Decision Modeling and Analysis of Category Pricing and Shelf Space Management

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Abstract:

Category management emphasizes that each retail store has its own characteristics and that each product category of the store represents a strategic business unit. The main purpose of applying category management approach is to create a true customer centered retail environment so that the store can quick response customers' needs to deliver the right products, right amounts to the right places with the shortest time.

In this paper, we discussed the execution structure of retail category management with the considerations of category assortment, shelf space allocation, inventory service level, and price determination. A mathematical model was formed with an objective to maximize the category profit and the features of the model were explained in detail as well. We then applied a heuristics algorithm called simulated annealing to solve the model and simultaneously undertake experimental verification by checking the factual information from a large retail store in Taiwan. According to the results of the experimental information, profit benefits were improved under the model of category management. This study reveals that the construction of the execution structure of category management provides proprietors the implementation guides for category management. Also, the model of category management and the formula mathematics provide them practical usage in decision making.

KEYWORDS: category management, retail pricing, shelf space management, decision modeling

1. Introduction

Product selection and allocation are two key decision factors for retail store management. The performance of each retail store is primarily based on its sales, profits, and number of customers that all three elements are determined by whether the store can provide the right product at the right time, right place with lower price to customers. In order to provide right product with lower price to customers and also make bigger profits, store managers need to provide all sufficient products with lower operations cost in limited shelf spaces. Therefore, store managers need to decide which product can make more contribution to the store and how many units to keep them (i.e., SKUs). A fairly new management approach called Category Management (CM) was proposed in early 90s to solve this problem. The concept of CM is to see each product category of the store as a business unit that each category is evaluated according to its performance and contribution to the store. In addition, product items are reviewed within category that bigger contribution items are allocated more shelf spaces and less contribution items are allocated fewer shelf spaces or even dismissed from the store. The CM approach, due to its category-based decision process, is more customer oriented and can provide a better responsive environment to fulfill customers' needs. This approach is quite different from traditional brand management for easier promotion and supplier control. In addition, brand management has its other merits such that the "Darwinian" effects (Zenor, 1994) to make the best brand surveying in market and provide a more competitive environment and better products. However, to dates, consumers are becoming more price sensitive and less loyal to brands especially for fast moving consumer goods (FMCG), therefore, applying CM is one of the best ways to quick fulfill customers' needs with lower price.

There have been a number of papers and articles published in CM area with the discussion primary focus on CM introduction and implementation procedures (e.g., Billson 1998, Bettigole 1998, Thayer 1997, Beninati et al. 1997). In addition, in marketing area, there are also some papers published with the discussion on product pricing (Zenor 1994, Manning et al. 1998, etc), shelf space allocation (Hansen and Heinsbroek 1979, Corstjens and Doyle 1981, etc), and promotion (Balachander and Srinivasan 1998, etc). However, most of these papers did not solve the problems from CM perspective or to solve the product pricing, shelf allocation, and inventory level issues simultaneously. Thus, in this paper, we discussed the execution structure of retail category management with the considerations of category assortment, shelf space allocation, inventory service level, and price determination. A mathematical model adopted and modified from Borin et al. was formed and a heuristics algorithm was developed to solve the CM problems.

2. Literature Review

There are several definitions of CM. Among them, Nielsen (1992) proposed that CM is a process that involves managing product categories as business units and customizing them on a store-by-store basis to satisfy customer needs. Joseph (1996) interpreted that CM is a method whereby vender and retailer team up to manage their mutual product categories on a store by store basis. Followed by Dussart (1998) suggested that there are three assumptions of CM processes which include (1) purchasing decision made based on and within the same category, (2) relying on a shift attitudes between suppliers and retailers, and (3) credibility relying on typical business-oriented benefits. In addition, the implementation successes, pitfalls and future scenarios of development are also stated. KSA (1993) proposed an organizational structure based on total profitability rather than vendor profitability by purchase. It would encourage increased concentration on consumer needs by allowing a category manager to offer the optimal breadth and depth of product to consumers. There were also some other papers discussing the issue of CM such as Carpenter and Lehmann (1985), Chernatony (1996), Dan (1998), Dewar and Schultz (1989), Hagel and Rayport (1997) etc.

