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Shelf space allocation methods for nested product categories and virtual segments in retail management

Doctoral Thesis - summary

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Wroclaw, 2022

The allocation of resources is a very common problem in many real-life scenarios; it is one of the fundamental problems in management, economy, engineering, operations research, etc.. In management and economy, resources are considered as savings, investments and expenses, which result in the total cost of production or services. In manufacturing, a resource can be represented as an element of the process with the help of which the goods or services are produced, i.e. material, tools, machines, labour and money. In project management, where the main goal is to deliver projects or programs, resources are provided as people, software or equipment. In telecommunication networks, the resource is determined as the bandwidth of the channel which is shared between the customers. In medicine, resources include medical and health-related materials, personnel and funds, which must be distributed among different patients.

Resource allocation problems are widely discussed in the literature, and several solving techniques are known. Mathematical programming is one of the most effective and widely used modelling and solution techniques. It is defined as the use of mathematical models, especially optimizing models, in the decision-making process. In mathematical programming, some modelling techniques could be specified, such as linear programming, nonlinear programming, integer programming and stochastic programming.

In recent years, shelf space allocation has become very popular among the leading retailers, as well as manufacturers and distributors. Solving the problem of allocating scarce shelf space can lead to significant savings for the company by determining the highest profit or most efficient business strategy. With increased advances in technology and information systems, retail problems become more and more complicated in terms of problem size and changing requirements.

Retail category management is one of the largest sectors of industry worldwide and addresses a series of issues for category managers on critical topics such as product assortment and shelf space planning. Efficient shelf space allocation increases customer satisfaction, provides better visibility of the products and contributes to more sales, which affects retail store organization. Shelf space allocation is a decision problem with the goal of achieving the best possible profit through product allocation under various operational constraints. For small retailers, limited shelf space is the most critical and difficult resource to manage. Allocation of products on the shelves is also a key factor to a store's competitiveness. The increasing number of products displayed in stores has magnified the importance of retail merchandising.

The category planning process includes several levels:

1. Assortment planning means determining which products to display on shelves; it includes listing and delisting products with regard to the substitution effects based on consumer behaviour.
2. Shelf space planning means determining the amount of scarce shelf space for the product, calculating the number of facings and assigning the appropriate position of the product on a shelf by taking into account the facings quantity and location of the product on the shelf, which may influence product sales.
3. In-store replenishment planning involves refilling regulations such as in-store logistics, replenish product amounts and cycles in order to display the required product quantities on shelves.

The presented three tactical planning domains become interconnected if shelf space and replenishment capacity are limited. Careful alignment of assortment, shelf and replenishment planning is of great importance to the retailer. Coordination of shelf replenishment processes and shelf space planning is thus critical, along with in-store inventories. The following interdependent problems may occur:

1. Larger product range implies fewer units per product on the shelf or more frequent replenishment.
2. Increasing the assortment decreases product visibility on the shelves and leads to reduced inventory levels, which raises the likelihood of OOSs and necessitates regular replenishment activities.
3. Several products may lose demand from potential consumers if they are not included in the assortment.

Retailers generally handle category management problems in a specific order: first, they define their assortment, then they distribute it to shelves, and ultimately, they handle in-store replenishment. By determining the interrelated challenges of assortment size, shelf space allocations, and shelf replenishment, retailers can match customer demand with shelf supply.

Category management is a retail management process aimed at enhancing the overall efficiency of a retailer in a product category through better purchasing practices, more organised merchandising, and determining the pricing of the category's products. The whole category management science and its rapid embracement in the retail industry are of great importance to retailers and manufacturers. In addition, long-term planning provides a thorough understanding of new methods of category management.

The extended shelf space allocation problem (SSAP) in retailing management is undertaken in this thesis. The extension relies on including nested product categories and virtual segments and, in consequence, new constraints of SSAP. The SSAP includes the products' category management, where a retailer chooses the store assortment, i.e. the collection of products that are sold in each store. Thereafter he/she defines the number of facings of each product and the positions of these products on the shelves. The retailer's main goal is to achieve the maximum profit or sales from selling product items subject to miscellaneous constraints, the most widely known of which is scarce shelf space for product exposure.

In the real store, retailers must determine how many items of a product to display on the shelves, how long it will take to sell them and how to avoid being "out of stock" (OOS). To perform this task, they use planograms. A planogram is a visual representation of the products in the retail store that establishes the position of the product and quantity of items of the product with the aim of maximizing profit or sales. It helps the retailer to manage the amount of space allocated to each category of products and to determine the amount of space for each product within the category. A planogram contains critical information for operating components. SSAP is the problem of managing the limited shelf space in a retail store among a set of products of a given category. The formulation of the problem depends on the company's strategy, retail segment, communication with vendors, store arrangement and many other factors. Generally, the goal of the SSAP is to obtain the maximum profit or sales out of the available space distributed to the products.

