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Optimization of shelf space using OR techniques

Janhavi Nangrepatil
janhavinp@gmail.com
SVKM's Narsee Monjee Institute of Management Studies, Mumbai, Maharashtra

Harsh Mehta
harshmehta5396@gmail.com
SVKM's Narsee Monjee Institute of Management Studies, Mumbai, Maharashtra

Jay Garkhel
garkheljay@gmail.com
SVKM's Narsee Monjee Institute of Management Studies, Mumbai, Maharashtra

Harshit Shah
harshitshah040@gmail.com
SVKM's Narsee Monjee Institute of Management Studies, Mumbai, Maharashtra

Harshit Nagpal
harshitnagpal2@gmail.com
SVKM's Narsee Monjee Institute of Management Studies, Mumbai, Maharashtra

ABSTRACT

This research paper focuses on shelf space optimisation in supermarkets or retail stores. Mathematical techniques have been used in the context of operations research in order to arrive at a set of findings. Through this research paper, methods of product placement on rack and shelves used in stores has been explained. Optimisation and linear programming methods have been used to find the optimal product placement. Binary integer programming has been used which uses a only two decision variables to come to a conclusion whether to place a certain product in a certain rack/shelf or not. The literature review also highlights work done in the past by other researchers in this field. Consumer psychology has also been explored to a certain extent when it comes to purchasing a product. The logic behind product placement has also been highlighted. Through the findings of this paper, basic decision making that goes behind product placement has been shown. Findings in the research paper are done on a small scale which is why several factors like shape, size etc. of the product have been ignored.

Keywords— *Operations Research, Shelf Space, Optimisation, Linear Programming, Binary Integer Programming, Product Placement, Stores, Consumer Psychology, Simplex, Excel, Solver*

1. INTRODUCTION

Every time you walk into a supermarket, you're unknowingly walking through a maze of carefully placed products that would reap in profits for the store. Operations research plays a huge role in determining these profits. Every bar of soap is given a specific spot on a rack which if changed could result in consequences for the store. The shelves in a supermarket are arranged in such a manner by the time you finish walking from the entrance of the store to the cashier, you've picked up products that caught your attention, without you actually needing them. In this manner, supermarkets and department stores trick their customers to spend more without them realising. Each and every item placed on a shelf is put there very carefully considering different factors but the main one being profit maximisation. In this research, we have tried to find one such solution for the proper and efficient optimisation of shelf space in stores. The techniques in focus are optimisation, linear programming and binary integer programming. With the help of these three concepts the objective of this paper will be achieved. The OR techniques that will be used are effective to ensure profit maximisation using already existing sales data or historical sales data that has been collected and collated by any particular store. Binary integer programming will be under focus since it helps us to come up with a solution with the help of only a yes or no decision variable and simplifies the process.

2. LITERATURE REVIEW

Optimisation is used to find the maximum or minimum value of a function which has constraints that are specified by the user according to the situation in question. Optimisation is used widely to maximise profits and minimise costs in businesses. The function that needs to be optimised (minimised or maximised) is the objective function and the alternatives available is the feasible region (FR). We will be using one such optimisation method i.e., Linear Programming to see how shelf space is optimised in supermarkets or retail stores. A hypothetical situation will be used in our research in order to make the solution clear and simple to understand.

Linear programming also known as linear optimisation is a strategy used for achieving the best possible outcome such as highest profit or lowest cost in a mathematical model with needs represented by linear connections. If such a point exists in the feasible space, a linear programming algorithm identifies it by finding the point where the objective function has the least (or biggest) value. The Simplex Approach is the most widely used algorithm for solving linear programming problems (Akamsha Maria Babu, 2021). LP is equally accessible and understandable to students even from limited mathematics background because it can be explained using a graph, has a simple solution method along with generally available LP software packages and large range of applications make LP. Furthermore, because of the robust tools for post-optimality research established for the LP model, LP gives a great chance to introduce the concept of "what-if" analysis (Arsham).

Linear programs can be expressed by:
1. Decision Variables
2. An Objective function: Must be linear
3. Constraints: Must be linear equalities or inequalities.

Linear Programming (LP) can be used for discovering the best way to allocate scarce resources and has found practical application in every aspect of business, from advertising to manufacturing planning. The most common applications include transportation, distribution, and aggregate production planning problems. For example, in the petroleum business, a data processing manager at a prominent oil company recently estimated that 5% to 10% of the firm's computer time was spent to the processing of LP and LP-like models (Arsham).

Linear programming is a type of programming issue in which both the objective function to be maximised and all relationships between variables related to resources are linear. In the late 1940s, this problem was originally articulated and addressed. Since then it has had a broad range of practical commercial, commerce, and industrial applications while also receiving such comprehensive theoretical development in such a short period of time. Today, the theory is successfully used to solve problems such as capital budgeting, advertisement, product placements, resource distribution and allocation, diet design, resource conservation, strategic games, economic growth projection, and transportation systems. In recent years, linear programming theory has also aided in the resolution and unification of numerous notable applications (Arsham).

