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DECISION SUPPORT MODEL FOR OPTIMAL DECISION IN STRATEGIC PRODUCTION PLANNING BASED ON PRODUCT LIFE CYCLE

Calista Elysia and Ditdit Nugeraha Utama

Computer Science Department, BINUS Graduate Program – Master of Computer Science
Bina Nusantara University, Jakarta, Indonesia 11480
calista.elysia@binus.ac.id; ditdit.utama@binus.edu

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Abstract. *The economy and its competition have reached a global level. To be able to survive in the fierce global competition, companies, especially companies engaged in the production sector, need to do a strategic production planning (SPP). This study aims to achieve optimal decisions in strategic production planning based on the product life cycle (PLC) using the decision support model (DSM). The DSM for suggesting the optimal model for SPP based on PLC is a proposed contribution to knowledge. In this study, several methods operated which are divided into 2 stages. The first step was to construct a similarity model. Here, Euclidean distance and fuzzy logic methods operated technically to determine the existence stage of a product in PLC. In the second stage, an optimization model was developed, where deep analysis and mathematical methods used for the selection of the right strategy and the hybrid L2HC method functioned to optimize the strategies chosen previously to produce optimal decisions in strategic production planning.*
Keywords: Decision support model, Product life cycle, Fuzzy logic, Strategic production planning, Latin-hyper-cube-hill-climbing, Optimization

1. **Introduction.** The company's competition has economically touched a universal level. Companies, especially production sector companies, for being able to survive, need to do a strategic production planning (SPP), which is efficient and responsive and has good performance in terms of reliability, sustainability, and flexibility. SPP is a function of managing priorities in production planning by integrating the functions of manufacturing, marketing, finance and engineering, both at the policy level and the decision level [1]. If the company is not able to perform a good production planning, it will cause a delay in various things; for example, supply delays and costs incurred will become higher. The wrong decision due to incorrect calculation and human error in production planning is also going to be fatal for purpose to consider the product produced by the company. In this case, optimal decision in SPP is a very imperative thing to do for industrial development. The decision for SPP here is more focused on determining what SPP strategies need to be taken next from a product by considering several aspects to get optimal results.

Furthermore, [2] explained that decision support model (DSM) was originally created for the strategic case. Decision making is also an important part of all businesses, so this DSM should be considered a valuable part of the company's operations. A successful decision is going to produce a profit, while an unsuccessful decision will make a loss [3]. Therefore, in this paper, DSM was made to reduce errors in SPP. The DSM is developed based on the product life cycle (PLC). From the 1950s, theories about PLC have gained significant recognition as a tool for the formulation and implementation of effective marketing strategies.

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The PLC provides a level of structure for product life and it provides direction and helps focus company's decision making so that the actions at each stage strengthen the achievement of company goals. This DSM consists of 2 namely similarity and optimization models. The similarity model uses the Euclidean distance method and by applying fuzzy logic, while the optimization model uses a deep analysis, mathematical method, and hybrid latin-hyper-cube-hill-climbing (L2HC).

Various previous works on DSM have been done scientifically. [4] proposed a prediction model based on fuzzy logic to manage the performance of the supply chain. [5] developed a DSM based on fuzzy analytic network process (FANP) and preemptive fuzzy integer goal programming (PFIGP) to provide logistics provider choices in the global supply chain. A model operating the combination of fuzzy and integer linear programming to produce a balanced solution between the level of feasibility and satisfaction was proposed by [6]. Also, [7] proposed a model named LHP-FSP which is a fuzzy mixed integer linear programming model to support the decision-making process in reallocating LHP stock and the number of master plans to orders placed.