In this research, practical shelf space allocation models aimed at maximizing profit whilst reflecting the retailer's visual merchandising rules are presented. Despite the fact that retail software applications are available and widely used in the shelf space planning process, there are a number of limitations: lack of key-practical merchandising constraints and combining a large number of parameters that are difficult to estimate and require much manual work.

This study is dedicated to the SSAP in order, among others, to maximize the total planogram profit, which was inspired by practice while developing programs for large supermarket chains and analyzing customers' problems and requests. Based on personal scientific interests and professional experience, the important area of investigating shelf space allocation in stores originated and was chosen as the subject of the research in this thesis.

The shelf width of the planogram fixture differs in each store, i.e. each store has a different amount of space where the planogram must be placed. For this reason, the space planning process begins with generating a template of a cluster-based planogram; next, store-specific planograms are created based on the given template.

In addition, while conducting this research, the problem of the lack of an integrated framework of Retail Information System was noticed. Therefore the thesis also includes a framework for positioning the retail business modules of the real retail chain into a retail information system (RIS) framework, which increases the quality of RIS models, which could be initial prerequisites for retail enterprise modelling that is relevant in practice and theory.

RISs are the tools, hardware and software that help retailers achieve goals in the retail sector. They provide lots of functions, including planning, budgets control, revenue targets, and any logistical activity. RIS is intended to improve the efficiency and effectiveness of retail operations. These applications collect information about data configuration, rules of merchandising, forecasting, ordering, pricing, replenishment, store operations, planning, post-season analysis.

The retail market is still growing and getting more dynamic nowadays. Therefore most retailers deploy a specialised RIS to execute targeted market practices. RIS received some attention in the latest retail literature.

RIS management is at the core of the company's productivity. It keeps the system working properly, links all aspects of a company, and enables the retailer to provide services and experiences that consistently exceed the customers' demands. Using information from various outlets, RIS offers a series of experiences that are readily available to decision-makers, allowing them to invest their time considering strategic policy problems rather than collecting data from different omnichannel environments.

It should not be neglected that constant quantitative growth of retail requirements and the scale of applying new methods in category management operation create conditions for beneficial opportunities of improving RIS. To provide context, a comprehensive retail framework is proposed for main retail operations. The proposed RIS integrates eight key topic areas: assortment management, shelf space allocation, planogramming, mobile applications, floor planning, pricing strategies, promotion, store operations.

Nowadays, the retail management process must be supported by RISs. The demand for RISs is rising rapidly. It is critical to understand that all these possibilities for the invention of RIS, and, consequently, for creativity, are beyond our predicting capacity and that these opportunities highlight the importance of combining matter and knowledge as part of creating application in a domain sense. Modern RISs that can provide cognizant, integrated business planning and forthcoming store operations are required. New technologies such as the Internet of things (IoT), artificial intelligence (AI), machine learning, robotics can efficiently process real-time data and bring new business models to retailers concentrating on their assortment, shelf space, inventory, pricing, store operations, as well as predictive analytics software focused on rigorous forecasting and optimising retailer operations, planning and execution. Such strategies undoubtedly assist retailers in fulfilling consumer needs, enhance profitability and improve reliability and customer satisfaction.

The thesis is mainly methodical. **The main aim of the research is to develop new methods of solving the SSAP from the retailer's point of view, extending the classic SSAP with the nested product categories and virtual segments on the shelves.**

Therefore there are two new variants of SSAP proposed in this research: the first one explores the SSAP with nested product categories on a planogram, the second one is dedicated to modelling the virtual segments on the planogram shelves. The goal in each problem is to determine the shelves for the product items and the number of facings, cappings and nestings of each chosen product under the constraints of limited shelf size subject to various additional categories of constraints related to shelves, shelf types, multi-shelves, products, product orientations, feasible allocations, categories and price subcategories, virtual segments and relationships between products. The mentioned problems are more difficult than the classical knapsack problem known from literature; therefore, the solution methods available for this problem cannot be applied here directly, and new metaheuristics or hyper-heuristics should be implemented. The research is motivated by the real shelf space management problems arising in the retail industry.

The epistemological aims of this thesis are as follows:

- **analysis and evaluation of the retail management process;**
- **analysis and evaluation of existing theories and methods of shelf space allocation problems;**
- **analysis and evaluation of the extended SSAPs with the nested product categories (SSAP-N) and virtual segments (SSAP-S) with the help of heuristic, metaheuristic and hyperheuristic approaches.**

The methodical aims are as follows:

- **identification of the components and their properties of the SSAP methods;**
- **developing mathematical models and solution methods for the extended SSAPs with the nested product categories and virtual segments;**
- **developing a theoretical retail information system framework.**

The utilitarian aim is to verify the developed methods using computational experiments performed for the test data which has been generated based on real data characteristics from the retailers' and customers' points of view.

