	2
18	Decoration room	25	-	1
19	Meting room	30	-	4
20	Store manager office	20	-	4
21	Department managers office	40	-	6
22	Lunchroom	33	-	5
23	Male dressing room	40	-	6
24	Feminine dressing room	50	-	5
25	Archive	12	-	2
26	Pharmacy warehouse	8	-	2

Caption:
R.F. - Replenishment frequencies.