Moreover, [8] developed a DSM for restaurant suppliers using the fuzzy analytical hierarchy process method, which results in increased restaurant profits. A fuzzy mathematical programming model was offered to overcome the lack of homogeneity in the product (LHP) in the "Make to Stock" company [9]. [10] recommended a DSM to assist companies in selecting "suppliers" using fuzzy analytical hierarchy process (fuzzy-AHP), fuzzy technique for order preference by similarity to ideal situation (fuzzy-TOPSIS), and fuzzy-multi objective linear programming (fuzzy-MOLP). There were aspects used as parameters which are uncertain conditions; thus fuzzy logic was used to reduce the uncertainty. DSM studies above [4-10] applied a fuzzy logic in their DSM research and got more accurate results compared to not using such a method. Therefore, in this paper, the proposed DSM is a fundamental contribution to knowledge. Based on the PLC, it is suggested as a model that is able to solve various challenges existing in the SPP domain. SPP here is more focused on determining the SPP strategy what needs to be taken to be done next from a product by considering several aspects to get optimal results.

As for all of the DSM work above, no one has discussed about SPP; thus, here we are going to discuss it more. The organization of this paper is as follows. The introduction section is followed by related works in Section II. The research methodology is going to be delivered in Section III. In Section IV, we present result and discussion. Finally, the Section V concludes all parts in the paper.

2. **Related Works.** A number of researches related to production planning has been done before. [11] analyzed the effects of a special order on inventory costs and developed an optimality ordering policy in response to sales by considering two fundamental decision variables of an inventory policy; i.e., order quantity and time. The results showed that in certain circumstances, special orders increase the effectiveness of the inventory system. [12] investigated the necessary and sufficient conditions to consider pricing and optimal order quantity decisions related to inventory models based on deterministic or probabilistic demand. Since pricing decision affects the period ending inventory level, optimally the multi period model does not follow from the analysis of the one period model.

Moreover, [12] explored scientifically a one-period imperfect inventory model with price dependent stochastic demand and partial backlogging. A single period stochastic inventory model was established assuming random percentage of defective units in the order quantity. The optimal order quantity and selling price were obtained to maximize the expected total profit. [13] adopted a rigorous mathematical analysis method to develop the complete solution algorithm to obtain optimal cycle time and pricing decisions for an integrated inventory system with order-size dependent trade credit in supply chain management. Numerical examples illustrated that this algorithm is rather accurate and simple. Correspondingly, [14] conducted a study to determine the optimal ordering policy for inventory systems that minimizes the long-run average cost by a lower bound approach. This work is done where the setup cost of each order operated as a general function, and the demand process is modeled as a Brownian motion with positive drift. This work also proposes a selection procedure for computing optimal policy parameters when the setup cost is a step function.

All researches performed by [11-14] did not cover the issue regarding an evaluation of product's stage position in PLC. Whereas, such a position is able to make decision maker easily to plan production strategically in the future. Specifically for [12,13] they studied optimization model in pricing, optimal order, optimal cycle time; however, in our study we used optimization conception to optimize the selected strategy after product's stage position in PLC and its strategy proposed.

3. **Research Methodology.** All stages of this research are presented in Figure 1, namely literature study, problem and method analysis, parameterizing, model construction, test, and evaluation. With the method of desk-based research, a literature study was conducted. Here, the review of several articles that are related to main topic was conducted. Based on literature study, the case's problem was able to be understood comprehensively. Problem and method analysis were carried out using the field study method, which is relating to the data that are going to be operated as research data.