Hence the scope of the SSAP research covers:

- analyzing the retail management process;
- mathematical modelling of practical problems;
- designing and implementing heuristic, metaheuristic and hyper-heuristic algorithms;

- performing computational experiments using data generated on the basis of real data characteristics;
- analyzing the results of computational experiments in order to evaluate the effectiveness of the implemented methods and to gain knowledge about the studied problems;
- developing the RIS framework.

The practical implications of the research are that newly proposed methods on which heuristics are based may be applied to similar SSAPs with slight modification because most of the category management problems share the same problem nature. The methods can be used in retail information systems to support real SSAP decisions in practice.

This study enriches the current literature by simultaneously analyzing different product orientations, incorporating cappings and nestings parameters into the models, categorizing the products based on their price subcategories or frequency of moving the product, allocation of products on different shelf levels and in specific virtual segments on the shelves, and also by investigating more complicated merchandising rules specific to the given store.

The main hypothesis is as follows:

Developed new shelf space allocation methods for nested product categories and virtual segments allow to increase profit of the planogram while allocating products on the shelves.

Auxiliary hypotheses:

- Developed methods allow to decrease computational time compared to commercial solvers.
- Developed methods allow to decrease unallocated free space on the shelves.
- Developed methods allow to improve planogram performance with regards to the substitution effect.

The input instance measures for the developed methods are the number of products, number of shelves, shelf lengths and number of categories and subcategories. The solution performance measures of the developed methods are execution time and total profit.

Shelf space allocation literature is highly influenced by other category management literature such as assortment, pricing, replenishment and inventory problems. The author's investigation of the SSAP identified some **gaps in the literature**. Based on the author's own analysis, the author suggests the following problems as possible retail research features in the SSAP:

1. Most scientists analyze basic SSAP parameters with the aim to maximize the profit function. The basic constraints involve shelf capacity, product facing size, LB and UB of the number of facings and number of shelves for a product, allocation restrictions for a product, profit related to a product. But, in practice, according to the merchandising rules, which differ from supermarket chain to supermarket chain, much more constraints and parameters are taken into account while allocating products to the shelves. For instance, constraints for flexible virtual segment sizes, multi-shelves allocations, nested price subcategories allocated on different shelf levels, more than one product display orientation, capping and nesting allocation constraints are not taken into consideration.

2. Despite the fact that researchers model the SSAP one-, two-, three-dimensionally, the existing literature totally omits product **capping**, i.e. allocation the product on the top of the same product, simultaneously rotating the product on the top in order to push in more products on the shelf; and **nesting**, i.e. allocation the product inside the same product as a basket or plate. This allocation method allows placing many more products on the shelf without extending the occupied shelf space. No model exists that investigates products allocation ways such as cappings and nestings. This gives additional stock keeping units (SKUs) on the shelves, but such models have not been analyzed in the literature yet. The only models that exist carry on some facings horizontally, vertically or in shelf depth using only one selected product orientation.

3. According to the type and the size of the package within which products are provided, the products cannot be allocated at all fixture types, e.g. the big heavy packages of products must be located on a pallet or sweets, and small children's products must be located at a lower level. To the best of our knowledge, this concept is totally omitted in the literature.

4. The next suggestion is to investigate more than one product orientation simultaneously. Obviously, it's better to use the same orientation for one product if it is placed on multiple shelves in order to create better rectangles visible to customers, but sometimes, depending on the product package, it could be faced to the customer on its other side as well as on its previous orientation (product rotation must be performed on all shelves where it is exhibited). Such orientation changing can help to create beautifier blocks concerning the whole category to which product is assigned as well as reducing the occupied shelf space or reducing the rest of unallocated space.

5. Among the next important issues that are commonly disregarded in the current literature, the author highlights the fact that products are categorized based on the frequency of product moving and the product price. Undoubtedly, the most expensive and brand products must be placed on eye levels, and the cheaper products are placed on the shelves below or anywhere where unallocated space exists. Some researches take into account horizontal and vertical position effects, but the author proposes to divide products into price subcategories and allocate them on different vertical shelf levels based on their sales potentials so that the products with the lowest sales potentials should be placed on the lowest shelf but can also be placed on higher shelves. Likewise, the products with the highest sales potentials must be placed on the highest shelf (at eye level) and cannot be placed on other (lower) shelves.

6. Nevertheless, a large number of existing studies have examined allocating products on different shelf levels, other studies report the importance of the direction of customer traffic flow in stores, but a number of questions regarding these issues remain to be addressed, meanwhile, horizontally dividing shelves into segments of flexible size (they could be reduced or extended on different shelves) and allocating such segments to different shelf levels on a planogram, thus creating different ways of product categorization and suggesting places where specific products may be located. The author proposes to differentiate such segments according to product categories (i.e., local (regional) products and convenience (complementary) ones). The question then becomes how to enrich the basic

SSAP profit maximization model with merchandising rules which includes stores' own product promotions, regional product presentation and allocation products on different shelf levels, and also segments near the aisle reflecting the direction of customer traffic flow. Not to mention the suggested SSAP model improves options of allocation products on store shelves, such as eye-level, low-level, and pallet shelf types. Additionally, allocation of complementary products near the main product (e.g. salad dressing is placed near salads, ketchup is near sausages) stimulates customer impulse buying.

