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New Product Production Decision Plan Considering Learning Curve Effect

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Abstract

With the development of productive forces in modern society and the increasingly fierce market competition, enterprises have never stopped the pace of pursuing benefits. It is of great significance for enterprises to improve their competitiveness to improve their production efficiency and effectively reduce the production cost and inventory cost of new products. This paper studies the production decision-making problem with learning curve effect in the production process of new products, and uses the production cost function under the learning curve effect to maximize the production profit of new products of manufacturers.

Keywords

Learning curve, new product, production decision.

1. Introduction

With the development of productive forces in modern society and the increasingly fierce market competition, enterprises have never stopped the pace of pursuing benefits. Today, leading companies derive a large portion of their sales revenue from new products. Nearly 60% of apple's sales, for example, come from products launched in the past four years. It is of great significance for enterprises to improve their competitiveness to improve their production efficiency and effectively reduce the production cost and inventory cost of new products. At the same time, considering the continuous growth of people's demand and better meeting customers' different demands for products, the enterprise tries to make production decisions and plans for new products so that they can be put on the market faster and better.

The life cycle of a new product is finite and predictable, and its production has a significant learning curve effect. When estimating the production and processing costs of new products, special attention should be paid to the learning curve effect. For established products, the learning curve effect is less obvious. Traditional research rarely focuses on the production decision-making of new products and ignores the production difference between new products and mature products. In addition, most studies on product production models ignore the learning curve effect that exists in the production process. In fact, the learning curve effect has a particularly significant impact on the production of new products. In actual production, with the increase of workers' proficiency, the time or cost of production unit product shows a decreasing trend. In this case, if the production rate of the new product is assumed to be a constant, it is not consistent with the actual production situation. Therefore, it is necessary to study the production collaboration of new products affected by the learning curve effect. This paper focuses on the manufacturer's production decision of new products. Firstly, it considers the impact of learning curve effect on production cost, and then considers the manufacturer's

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production batch influenced by learning curve effect. The discovery of the Learning Curve was originated from the aircraft manufacturing industry during the Second World War. During the aircraft assembly and operation process, with the increase in the number of aircraft produced, the direct labor time required would gradually decrease. In 1936, Dr. T. P. Wright of Cornell University first discovered and proposed the learning curve through observing, analyzing and studying a large number of relevant materials and cases in the process of aircraft manufacturing. The learning curve theory is based on the following assumptions: a) after completing the same task each time, the time to complete the task or the production unit product next time will be reduced; b) the production time per unit product will decrease at a decreasing rate; c) the reduction in production time per unit product will follow a predictable pattern. By World War II, the learning effect was widely recognized as the pricing basis for government orders for aircraft and other hardware. During and after World War II, the use of the learning curve spread to other industrial sectors, including machine processing, mass assembly operations, and a variety of other industrial applications. The latest research finds that the learning curve is not only related to the direct labor force, but also depends on the difference of organizational adjustment and its technical structure.

2. The Research Reviewed

2.1. Review of Learning Curve Studies

The learning curve was one of the earliest management science tools. There are three kinds of learning curve models: logarithmic linear model, exponential model and polynomial model.

Wright [1] first proposed mathematical equations for learning curve in document form. Later, Baloff and Carlson et al. extended Wright's model respectively. Grosse [2] aggregates and classifies these classical learning curve models and USES a large amount of empirical data to evaluate the applicable patterns and processes of various types of learning curve models in economic production. Under the assumption that demand is constant, Salameh [3] introduced the learning effect into the production inventory model, but this model did not consider the shortage situation. Jaber [4] extended Salameh's model and studied the production inventory model under the condition of constant demand rate and shortage. Jaber et al. [5] studied the optimal production inventory model with limited learning effect under constant demand, but did not consider the shortage situation. Balkhi [6] introduced the learning effect into the production inventory model of perishable products with partial deferred payment under time-varying demands. Jaber et al. [7] applied compound learning effect curve to deterministic storage model. Jaber [8] on the basis of assuming that demand is dependent on price and time, applied the learning effect and forgetting effect to the deterministic inventory model to discuss the impact of the two effects on inventory cost. When receiving the paper, we assume that the corresponding authors grant us the copyright to use the paper for the book or journal in question. When receiving the paper, we assume that the corresponding authors grant us the copyright to use the paper for the book or journal in question. When receiving the paper, we assume that the corresponding authors grant us the copyright to use.