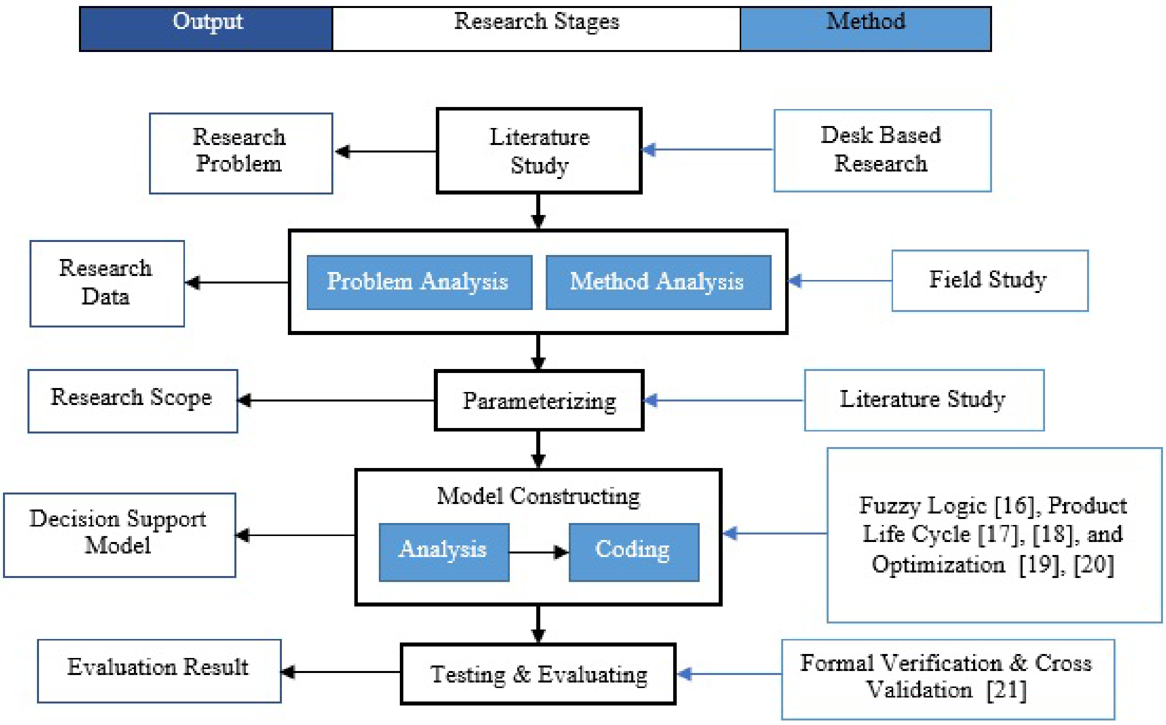

Figure 1. Research stages

The next stage is parameterizing. Here the literature study method was operated systematically. In this parameterizing stage, not all parameters are definite conditions, but some are uncertain conditions, fuzzy logic was used to reduce the uncertainty. The parameters resulted were operated for model construction. They were practically and scientifically reasonable, as they were taken from nine scientific-references based on studies correlating to SPP topic.

The next step is constructing the model using the similarity model, optimization, and product life cycle conception. In this similarity model, Euclidean distance and the process of fuzzification and defuzzification were carried out. For the optimization, we functioned deep analysis, mathematical method, and hybrid L2HC. This constructed model will suggest the optimal decision as the result. After the constructing model was completed, we did testing and evaluating the results of the constructing model.

4. Result and Discussion.

4.1. Proposed model.

Parameter is a numeric factor or any measurable factor that can help in determining or classifying a particular system. Table 1 shows the parameters benefited in constructing model. These parameters operated for 2 things; as parameters in determining the stages of the product in the product life cycle and as parameters in making strategic decisions that applied next for optimal strategic production planning.

Table 1. Model parameters

No.	Parameter	Reference
1	Time	[22]
2	Product price	[22]
3	Profit	[22]
4	Production cost	[22]
5	Marketing cost	[22]
6	Demand	[23]
7	Production capacity	[23]
8	Revenue	[22,24]
9	Cash flow	[22,24]
10	Sales growth	[25,26]

The constructed DSM is based on PLC that has four stages: introduction, growth, maturity, and decline [17,26]. The product life cycle model operated in this study is coming from [27,28]. Each stage in the product life cycle has its own characteristics and strategies; it is shown in Table 2 and Table 3 respectively. From the results of literature studies, 4 characteristics for the introduction stage, 5 characteristics for the growth stage, 5 characteristics for the maturity stage, and 6 characteristics for the decline stage were discovered academically. For the strategies, 3 strategies for the introduction stage, 3 strategies for the growth stage, 3 strategies for the maturity stage, and 2 strategies for the decline stage were also obtained.

The model consists of 2 parts, i.e., similarity and optimization. The similarity part here was developed to find the position of the stages in the product life cycle ("IGMD") by matching stage's characteristics to the product characteristics. The method operated in this part is the Euclidean distance and fuzzy method. While optimization was established to obtain which strategy is the best to achieve optimal PPS. Using inherent analysis, mathematical method, and hybrid L2HC method, this part is conducted after the position of the stages in the product life cycle has been known. The data needed in this study are sales data (sales), production data (production) such as production costs, product data itself (product), and others. The model schema can be seen in Figure 2.