Apart from the indicated above literature issues, most of the studies neglect complicated merchandising rules which differ in each store and lie in the responsibility of retailers or suppliers with a deeper knowledge of each category. Merchandising rules are guidelines that determine complex criteria for how the products should be placed and arranged on the shelves based on customers' way of looking for the product on shelves and market basket analysis. Merchandising rules are instructions that describe how items should be placed on shelves based on product families and may contain complicated hierarchical criteria that cover many layers/levels

The research methodology is as follows.

The identification and analysis of the research area was performed in the first step. The SSAP research area was chosen due to the author's scientific interests and professional experience. Selecting an SSAP topic was the main and the most challenging part of the research. Here a review of the literature was done. The SSAP topic is not new and there is a manageable amount of information on this topic. In this step, the existing SSAPs were studied, the premises for new SSAPs were initiated, and gaps in literature were identified. There are a number of places where SSAP information could be found. A keyword search was also performed in different online libraries. A wide range of data sources such as scientific articles, books, magazines, journals, websites and search engines were studied. Next, the research aim, objectives and hypothesis were formulated.

The retail management process was analyzed in the second step. Retail process visualization is an integral part of category management, and it is a vital tool for research purposes. Retail information systems in retail environments pose unique challenges. They are a significant trend in retail management today. The proposed RIS framework handles retail objectives and specifies the place of the SSAP in store business processes.

After analyzing the advantages and disadvantages of existing SSAP models and methods, the new SSAP models were formulated (the third step). Here, new practical merchandising constraints and parameters were included.

In the fourth step, the new SSAP methods for nested product categories and virtual segments were developed. The SSAP solution approaches combine special features dedicated to the proposed SSAP models with nested product categories and the virtual segments of flexible sizes. In some methods such as heuristics, the solution time significantly decreased because only suitable solutions are provided, selected and compared.

In the fifth step, the experiments were conducted. Data preparation is important to achieve research aims and objectives. The data was simulated based on professional knowledge and practical experience. This step also includes processing and analyzing the obtained results.

The last Conclusions step summarizes the main idea of the thesis. It also shows that the objectives have been met. Later it outlines the recommendations for future research directions.

This dissertation is organized into six chapters. The first one presents the introduction, in which the background, motivation, aims and scope of the research are explained. The remaining chapters are organized as follows.

In chapter 2, characteristics of retail information systems, their architecture and their significance are presented.

Chapter 3 summarizes the existing literature. Here the context of assortment and shelf space planning, including the core models and features, are given. Furthermore, the knapsack problem in shelf space allocation models is described. Next, different shelf space allocation approaches are summarized.

In chapter 4, constrained optimization issues and the premises for the development of new methods for shelf space allocation are given. Special attention is given to merchandising requirements which result in shelf space allocation constraints.

Chapter 5 is dedicated to the design of new shelf space allocation methods. Here mathematical models and solution approaches are presented for both problems investigated in this research. They are: SSAP with nested product categories (SSAP-N) and SSAP with virtual segments (SSAP-S). SSAP-N has two extensions: SSAP-N1 (which differs from the SSAP-N with the multi-shelves constraints) and SSAP-N2 (which differs from the SSAP-N with the shelf and category constraints). Moreover, the developed heuristics, genetic algorithms, simulated annealing and their application in shelf space management problems are analyzed. Also, in this chapter, the results of the computational experiments and the impact of the developed methods on improving shelf space allocation processes are described. Results of comparing different methods for both SSAP-N and SSAP-S problems are further presented.

The last chapter 6 provides the conclusions and an outlook on further research topics devoted to SSAP and the discrepancies between scientific modelling and specific retail practice.

The SSAP-N can be formulated as follows. There is a given number of products that are assigned to categories based on their types and price subcategories based on their sales potentials. These products must be allocated on the shelves of a planogram. Generally, the categories are vertical, i.e. shelves on all levels on a planogram can display products of the defined category. The price subcategory is horizontal, i.e. shelves on only one level can be assigned to the defined subcategory. Each shelf is assigned its price subcategory. In consequence, all products are also marked with a price subcategory and are assigned to the category.