Chen [9] proposed its application in product research and development, enterprise operation system management and non-manufacturing operation by analyzing the expression form and characteristics of international research literature and learning curve. Zhou [10] further extended the optimal production batch model of production inventory system considering human learning by assuming that human learning follows the learning curve proposed by DeJong. Hao and Ye [11] introduced the development and function of schedule planning, and studied the learning effect on employee behavior.

Throughout the research on learning curve.it is found that the early research mainly focuses on expanding the form of learning curve and its application scope. Later scholars focused on using

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learning curve to solve some problems in production or enterprise management. In general, there are few in-depth studies on the learning curve, especially considering the learning curve effect of new products.

2.2. Review of Economic Production Batch Research

The size of the production lot greatly affects the size of the cost. When the production volume is large, the cost of equipment adjustment can be saved, but the wip inventory will increase, so wip cost will increase accordingly. On the contrary, the cost of wip is relatively low when the production volume is small, but the cost of equipment adjustment will increase. Economic Production Quantity (EPQ) has been widely used in practical Production. In a production cycle, since each production will have a certain production preparation time, it is necessary to determine how many products are produced at one time when replenishing inventory to maximize the profit of the enterprise, and the production capacity that maximizes the profit of the enterprise is the economic production batch. The problem of how to find the optimal yield is the EPQ problem. For this problem, a large number of literature studies have been conducted, and different assumptions and algorithms have been used to study and solve this problem.

In the related research fields, Zhu [12] and others to set up a product designers and brand owners that inventory model between manufacturers and suppliers, from the perspective of the whole supply chain, studies the under the EPQ model of supply and demand both sides can take measures to improve the quality of the products, but also discusses the management and operation decision including orders and production batch and improve the relationship between the quality of the product. Porteus [13] hypothesized a simple model to analyze the relationship between product quality and batch size, as well as three measures to improve product quality. Rajaram and Karmarkar [14] mainly studied the problem of dynamic product production cycle. The question of how many products should be produced at what time is discussed with the uncertainty of output and the limitation of buffer space, and the minimum total cost to the manufacturer. Huang and Zhang [15] studied the economic production batch problem by considering the output flexibility of the manufacturing system, established a new model about productivity and production cost, and proposed a feasible algorithm to solve the problem. Guo et al. [16] studied the EPQ model that considers the product defect rate and allows the product to be out of stock under a special fuzzy environment, and solved the model by combining with the actual calculation example, thus obtaining certain conclusions. Qu and Zhang [17], when studying the EPQ problem, took production cost and other factors into comprehensive consideration. On this basis, they established a model with production batch as the unknown quantity and the joint cost composed of production cost and supply cost as the optimization objective. Zeng, Wang and Zhou [18] established a joint economic batch model of supply chain under carbon cap-and-trade mechanism by considering the two-level supply chain system composed of suppliers and purchasers to optimize the operation of supply chain under carbon cap and trade mechanism. Lu, Guo and Xu [19], based on the classic EPQ model and considering the periodic incomplete preventive maintenance strategy, set up the optimal economic production batch decision model with the goal of minimizing the total cost per unit product.

3. Modle Building

The model of this paper is based on the following assumptions:

1 There is a learning curve effect in the production process.

2 The production inventory model runs on an infinite schedule.

3 The effect of production disruption on the learning curve effect was not considered.

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For convenience, the symbols are defined into three categories: parameters, decision variables, and functions.