In addition to the discussion of CM, a number of papers were published to discuss the issues of marketing decision and modeling in general (e.g., Borin et al. 1994, Curhan 1972, Lee 1998). For the issue of space allocation, Anderson and Amato (1974) suggested that the space allocated to each product item should be a positive ratio to the customer preference. Corstjens and Doyle (1981) proposed that the product demand and various costs need to be considered while solving the shelf space allocation problems. Brown and Lee (1996) developed a mathematical model with primary the consideration of shelf space and to maximize the total profit with respect to space allocation and arrangement. There were also a number of papers discussing the issue of pricing specifically such as Raju (1992), Walters and Bommer (1996), Inman and McAlister (1993) etc. In particular, Rao (1984) pointed out the difference between the marketing perspective and the Economics perspective to develop the pricing model is that the former perceives price as a decision variable but the latter as a known data. Walters and MacKenzie (1988) suggested that the objective of the retail store might not only restrain to the sales volume but also need to consider other objectives like store profits and store traffic. The category performance and contribution may not reviewed only by sales and profits, it would also depended on the role the category play in the store - destination, routine, occasional, and convenience roles. If the category is played as a convenience role, its displaying purpose is more focus on alluring more customers than making profits.

3. The Model and solution approach:

The structure model:

Maximize: category profits = total margins of items in the category – total inventory costs of items in the category

Subject to: total product items ' allocation spaces less equal to total allocation space for the category

total product items' display spaces less equal to total displaying space for the category

the actual service level must larger or equal to the pre-set service level

Assumptions:

- 1. The inventory cost is equal to the item unit holding cost times the number of units in store and assume the ordering cost can be ignored.
- 2. The size of category space is pre-defined and can't be changed.

Notations:

 W_i : unit cost of product item i

- \boldsymbol{I}_{ii} : price elasticity of product item i to price change of product item j
- \boldsymbol{g}_{ij} : space elasticity of product item i to price change of product item j
- \boldsymbol{a}_i : loyalty percentage of product item j
- n: number of total product items in category
- n_1 : selected number of product items in category
- **C**_i : unit inventory cost of product item i

- Z_i : the minimum service level of product item i
- F : category total display space
- T: category total allocation space
- Q_i : the sales volume of product item i
- M_i : displayed demand of product item i
- A_i : acquired demand of product item i
- B_i : stock-out demand of product item i
- L_i : stock-out of product item i
- R_i : initial demand of product item i
- \boldsymbol{b}_i : the shelf space factor to product item i
- S_i : shelf space of product item j
- $E_{\boldsymbol{i}}$: units of inventory of product item I

Decision variables:

- P_i : retail price of product item i
- X_i : display units of product item i

Model formulation:

[Model] Category pricing and shelf space management

(2)

Maximize

Where

$$\boldsymbol{p} = \sum_{i=1}^{n_1} \left(P_i - W_i \right) \cdot Q_i - \sum_{i=1}^{n_1} c_i \cdot E_i$$
⁽¹⁾

$$Q_i = M_i + A_i + B_i - L_i$$

$$M_i = R_i \cdot \boldsymbol{b}_i \tag{3}$$

$$R_{i} = a_{0i} + \sum_{j=1}^{n} I_{ij} P_{j}$$
(4)

$$\boldsymbol{b}_i = \prod_{j=1}^n S_j^{\boldsymbol{g}_{ij}} \tag{5}$$

$$S_{j} = 1 \quad \text{if } X_{j} = 0$$

$$S_{j} = X_{j} \quad \text{if } X_{j} > 0$$

$$\mathbf{b}_{i} = 0 \quad \text{if } X_{i} = 0$$

$$L_{i} = (M_{i} + A_{i} + B_{i}) - E_{i} \quad \text{if } (M_{i} + A_{i} + B_{i}) > E_{i} \quad (6)$$

$$= 0 \quad \text{if } (M_{i} + A_{i} + B_{i}) < E_{i}$$

$$A_{i} = \sum_{j=n_{1}+1}^{n} \left[\left(\frac{\boldsymbol{g}_{ij}M_{i}}{\sum_{i=1}^{n_{1}}\boldsymbol{g}_{ij}M_{i}} \right) (M_{j}(1-\boldsymbol{a}_{j})) \right]$$

$$B_{i} = \sum_{j=1}^{n_{1}} \left[\left(\frac{\boldsymbol{g}_{ij}M_{i}}{\sum_{i=1}^{n_{1}}\boldsymbol{g}_{ij}M_{i}} \right) (L_{j}(1-\boldsymbol{a}_{j})) \right]$$
(8)

ubject to
$$\sum_{i=1}^{n_1} S_i \le F$$
 (9)

$$\left(\frac{E_i}{(M_i + A_i + B_i)}\right) \ge Z_i \tag{10}$$

$$\sum_{i=1}^{n_1} E_i \le T \tag{11}$$

$$X_i$$
 integer + $\forall i$ (12)

$$\mathbf{P}_i$$
 integer + $\forall \mathbf{i}$ (13)