The products with the lowest price subcategory are placed on the lowest shelf but can also be placed on the shelves dedicated for higher price subcategories. Otherwise, the products from the highest price subcategory are placed on the highest shelf (at eye level) and can’t be placed on other shelves, especially if they are dedicated to products from lower price subcategories. Products of the same category must be grouped together in such a way that one category is not interrupted by products from the other category. This SSAP-N model presents the retail practice when the more expensive products (from higher price subcategories) are located on the higher shelves (at eye level), the cheaper products (from lower price subcategories) can be placed on the lower shelves as well as on the higher ones. According to merchandising rules, overpriced products cannot be placed on the lower levels. The goal is to determine the shelf space for each product defining the quantities of each product, thus maximizing retailers' profit.

To solve the problem, the task is to find combinations of the number of facings, cappings and nestings of a product which is allocated on the shelf, defining its front or side orientation subject to 5 classes of constraints — shelf constraints, product constraints, orientation constraints, multi-shelves constraints, and category constraints — in order to maximize the retailer's profit. Eight heuristics to solve the planogram profit maximization problem, as well as a genetic algorithm are proposed.

The SSAP-S can be formulated as follows. There are a given number of products that are placed on the shelves on a planogram. Each shelf is divided into virtual segments, i.e. the shelf is visually divided into sections for appropriate products allocation considering their types. There is no visible physical boundary between the sections on the shelf; for this reason, segments are called "virtual". It is assumed that all virtual segments are of identical integer width on the shelf. Virtual segments are used to place some products on the fixed shelf part. Therefore customers notice the shelves with the products, which are grouped by their types or by categories which allow comparing adjacent products easier.

Corresponding to the vertical levels, the shelves are differentiated into pallet (the separate lowest wooden shelf positioned on the floor and commonly used for big packages or heavy packages of products), low-level shelf (commonly used for cheap products or goods dedicated for children), and eye-level shelf (for new, brand or expensive products). Corresponding to the horizontal shelf position and the customers' store traffic direction, there are several types of virtual segments: first aisle, last aisle, local, convenience and central virtual segments. In this problem, it is supposed that there is no more than one local and one convenience virtual segment allocated on one planogram. Otherwise, the first and the last aisle special virtual segments may exist on each shelf on a planogram.

Based on the traffic direction on each shelf, two aisle virtual segments exist, the first and the last ones. The rest part of the shelf is dedicated to central virtual segments which are not located near the aisles. From practice, it is known that at the end of the shelf, customers generally spend less time; therefore, retailers intend to place their ordinary products, the buying decisions of which does not require too much considering. Contradictory, in the middle part of the shelf, customers generally spend more time while shopping as there is the right place to look over the whole shelf assortment. On the grounds of that, the new brands or the most contributive products are located in the central part of the shelf to stimulate impulse buying.

Commonly **local products** are not included in the primary assortment cause of their variety in each retail store. The primary store assortment is prepared using the template planogram, next the local assortment is included in the store assortment of the prepared planogram by the particular retail store. **Convenience products** are unplanned impulse purchases during shopping. They can be an augmentation of the principally selected products and usually placed near the main product (e.g. dressing and spices are convenience products on the main fresh vegetable planogram). Allocating products on the shelves trying to form rectangular shapes in local and convenience virtual segments supports their better visibility.

To solve the problem, the goal is to define the number of facings, cappings and nestings of a product allocated to the shelf defining its front or side orientation and considering 5 classes of constraints: shelf constraints, product constraints, orientation constraints, multi-shelves constraints and virtual segments constraints. Moreover, each product must be assigned to the suitable subset (i.e. subsets before, after or inside the special virtual segment) on the shelf. The goal is to maximize the total retailer's profit. A method that finds an optimal solution on pallet shelves was developed. Metaheuristic and hyper-heuristic algorithms are implemented for other shelves. **The genetic algorithm incorporates three practical methods of improving results (increasing shelf ratio, increasing shelf profit, reducing free shelf space). The simulated annealing also includes result improvement methods as well as product reallocation methods.**

This research investigates heuristic, metaheuristic and hyper-heuristic approaches in order to maximize the total planogram profit. Retailers are interested in various approaches which can find a balance between satisfying customer requirements while minimizing lost revenue and maximizing achieved profit. By reason of this, there is the growing interest of practitioners in developing heuristics, metaheuristics and hyper-heuristic for retail shelf space allocation.

Computational experiments are based on simulated retail data generated with regard to real retail conditions. The efficiency of the proposed methods was evaluated using a CPLEX solver. Among the main benefits of the proposed approaches is their applicability in practice, as they make it possible to obtain sufficient results for small and large product instances in acceptable running time.

This research proposes 8 heuristics for the 2nd modification of SSAP-N (SSAP-N2), the basic ideas of which can be implemented while solving similar category management problems. Heuristics $H_1 - H_3$ are applicable for small instances; otherwise, heuristics $H_4 - H_6$ are used especially for large instances because they propose methods of processing large amounts of data in a short time. Heuristics $H_7 - H_8$ can be applied to all data. The explanation of all methods also includes an example of steering parameters selection.