The algorithm of the model is depicted in Figure 3. The first stage focused on determining the position of the product stages on the PLC, where at this stage will be calculated distance between the characteristics of a product with the characteristics that exist at each stage in the PLC. Euclidean distance is used for this process. Equation (1) is the Euclidean's formula used in this work.

$$d = \sqrt{\sum_{i=1}^{k} (x_i - y_i)^2} \tag{1}$$

Table 2. Characteristics of product life cycle stages

No.	Parameter	Reference
	INTRODUCTION	
1	Time: still new, just entered the market	[24,25]
2	Production capacity: low	[24]
3	Revenue: low	[22]
4	Cash flow: negative	[29]
	GROWTH	
1	Revenue: significantly increased	[22,24]
2	Cash flow: began to change to positive	[22,24]
3	The market is starting to accept the product	[25,26]
4	Sales growth: high	[25,26]
5	Production capacity: increase	[25,26]
	MATURITY	
1	Profit: high	[24]
2	Cash flow: strong positive	[24]
3	Sales growth: lower than average sales growth	[25,26]
4	Production capacity: high	[24-26]
5	Revenue: increase	[22]
	DECLINE	
1	Profit: significantly decreased	[22,26]
2	Cash flow: decrease, become negative	[22,24]
3	The market is saturated, no longer in salable/use	[22]
4	Sales growth: decrease	[26]
5	Production capacity: decrease	[26]
6	Many competitors are out of the market	[24]

Table 3. Product life cycle stages strategies

No.	Strategy	Reference
	INTRODUCTION	
1	Focus on product innovation	[28]
2	Promote supplier relations	[28]
3	Improve marketing program	[30]
	GROWTH	
1	Improve product quality	[30]
2	Enter a new market segment	[30]
3	Enter a new market segment shifting from community awareness	[30]
	MATURITY	
1	Product modification	[30]
2	Market modification	[30]
3	Marketing program modification	[30]
	DECLINE	
1	Perform product updates/innovation	[28]
2	Ignore the product	[28]

The distance calculation results will be processed with fuzzy logic (also ever operated by [31]). We defined the linguistic variables, rules, and fuzzy membership function. All parameters distances use the same linguistic variables: short, medium, and long. The shorter distance means better.