In model I, (1) is the objective function to maximize the category profits with respective to the differences of product sales and inventory cost. (2) to (8) is adopted from Borin et al. and Farries et al. () to calculate the product sale volume that is equal to the summation of initial demand plus displayed demand, acquired demand, stock-out demand and minus stock-out units. (9) and (11) indicate the constraints of displaying space and allocation space respectively. (10) stands for the minimum requirement of product service level.

The solution approach:

The simulated annealing algorithm was used to solve model I. The simulated annealing algorithm has been developed to solve many mathematical programming problems with NP complete nature. Due to hard to get optimal solution for NP complete problems like integer programming problems and nonlinear programming problems, it has been proved that using simulated annealing algorithm can provide good solutions with reasonable time. Therefore, we developed a simulated annealing algorithm and try to get a good solution for the category management problem. The flow chart of the algorithm is depicted below (Figure 1).



Fig. 1 Flow chart of applying simulated annealing algorithm for model I

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4. Price elasticity and an example:

In this section, an industry example was adopted to show the calculation of price elasticity and the use of simulated annealing approach to solve model I. This example is a film category with the data from a Taiwan famous retail chain store in 92-day period. The information obtained from the store manager includes category allocation and displaying spaces, selling price, volume, and margins, and the size of each product etc.

Price elasticity:

The price elasticity indicates that how the price changed for a certain product would affect the sales volume of itself and other products in the same category. In this example, as stated before, we collected data for 92-day period including the promotions and resulting sales volume for each product item. We then use the sales volume of each product item as an independent variable one by one, the prices for all product items as dependent variables and run regression analyses. The results are shown in table 2, which indicates all the variables are significant with P-value < 0.01. So we include coefficients of all six regression models as the parameters of price elasticity (I_{ii}) (table 3).

Film Category			_	Correlatio	n analysis
Independent Variables (sales	R ²	Adjusted	Est. std. error	F test	P-Value
volume)		R²			
Brand KN VX100 6-pack	.785	.668	3.71	6.700	.003***
Brand KN 400 3-pack	.775	.653	6.46	6.326	.004***
Brand KD100 4-pack	.941	.908	21.20	29.037	.000***
Brand KD 400 3-pack	.924	.879	8.12	20.290	.000***
Brand FJ SUPER100 6-pack	.835	.737	7.36	8.461	.002***
Brand FJ 400 3-pack	.948	.919	6.20	33.110	.000***

Table 2 Regression Analysis Results

*** : P-Value < 0.01

Table 3	Price	Elasticity	for	Film	Category
					outogoij

	Price elasticity I_{ij}							
Product item (I)	$coefficient a_0$	1	2	3	4	5	6	
Brand KN VX100 6-pack (1)	12.0260	0335	2290	.1120	.0290	.1010	.0089	
Brand KN 400 3-pack (2)	304.9370	6500	3090	.0298	.0706	.0002	.0248	
Brand KD100 4-pack (3)	1520.3100	9160	.4690	-2.278	3790	-1.323	.4950	
Brand KD 400 3-pack (4)	-51.5400	.7000	0940	.1130	6530	0331	.1250	
Brand FJ SUPER100 6-pack (5)	-331.4370	2.361	5470	0038	.1960	-1.330	.2580	
Brand FJ 400 3-pack(6)	186.3270	.4050	0919	0088	.1150	2930	6930	

Other parameters setting:

In addition to the calculation of price elasticity, the setting of space elasticity is based on the principals stated in Curhan (1972) and calculated with results shown in table 4. All other input data are shown in tables 5 and 6.