To evaluate the performance of the proposed heuristics, 45 test cases were analyzed. Among them, developed heuristics obtained the solutions in 34 cases while CPLEX only in 23 cases. The average profit ratio of the proposed heuristics is 95.35%, with its minimal and maximal values of 87.78% and 99.84%, respectively. Time for looking for a maximum feasible solution on average varies from 16.79 s up to 8.74 min comparing all heuristics.

The main feature which characterizes the proposed method and set it apart from other ones is the lack of randomly generated or randomly chosen elements as at first the solution of the decision problem is obtained, next the optimization problem is solved. In other words, initially, it is determined if the product fits the shelf; later, the feasible number of facings for each product is adjusted. Furthermore, the data on all processed steps can easily be checked and analyzed; steering parameters can be chosen.

This research proposes a genetic algorithm (GA) for the 1st modification of SSAP-N (SSAP-N1). To evaluate the performance of the proposed metaheuristics 25 test cases covering different parameter sets were analyzed. The average profit ratio of the proposed GA within the same and maximum time intervals as the best solution is 78.64%, with its minimal and maximal values of 59.08% and 94.20%, respectively. The profit ratio within the average time interval slightly differs and equals 78.65%, with the same minimum and maximum values of 59.08% and 94.20%, as a consequence. The time for looking for the maximum feasible solution on average is 3.40 min and varies from 22 s up to 15.61 min.

In five cases out of 20, the shelf allocations were not found. Such test cases model category managers mistakes so that the solution could not be found on initial input data. The real situations involve the following scenarios: too many products are tried to be placed on too short shelves; the shelf height is too low for such products; too many products are tried to be placed in the upper price subcategories locations, so in such a manner they must be explicitly moved to the upper shelves, which results in that the lower shelves are not fully filled, etc.

This research proposes GA for SSAP-S. The same 25 test cases were used to evaluate the performance of the proposed GA. Within the same as GA execution time set to CPLEX, the average profit ratio GA to CPLEX was 96.01% with its minimal and maximal values 80.62% and 126.07% consequently. In 7 cases, GA found better solutions than CPLEX.

This research proposes a simulated annealing (SA) hyper-heuristic algorithm to solve the SSAP-S. SA is a methodology for handling combinatorial optimization issues. The performance of the SA algorithm was also examined for various data sets. The 25 test cases are the same as in the previous tests. Within the same as SA execution time set to CPLEX, the average profit ratio SA to CPLEX was 99.16% with its minimal and maximal values 84.92% and 123.68% consequently. In 10 cases, SA found better solutions than CPLEX.

This demonstrates the reasonability of the proposed solution improvement techniques. In the test cases where GA and SA found worse results than CPLEX, the achieved profit gain was less than the time spent for obtaining it. Therefore less improvement was implemented in order to get the result faster. Such decision is valuable for the retail stores, thus generating planograms on large problem instances with profit ratio even less than 80.62% for GA and even less than 84.92% for SA but obtained in a reasonable time - 21.80 min on average for GA and 30.17 min for SA - helps to get much money.

In this research, new heuristics, GA and SA, were implemented because these are efficient and effective methods for solving optimization problems. Different variations of them are widely applied in business, management decisions, as well as solving various scientific and engineering problems. The concepts of heuristics, metaheuristics and hyper-heuristics are easy to understand and implement.

The author builds and solves the SSAP from the retailers' point of view to better address the challenges reported by the retailers and match actual requirements with relevant and appropriate decision models. As a result, on the basis of the findings from collaboration with practitioners, this study provides a realistic approach. The investigated SSAP considers capping and nesting allocation possibilities and allows for the efficient resolution of retail-specific problem sizes.

The research makes the following contributions:

- Presenting practical retail SSAP models (SSAP-N1, SSAP-N2, SSAP-S) with regard to the multiconstrained SSAP and visual merchandising features.
- Investigating allocation of products on different vertical levels based on their price subcategory (SSAP-N).
- Investigating allocation of products on different horizontal shelf segments based on the products nature and utilization as well as based on the customer traffic inside the store

(SSAP-S).

- Including not only facings but also cappings and nestings product parameters in all presented SSAP models.
- Adjusting the SA hyper-heuristic for solving the retail SSAP (SSAP-S).
- Adjusting the GA metaheuristic for solving the retail SSAP (SSAP-N1, SSAP-S).
- Developing fast heuristics to the retail SSAP (SSAP-N2) with a preceding product to shelf allocation enables to obtain only appropriate solutions which satisfy all constraints.
- Implementing solution improvement (in SSAP-N1, SSAP-S), product reallocation (in SSAP-S), mutation (in SSAP-N1, SSAP-S) procedures enable to obtain a more profitable solution within a small number of iterations.

The selection of the solution method significantly depends on the nature of the problem. Compared to GA, SA is a single solution based technique, while GA is a population-based technique. Next, SA has only a search space exploitation function, but GA has both exploration and exploitation functions. GA generates lots of solutions that depend on the population size. This significantly increases processing time.