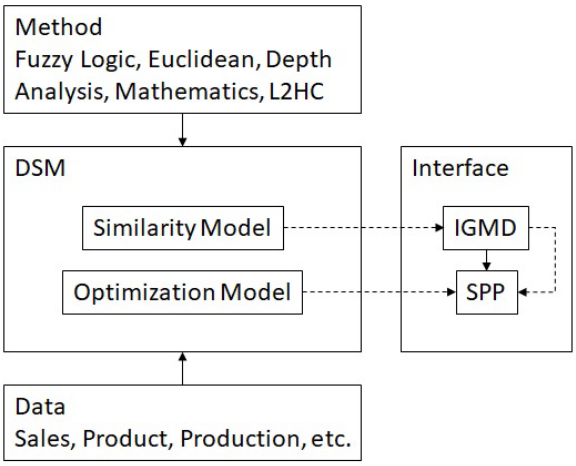

FIGURE 2. High level schema of the constructed model

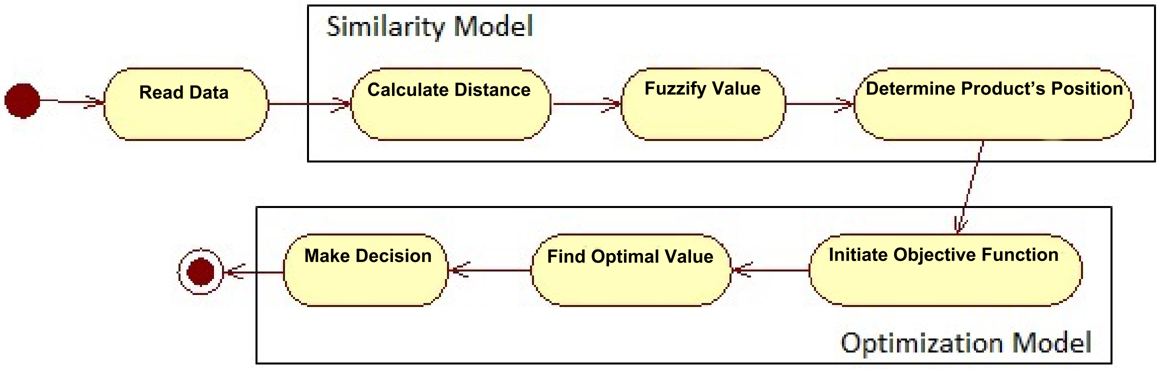

FIGURE 3. Model algorithm schema

Technically, each parameter here needs to have a fuzzy membership function which in this study was formed using the triangular membership function (TMF) model. The method used for defuzzification is weighted average method which multiplies each membership function weight (see Equation (2)). In the end, the positioning of the product stages is done by calculating the average of all the parameters results of distance fuzzification, the stage that has the highest value becomes the position of the stages of a product. This process is called the similarity model.

$$Z^* = \frac{\sum \mu_c \left(\overline{Z}\right) Z}{\sum \mu_c \left(\overline{Z}\right)} \tag{2}$$

Then in the second part, the optimal SPP strategy decision making process is carried out using the optimization model. It uses deep analysis and mathematical method to choose the strategy and then will be processed by the hybrid L2HC method to optimize the chosen strategy. Hybrid L2HC method is a hybrid method that combines the Latin hyper-cube method and the hill-climbing method. Based on the results of experimental testing that has been done, the hybrid method gives better results [32].

In this intense analysis and mathematical method, we made a mathematical formula with weighting for each strategy based on the parameters that influence the selection of that strategy. The strategy that has the smallest return value is the one that is chosen to be done. The example of the formula is written down in Equation (3); $f(pq)$ is a product modification strategy, s is a product sales point, ct presents a product cost point, cp symbolizes a product capacity point, d is a product demand point, pq is a product price and quality point, and c is a weight value for each parameter (in percentage form).

$$f(pq) = c_1 s + c_2 ct + c_3 cp + c_4 d + c_5 pq c_1 s + c_2 ct + c_3 cp + c_4 d + c_5 pq \quad (3)$$

After the strategy has been chosen, it will be optimized methodically. The optimization was done using the hybrid L2HC method with its optimization objective function. Optimizing the strategy here is done by optimizing one of the parameters that can be controlled by the product's company. The optimization objective function example for product modification strategy above is written in Equation (4), where P is a price, ul is price's upper limit, ll is a price's lower limit, and pq_{opt} is optimal product price and quality point. That equation is an example of optimizing a strategy by optimizing its product price.

$$opt(f(pq)) = c_1 s + c_2 ct + c_3 cp + c_4 d + c_5 \frac{(P - ll)}{(ul - ll)} pq_{opt} \quad (4)$$

4.2. **Experimental result.** Data necessitated from each product as a parameter is described in Table 4. It can be seen that this model uses 5 socks products for its experiments and the parameters used are product age, product price, production capacity, revenue, profit, demand, cash flow, sales growth, revenue growth, and production cost. Almost the entire data comes from the XYZ Company and some of it contains dummy data, which is processed according to the modelling in this study.

Table 4. Sample data of product

Parameter	Product A	Product B	Product C	Product D	Product E
Product age (month)	20	40	28	5	15
Product price	60,000	30,000	50,000	70,000	40,000
Revenue (Rupiah)	1,639,440,000	6,504,120,000	906,000,000	43,680,000	597,600,000
...	...	...	...	...	...
Revenue growth (Rupiah)	−46,080,000	4,423,320,000	−32,400,000	−16,800,000	−7,200,000
Production cost (Rupiah)	446,884,885	1,720,999,890	223,385,938	6,402,703	149,690,295

The data is inputted and then will go through the first process, namely similarity models to find the position of product's stage in PLC. The results are shown in Table 5, Product A, C and E are in the "growth stage" with the same score 89.500; product B is in the "maturity stage" with score 74.920, and the last, product D is in the "decline stage" with score 89.500.