	, ,			,		
	Space elasticity \boldsymbol{g}_{ij}					
Product item (I)	1	2	3	4	5	6
Brand KN VX100 6-pack (1)	.2713	0221	1001	0545	0602	0272
Brand KN 400 3-pack (2)	0300	.2496	1008	0389	0689	0377
Brand KD100 4-pack (3)	0124	0033	.1713	0357	0603	0251
Brand KD 400 3-pack (4)	0199	0063	0653	.2314	0440	0233
Brand FJ SUPER100 6-pack (5)	0538	0179	1232	1058	.2096	0872
Brand FJ 400 3-pack(6)	0247	0079	0931	0326	0812	.2452

Table 4 Space Elasticity for Film Category

	Actual Size (cm)			Rep. Unit		
Product item(i)	Width	Height	Thickness	Width	Height	Thickness
Brand KN VX100 6-pack (1)	11	11	4	2	1	1
Brand KN 400 3-pack (2)	6	11	4	1	1	1
Brand KD100 4-pack (3)	6	16	4	1	1.5	1
Brand KD 400 3-pack (4)	6	11	4	1	1	1
Brand FJ SUPER100 6-pack (5)	12	11	4	2	1	1
Brand FJ 400 3-pack(6)	6	11	4	1	1	1
Shelf Space – 1 st layer	145	20	53	24	1	13
Shelf Space – 2nd layer	145	30	53	24	1	13

Table 5 Shelf Space and Film Size

Product item (i)	\boldsymbol{a}_i	Product cost	Inventory	Minimum Service	
	J		cost	Level	
Brand KN VX100 6-pack (1)	.2183	324.72	16.236	40%	
Brand KN 400 3-pack (2)	.2524	293.04	14.652	40%	
Brand KD100 4-pack (3)	.6132	342.32	17.116	40%	
Brand KD 400 3-pack (4)	.3694	308.00	15.400	40%	
Brand FJ SUPER100 6-pack (5)	.4565	307.12	16.676	40%	
Brand FJ 400 3-pack(6)	.3271	289.52	14,476	40%	

 Table 6
 Other Parameter Setting

Results of Simulated Annealing Approach:

Brand FJ 400 3-pack(6)

After all parameter values are calculated or assumed, a recent store data (table 7) is input as an initial solution for the simulated annealing approach. To run the algorithm, the initial temperature is set to 120 degree, gradient = 99%, repeat number = 50, stopping number = 50 and run for 10 replications. From the results, we found the best solution which is shown in Figures 2 and 3.

				0	
Product Item (i)	Actual Size (cm)			Shelf Space	
_	Width	Height	Thickness	Units	Price
Brand KN VX100 6-pack (1)	59.5	30	53	10	369
Brand KN 400 3-pack (2)	41.5	20	53	7	333
Brand KD100 4-pack (3)	60.0	30	53	10	389
Brand KD 400 3-pack (4)	59.5	20	53	11	350
Brand FJ SUPER100 6-pack (5)	24.0	30	53	4	349

36.0

 Table 7
 Initial solution of the simulated annealing approach



20

53

6

329

Fig. 2 Comparison of sales volume for initial demand and displayed demand



Fig. 3 Improvement of margins, Inventory cost, and profits

From figure 2 and 3, they show that the sales volume with respective to initial demand is increased from 193.83 to 200.6 and displayed demand is increased from 191.7 to 213.34. Also the total category margin is increased from 8246.94 to 11753.28, the inventory cost is decreased from 2602.22 to 1978.3. Therefore, the category profit is increased from 5644.72 to 9774.92 which has near 80% improvement. In addition, figure 4 shows that the adjustment of service level would have impact on sales volume and profits as well. We make adjustments of the service level with four tests. In test 1, the service levels of all items are set to 40%. In test 2, some items are set to 40% and others are set to 80%. In test 3 with service level set to 40%, 60%, and 80% for different items and in test 4, the service level of all items are set to 80%. The results show that the inventory cost is increased while the service level is increased, but the service level may not have positive relations to sales volume and category profit.



5. Conclusion

In this paper, we discussed the execution structure of retail category management with the considerations of category assortment, shelf space allocation, inventory service level, and price determination. A mathematical model was formed with an objective to maximize the category profit. We then applied a heuristics algorithm called simulated annealing to solve the model and simultaneously undertake experimental verification by checking the factual information from a large retail store in Taiwan. According to the results of the experimental information, profit benefits were improved under the model of category management. This study reveals that the construction of the execution structure of category management provides proprietors the implementation guides for category management. Also, the model of category management and the formula mathematics provide them practical usage in decision making.

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