GA operates on a large and wide solution search space. This signifies that GA can process diverse solution representations and construct a solution based on the population of individuals, not from a single individual. In GA, the solution improves (or does not worsen) on each subsequent iteration. Contrary, SA accepts better and worse solutions which help to achieve a more extensive search for the optimal global solution.

Furthermore, multiple constraints checking in complex SSAPs and intermediary result correction is required in each operation of the GA framework, such as selection, crossover, mutation. This also increases the computational time in enhanced retail SSAP models. The developed solution improvement, reallocation and mutation procedures help to achieve the solution of better quality faster enough (within less number of iterations).

The obtained results for SSAP-N prove that vertical categories and horizontal price subcategories, as well as product parameters, has a considerable impact on the profit received by the retailer. The results for SSAP-S also confirm that horizontal dividing shelf into virtual segments and allocating of products on different levels as well as product parameters have a significant impact on the total profit. The experiments also present that the proposed method allows obtaining a sufficient solution in an acceptable processing time for both small and large instances. The proposed in this research approaches can be implemented in RISs. In this study, a structural framework that includes the main business modules applied to retail business was also provided. Such types of retail information system frameworks strengthen the performance of RIS models and the initial necessary conditions for retail sector modelling that are applicable in practice and theory. RIS tools may also be required to combine all financial data in order to record expense reports and ensure that the retail company has a comprehensive understanding of all operational costs and their accuracy. Therefore the second methodical aim (developing a theoretical retail information system framework) has been achieved.

The key benefits of the use of powerful RIS frameworks can be summarized as follows:

- Utilizing open shelf spaces in the stores to maximize efficiency.
- Ensuring that the right items are distributed to the right positions in the right stores.
- Improving customer loyalty with the availability of assortments and presentation of planograms.
- Reduction of OOS expenses which maximizes revenue in the product category.
- Improving the employees' productivity and facilitating the creation of a working schedule for them.
- Compatibility with other systems, e.g., forecasting, inventory and replenishment systems) that enable connectivity with the supply chain.

This research is an important contribution both for academic society and retail practitioners. Moreover, the proposed methods can be implemented in retail information systems. The findings demonstrate the effectiveness and efficiency of the proposed methods by comparing the outputs to the CPLEX solver solution for small data sets and the method performances for large data sets. The solution approaches are expected to enable a continual decision-making process for retailers in order to optimize revenue.

The customer is a core element of retailing. In the especially competitive retail environment of today, there is absolute certainty that retailers can benefit from analytic solutions in dealing with category management, which can help to increase their profitability. This thesis is a vital contribution to this direction which aids in using new heuristic, metaheuristic and hyperheuristic approaches in real retail issues.

Retailing operations involve a decision-making process. The developed approach allows sellers to make rational decisions to maximize revenues. The SSAP determines the best combination of product mix allocated on store shelves. Because shelf resources are limited, it is necessary to make choices as to the correct product on the right shelf with appropriate space allocation. The approaches presented in this study are beneficial to retailers seeking professional guidance on ways that might be utilized to solve the SSAP, allowing them to optimize profit, decrease lost income, and strike a balance between guaranteeing customer satisfaction and dealing with various input channels. From the retailer's point of view, the importance of this cannot be ignored.

As the retail sector grows and diversifies, retailers' choices become more critical and difficult. Product selection, shelf-space allocation, and replenishment decisions all have an impact on profit, thus retailers want a tool to assist them in making these decisions in order to maximize profits. There is no doubt that if the products are placed on appropriate shelves and their number of facings is efficient, this strategy will definitely increase the product's sales and improve the retailer's business. Otherwise, it could be a waste of shelf resources for the retailers.

This work provided an overview of recent retail management including SSAP topics, the state of the art for researchers and practitioners. In this work, an effort was made to perform a review of retail shelf space planning literature and of the most relevant topics. Therefore epistemological aims have been achieved.

In order to achieve the utilitarian aim, verification of the developed methods using computational experiments performed for the test data generated based on the real data characteristics has been done.