Parameters

a the coefficient of price on demand

c_0 the initial learning production cost at time 0

c_1 the purchase cost per unit

r the learning coefficient

o the set-up cost per production run

p the annual production rate which is larger than the annual demand rate, in units

u the annual production rate which is less than the annual demand rate, in units

w the out of stock cost per unit

h the inventory holding cost per unit per year excluding interest charge

m the Setup cost per production run

k the maximum number of potential customers

Decision variables

S the selling price per unit with S ≥ $c_0 + c_1$

T the production cycle time which is equal to $Q/D(S)T$

Functions

C (t) the learning production cost per unit at time t

D (S) the annual demand rate as a function of selling price S ,in units

Q the manufacturer's production lot size $Q = D(S)T$, in units

V (t) the cumulative production volume at time t , in units

Π(S, T) the manufacturer's profit function per year, in dollars

To quantify the learning curve effect, we follow Rosen (1972) and Teng and Thompson (1983, 1996) by assuming the production cost under learning curve effect is described by a power law function as follows:

$$c(t) = c(0)\left[\frac{V_0}{V_t}\right]^r$$

Where V (t) is the cumulative production volume at time t, and r is the learning coefficient which usually falls in the range of $0.1 \le r \le 0.25$. The learning coefficient r in the learning curve effect can be estimated by plotting production cost vs. production volume on a log-log scale to obtain a nearly straight line with a negative slope -r. Furthermore, the learning production cost for making V units is as follows:

$$c(t)V(t) = c(0)\left[\frac{V(0)}{V(t)}\right]^r V(t) = c_0V(t)^{1-r} = c_0[V(t)]^e$$

Where $c_0 = c(0)[V(o)]^r$， r and e are positive constants，$0.1 \le r \le 0.25$，and hence $0.75 \le e = 1 - r \le 0.9$. Note that if e = 1, then the unit production cost is constant and there is no learning curve phenomenon.

In academic research literature, there are three simple ways to represent a decreasing demand of selling price S as follows: lin-ear, polynomial, or exponential. However, there is little significant difference in results obtained from using any of these three price functions. For simplicity, we assume that the demand rate D (S) is an exponential function of the selling price S as

$$D(S) = Ke^{-aS}$$

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Where both K and a are positive constants, K is the maximum number of potential customers and a represents the coefficient of price on demand. For convenience, D(S) and D will be used inter-changeably.

In a supplier-manufacturer-customer supply chain system, the production decision of new products is considered from the perspective of the manufacturer. Based on the above assumptions, the inventory system considered here is as follows. The manufacturer must decide the selling price S and the production lot size Q of a single product simultaneously in order to maximize profit per year. Based on the above assumptions, we know the manufacturer's relevant costs are as follows:

1 The learning production cost per year is $c_0[D(S)]^e$

2 The purchase cost for parts per year is $c_1 D(s)$

3 The set-up cost for per year is $\frac{D(S)}{Q} o = \frac{o}{T}$

4 The holding cost per year is $\frac{Q}{2}\left[1 - \frac{D(S)}{p}\right] h = \frac{TD(S)}{2}\left[1 - \frac{D(S)}{p}\right] h$

5The Shortage cost per year is $\frac{Q}{2}\left[1 - \frac{D(S)}{u}\right] w = \frac{TD(S)}{2}\left[1 - \frac{D(S)}{u}\right] w$

When the production inventory exceeds the demand, it belongs to the state of overstock, We know the manufacturer's profit is as follows:

$\Pi_1(s,t)$ = revenue from sales – purchase cost – learning production cost – set-up cost – holding cost

$$\Pi_1(s,t) = SD - C_1 D - C_0 D^e - \frac{o}{T} - \frac{TD}{2}\left[1 - \frac{D}{p}\right] h$$

When Production inventory less than demand, out of stock status, We know the manufacturer's profit is as follows:

$\Pi_2(s,t)$ = revenue from sales – purchase cost – learning production cost – set-up cost shortage cost

$$\Pi_2(s,t) = SD - C_1 D - C_0 D^e - \frac{o}{T} - \frac{TD}{2}\left[1 - \frac{D}{u}\right] w$$