An objective function and a set of constraints are at the heart to solve any LP problem; like when you seek to achieve a desirable goal, you will notice that the environment places some limits (i.e., problems, restrictions) in completing your desire or purpose. (Arsham)

In the following paper we shall take one such business problem and try solving it through the linear programming to create an optimality in the business. Have you ever noticed that whenever you go to the supermarket to buy something, you notice the centre shelf first, followed by the top and bottom shelves? This is in contrast to our usual sequential behaviour, in which we prefer to begin at one end and terminate at the other. Of course, we frequently begin at one end of the market and work our way around to the other, but we always begin at one of the shelves, which is generally in the centre (Modi, Thondamallu, Veetil, & Sagar, 2018).

Does this imply that having a product on the middle shelf will attract more attention and result in more sales? Yes, it is why things in a retail store are placed in a specific order regardless of which store you visit. This is carefully picked based on the items' popularity and demand. With cutthroat rivalry between behemoths like Walmart and Target, D-Mart and Big Bazaar, etc. looking into every potential to increase sales includes the critical duty of shelf placement as one of the first duties (Modi, Thondamallu, Veetil, & Sagar, 2018).

With increased data and new stores opening up all the time, we have terabytes and petabytes of data to evaluate and decide on each brand's marketing plan and their demand and supply cycles. LP helps us in evaluating this data of choices depending upon the previous sales for obtaining the optimal placement positions of the products in the different shelves in different aisles. (Modi, Thondamallu, Veetil, & Sagar, 2018).

Integer Programming which is a subset of Linear Programming (in which the decision variables must be integers) can be used to solve these kind of shelving problems. We'll work on an Integer Programming problem that has just binary 0-1 outcomes.

Binary integer programming also known as zero-one linear programming is a mathematical method which allots each variable a distinct value of either 1 (Yes) or 0 (No). The respective numbers may represent either the selection of or the rejection of an option when there are mutually exclusive options. Bounded Integer which are variable can be expressed as a pair of the binary variables.

There are two main reasons for using integer variables when modelling problems as linear program.
1. The integer variables represent only in integer quantities for example it is impossible to stock 4.2 bottles of water.
2. The integer variables represent distinct decisions hence they take on values of 0 and 1

In addition to helping capital rationing problems, binary integer programming assists in planning, transportation and production of goods and services. It is a mathematical program connecting the goal of solving various problems is choosing the correct the course of action (Chinneck).

3. METHODOLOGY AND ANALYSIS

The problem of shelf space is one of optimization. Apparently, the complexity of shelf space allocation can be considerably decreased by optimization. Optimization can happen only when there are restrictions to an issue and shelf space contains a lot of constraints. This includes, among other things, shelf space, the size of each item, the number of shelves, aisles, and different sorts of merchandise. It's difficult to tell which product should go on which shelf based on this information alone in order to maximise sales. These figures can reflect product sales or sales growth, but regardless of which approach you use, the result and procedure will be the same. Choosing the best route from one location to another from a range of possibilities, as well as managing your monthly budget in terms of bills, expenditures, and savings, are examples of optimization.

We need to have data as well as constraints defined in separate cells in Excel. Linear programming is available as a plug – in solver. It can be activated by going to File -> Options -> then Add – Ins and checking the Solver add – in. Solver is located in the data tab's rightmost ribbon. Before we can solve, the solver will display a dialogue box in which we must fill out all of the fields. Our goal function was to maximise the sum of the sales – matrix and 0-1 matrix multiplications. This can be accomplished by taking the sum of the two matrices. We will choose a solver and a target cell. The entire 0-1 matrix's cells must be changed. The constraints will then be added as the two constraint rows to be less than or equal to 1. Finally, we will use the simplex method to solve the problem. By selecting solve, you can quickly find a solution to the problem. It is worth noting that the solver tries to keep each product on the shelf for as long as possible in order to maximise sales, but this is not possible for all products. If there are two products with the highest sales on the same shelf, it will choose the one with the higher sales. This shelf space example is relatively simple, and the answer is 1103 on solution. In practise, the number of shelves and products are not equal, and products can be stored on multiple shelves. Furthermore, their sales on different shelves are not random numbers, but rather follow a pattern based on the shelf. These complexities may be beyond the capabilities of Excel alone.

Methodology to obtain maximum sales using excel:

1. Number of restrictions and specifications are selected.
2. Two matrices are prepared, *Table 1* consists all the values that will be assumed and *Table 2* consisting as 0 as all values.
3. Sum of all rows and columns is obtained.
4. The sum-product function on excel is used to get a unique value with respect to both matrices.
5. Solver is used to set the value of the sum-product to maximum since the objective is to find the maximum sales. *Table 2* is selected in order to add constraints. Constraints are entered in a manner that only 1 product will be placed on each shelf in the three racks.
6. Solver provides a solution where only 1 product is placed in each shelf so that the sales can be maximised.