Because of the nature of the examined SSAP-S problem and the fact that there is only one pallet shelf on the floor in the real store, it could be evaluated separately from the other shelves. Despite many more constraints than in the classical knapsack problem, in this research, the dynamic programming approach is developed for a pallet shelf, which allows to find an optimal solution on that lowest shelf. For other general shelves in SSAP-S GA metaheuristic and SA hyper-heuristic are proposed. GA is also implemented for SSAP-N1. Different mutation techniques are proposed in GAs for SSAP-S and SSAP-N1. Both GA and SA incorporate solution improvement techniques. In addition, in SA, the product reallocation method is proposed and implemented. Separate GA and SA procedures could also be applied as a component for solving similar practical SSAPs. The in-depth knowledge about the modelled SSAPs and the explained methods provided inside the solution approaches can help the retailer to improve business optimization and thereby increase profits. This information proves the main hypothesis. For SSAP-N2 new heuristics, the main characteristics of which are the lack of randomly generated or randomly selected elements are proposed. Interestingly, that data in all steps of heuristics execution are visible to the retailer, they can be easily analyzed, checked or the number of intermediate parts of solutions could be adjusted by the coefficient steering parameters. A further novel finding is that the nature of heuristics allows to quickly check constraints and reject allocation that would be incompatible with the defined constraints before starting the execution of heuristics. This reduces computational time significantly. That's why the heuristic-based methods of solving the product to shelf decision problem in advance are so important. This confirms the first auxiliary hypothesis.

When a brand's price rises, the substitution effect occurs, resulting in a drop in sales due to consumers choosing cheaper alternatives. A product's market share may be lost for a variety of causes, but the substitution effect is one of the main factors in this. Some customers choose a cheaper option if a company has increased its pricing. In the developed SSAP methods, cluster constraints are included, which means that the products affected by the substitution effect are grouped in a cluster and placed on the same shelf. This factor confirms the second auxiliary hypothesis related to product substitution. The substitution effect is most vital for products placed close to their substitutes.

Because the developed solution of the SSAPs assigns the most appropriate number of product items to the shelves, this allows reducing unallocated free space on the shelf due to the OOS occurrences. This confirms the third auxiliary hypothesis. Consequently, unallocated shelf space also results in additional costs for the retailer, so it is better to reduce it as much as possible.

The developed methods can be implemented in modern retail information systems.

The investigation of SSAP performed in this study intends to promote further research of the application of RIS and shelf space optimisation methods in the real retail chain. There are many ways to bring these techniques into retail modules in practice. However, in real situations, since separate RIS modules typically belong to multiple organisational hierarchies or external companies, there may be barriers in integration and control of their functions in practice. There is also a necessity for a deeper knowledge of certain essential issues: the IoT, virtual reality, augmented reality, cognitive agents and AI. The main limitations of the approaches proposed in this study for SSAP-N and SSAP-S are:

- Examining a single product category's planogram.
- The suggested models have no time-dependent variables.
- No perishable products, such as daily deliveries, are investigated.
- The proposed models do not include the nonlinear profit function (e.g., space elasticity and cross-space elasticity effects).
- No data on products sold in multipacks.

Further limitations of the proposed approaches for SSAP-N are:

- Only one customer direction is investigated with regard to the product price subcategory.
- A lack of possibility to define product positioning for each product inside the category and subcategory.

Further limitations of the proposed approaches for SSAP-S is:

- A lack of possibility to define product positioning for all products, rather than just for specific ones.

The limitations of the SSAP-S and SSAP-N models developed in this work suggest several practically relevant future research directions. The first is to maximise the profit of product groups (not only cluster products) rather than individual products. Following that, the future model might include supply chain choices, as well as the timetable and delivery costs of products from warehouses to retailers. Finally, the proposed algorithm would place products on the correct shelf or shelf section. This refers to the practical feasibility of product allocation without providing the precise row or column number. As a result, various sorting or grouping (e.g., by price, brand, category, etc.) approaches may be used as an extension of the approach in the following study, with the product location on the shelf or the adjacent products restricted. A suggestion for further analysis is to determine exact linear coordinates for each product. Next, different constraints of store layout could be taken into account. Moreover, it would be interesting to expand the proposed SSAP models with the goal of maximising customer traffic. In addition, the model should incorporate clockwise or anti-clockwise customer direction. Because the SSAP models do not deal with the nonlinear profit function, shelf space elasticity and cross-space elasticity effects parameters can be added and investigated. Product package types and multipack sales are also recommended for future studies. All of these issues may be taken into account in future research.

Another future research opportunity could include the solution of the SSAPs with different meta-heuristics, such as tabu search, particle swarm optimisation, ant colony optimisation or neural network-based optimisation. The results of the GA and SA heuristics proposed in this research could be compared to give a better understanding of the new approaches' efficiency.

Furthermore, it could be interesting to combine machine learning and optimisation techniques to solve the retail SSAPs. That is, more recently, there has been a much greater focus on artificial intelligence and machine learning which might be the next step in developing effective methodologies to help retailers deal with these kinds of problems.

Future research in the RIS framework can be related to combining retail know-how to maintain date-sensitive and temperature-sensitive goods to minimise spoilage and maximise the number of fresh products that consumers demand and to providing up-to-date connectivity with other retail platforms in order to accelerate the speed of real-time decision-making by access to consolidated results across all retail chain stores.

By drawing attention to the investigated problem, this research can stimulate similar studies and encourage the use of optimisation techniques in other fields of category management. The results obtained in this research can also be implemented in RISs in shelf space allocation modules.