Table 5. The results of a product stage position in the product life cycle

Stage	Product A	Product B	Product C	Product D	Product E
Introduction	48.025	24.450	61.150	88.200	78.725
Growth	89.500	50.600	89.500	83.600	89.500
Maturity	88.540	74.920	81.380	57.360	73.300
Decline	60.580	16.600	75.440	89.500	83.060

After knowing the position of the product stages in the product life cycle, deep analysis and mathematical method are performed to find the optimal strategy based on the position of the product stages. Table 6 describes the results of scoring each strategy for each product. The results were found that product A and product C needed to improve product quality, product B needed to make product modifications, product D needed to ignore the product, and product E needed to shift from community awareness and trial to communication loyalty. The chosen strategy is then optimized with the hybrid L2HC method; the results are shown in Table 7. Strategy optimization aims to increase the objective function value of a strategy, $f(x)$ is the result of the objective function before strategy optimization and $f(x)'$ is the result of the objective function after the strategy optimization.

Table 6. The results of a product strategy

Stage	Strategy	Score
	PRODUCT A	
Growth	Improve product quality	6.20
	Enter a new market segment	8.70
	Shifting from community awareness and trial to communication loyalty	8.50
	PRODUCT B	
Maturity	Product modification	6.40
	Market modification	7.50
	Marketing program modification	6.50
	PRODUCT C	
Growth	Improve product quality	6.40
	Enter a new market segment	7.70
	Shifting from community awareness and trial to communication loyalty	7.00
	PRODUCT D	
Decline	Perform product updates/innovation	4.00
	Ignore the product	2.50
	PRODUCT E	
Growth	Improve product quality	6.20
	Enter a new market segment	7.30
	Shifting from community awareness and trial to communication loyalty	6.00

Table 7. The result of optimized strategy

Product	Strategy	$f(x)$	Optimization strategy	$f(x)'$
Product A	Improve product quality	6.20	Increase product price and quality	6.40
Product B	Product modification	6.40	Increase product price and quality	7.00
Product C	Improve product quality	6.40	Increase product price and quality	6.80
Product D	Ignore the product	3.20	Increase product sales	4.60
Product E	Shifting from community awareness	6.00	Increase product sales	7.50

4.3. **Discussion.** In this study, the constructed DSM for optimal decision in SPP based on product life cycle was created. It also was verified and valid through formal verification and cross validation with verification and validation values being 1.00. They mean that the model developed is 100% true theoretically and data operated in the model is 100% true practically.

This model was constructed with the aim of assisting companies in making optimal decisions in SPP. No previous DSM work has been discussed on this case, which means the topic of this model is new. Four main methods were operated to construct the model, which are Euclidean distance, fuzzy logic, depth analysis and mathematics, and hybrid L2HC method. Sequentially the first two methods are used to determine the position of the product stages in the PLC, while the next two methods are used to determine the SPP. Fuzzy logic here is used to reduce the uncertainty of parameters' value. This model is implemented in five products coming from the XYZ Socks Company, but some are still dummy.

5. **Conclusion and Further Works.** Based on PLC, a DSM for optimal decision in SPP was built. This model uses 10 main parameters; time, product price, profit, production cost, marketing cost, demand, production capacity, revenue, cash flow, and sales growth. These parameters are the chosen parameters from the result of literature studies that have been carried out, which helps us to find the position of the product stages in PLC and find recommendations for optimal SPP. A combination of Euclidean distance, fuzzy logic, depth analysis, mathematics, and L2HC method were adopted in constructing this DSM.

The future study regarding other parameters is possibly able to enrich the model, e.g., budget, and marketing cost. Further study of the characteristics and strategies at each stage of PLC can make the model more perfect. The use of other optimization methods that give a better result can be considered as future work as well.

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