The following example contains 9 shelf spaces and 3 racks.

Table 1: Matrix A

Matrix A	Shelf	Company 1			Company 2			Sum
		Product 1	Product 2	Product 3	Product 1	Product 2	Product 3	
Rack 1	1	148	105	162	116	158	126	815
	2	180	148	193	160	148	134	963
	3	133	113	191	129	159	186	911
Rack 2	4	136	144	148	165	176	177	946
	5	149	173	156	101	126	193	898
	6	114	177	164	177	195	187	1014
Rack 3	7	107	134	172	101	170	176	860
	8	135	169	161	106	119	169	859
	9	176	107	187	111	193	140	914
	Sum	1278	1270	1534	1166	1444	1488	

Table 2: Matrix B

Matrix B	Shelf	Company 1			Company 2			Sum
		Product 1	Product 2	Product 3	Product 1	Product 2	Product 3	
Rack 1	1	0	0	0	0	0	0	0
	2	**1**	0	0	0	0	0	1
	3	0	0	**1**	0	0	0	1
Rack 2	4	0	0	0	0	0	0	0
	5	0	0	0	0	0	**1**	1
	6	0	0	0	**1**	0	0	1
Rack 3	7	0	0	0	0	0	0	0
	8	0	**1**	0	0	0	0	1
	9	0	0	0	0	**1**	0	1
	Sum	1	1	1	1	1	1	

Solution = 1103.

The solution 1103 (Rs.) is the maximum number of sales (obtained by finding sum product of both matrices) that would be achieved by the combination of product placement that would be made in the shelves with the help of the binary integer problem solved with the help of Excel. The highlighted cells represent the shelves in the three racks where each product would be placed. Each position ensures the highest possible revenue for each product placement. Since the condition that we have given is that each shelf only holds one product, any changes in this product placement would result in a loss of revenue.

4. FINDINGS AND CONCLUSION

The results of this study show how beneficial operations research can be in optimising shelf space. Supermarkets, in general, strive to capitalise on client attention points in order to increase sales and income. Companies such as Walmart, Big Bazaar, and Target have tried these techniques in the past, and they have shown to be effective in increasing sales. Shelf space optimisation can also assist customers in purchasing not just the finest deal for them, but also the most profitable item for the supermarket. The use of operations research in this study was very helpful in determining the best places for a variety of products in order to maximise revenue and keep customers satisfied. The final choice, based on the approach of Linear Programming, reduces the risk of ambiguity and errors, providing a strong foundation for picking the best positions for products and optimising shelf space. As a result, we may infer that by optimising shelf space, Operations Research aids in attaining the optimal equilibrium between customers, the supermarket, and it's revenues. We can see that operations research can also intertwine with concepts such as consumer psychology since it tests the consumers' tendencies while in a store. Thus, we can conclude that using simple methods such as binary integer programming can help businesses to a great extent.

5. LIMITATIONS

Apart from the knowledge that we got form this research, A few limitations that we observed and found while doing the calculations and research are as follows:

- With the present mode of COVID 19, we were unable to get a practical exposure of our topic. As a group all of us worked online if instead we could have met personally and visited stores and actually observed the way the products are placed and seen how it affects in maximizing the sales. It would have given us a practical aspect of the topic.
- As the problem was not large it was possible for us to do it on Excel with the help of few references. However further on excel too there are constraints and is not feasible for problems of large size. Also, for problems where there are too many constraints it would be strenuous to solve on excel
- Using spreadsheets for optimization becomes unmanageable for day-to-day operations and also excel has a finite scalability hence using other sources like Python, CPLEX and GUROBI are useful as it has better speed and results and proves to be a better environment as also Gurobi accepts Python codes directly. These commercial solvers have an edge over Excel as it can only handle limited number of decision variables.

6. RECOMMENDATIONS

- Binary integer programming gives us information about placements of the goods in the shelf based on quantity and number of racks, but it leaves out very crucial information about the sizes of the goods, the purchase pattern, etc. For an optimal solution there are a number of variables other than quantity of goods and racks that shall be taken into consideration.
- It is recommended to set the dimensions of the racks according to products for optimality.
- To increase profits arrangements should be made on price factor in place of quantity or size.
- Racetrack Aisle Network can also be used for ideal results as it takes customer behaviour and revenue into its core consideration.
- Allocation is also recommended to be done according to the brands, as this can help not only in the marketing, but also for creating an image for the store itself when fast moving brands and their products are easily available.
- A strategic allocation is also recommended, which is allocation with respect to latest trends, tastes, demographics, season, time, etc.
- Shelf space elasticity should also be taken into consideration that is the ratio of relative change in unit sales to relative change in shelf space. Positive change in space allocated to a brand brings positive change in sales. This change may or may not be a linear function.
- We should also keep inter product and brand elasticity in mind as sales of one brand or product can have impact on others.

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