4. Conclusion

Determining optimal pricing and volume policies is an important issue in the field of operations and sales. This is especially important in the early stages of a new product launch, when the impact of the learning curve is most apparent. In this paper, we develop an EPQ model to reflect the following relevant facts: a) the manufacturer's model in the two states of out of stock and overstock; b) due to the phenomenon of learning curve, for every 10%-25% reduction in the manufacturer's unit production cost, the cumulative production capacity is doubled; c) the manufacturer's batch size is also affected by the sale price. The follow-up study can add numerical calculation to verify the hypothesis. For example, an increase in the learning curve effect lowers the selling price, but increases the production batch size and total profit, etc.

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References

[1] T. P. Wright. Factors Affecting the Cost of Airplanes, Journal of the Aeronautical Sciences, Vol. 3,No. 4 (1936), pp. 122-128.

[2] Grosse E H , Glock C H , Müller, Sebastian. Production economics and the learning curve: A meta-analysis[J]. International Journal of Production Economics, 2015, 170:S0925527315002297.

[3] Salameh M K , Abdul-Malak M A U , Jaber M Y . Mathematical modelling of the effect of human learning in the finite production inventory model[J]. Applied Mathematical Modelling, 1993, 17(11):613-615.

[4] Jaber M Y , Salameh M K . Optimal lot sizing under learning considerations: Shortages allowed and backordered[J]. Applied Mathematical Modelling, 1995, 19(5):307-310.

[5] Jaber M Y , Bonney M . Optimal lot sizing under learning considerations: The bounded learning case[J]. Applied Mathematical Modelling, 1996, 20(10):750-755.

[6] Alamri A A , Balkhi Z T . The effects of learning and forgetting on the optimal production lot size for deteriorating items with time varying demand and deterioration rates[J]. International Journal of Production Economics, 2007, 107(1):125-138.

[7] Jaber M Y, Guiffrida A L . Learning curves for processes generating defects requiring reworks[J]. European Journal of Operational Research, 2004, 159(3):663-672.

[8] Jaber M Y, Bonney M, Moualek I. Lot sizing with learning, forgetting and entropy cost[J]. International Journal of Production Economics, 2009, 118(1):19-25.

[9] Zhixian Cheng. Study curve and its application in industrial production operation research [J]. China engineering science, 2007, 9(7):82-88.

[10] Yongwu Zhou. Further expansion of optimal production batch model considering human learning phenomenon [J]. Systems engineering and electronics, 1998(3):36-38.

[11] Renyi Hao, Chunming Ye. Application of learning effect in project scheduling to project schedule [J]. Logistics engineering and management, 2017(05):153-155.

[12] Zhu K, Zhang R Q , Tsung F . Pushing Quality Improvement Along Supply Chains[J]. Management Science, 2007, 53(3):421-436.

[13] Porteus, Evan L. Optimal Lot Sizing, Process Quality Improvement and Setup Cost Reduction[J]. Operations Research, 1986, 34(1):137-144.

[14] Rajaram K, Karmarkar U S . Product Cycling With Uncertain Yields: Analysis and Application to the Process Industry[J]. Operations Research, 2002, 50(4):680-691.

[15] Weilai Huang, Zigang Zhang. Research on economic production batch model based on output flexibility [J]. Journal of management engineering, 1998(3):53-58.

[16] Caiyun Guo, Jinsong Hu, Lei Wang. Economic production batch model with defect rate and allowable shortage under fuzzy environment [J]. Computer integrated manufacturing system, 2008, 14(11).

[17] Chunmei Qu, Lianbo Zhang. Modeling and analysis of supplier economic production batch under JIT supply [J]. China electronic commerce, 2011(5):273-273.

[18] Wei Zeng, Yaochi Wang, Hongtao Zhou. Optimization of supply chain operation under carbon cap-and-trade mechanism [J]. Journal of management engineering, 2015, 29(3).

[19] Teng J T , Lou K R , Wang L . Optimal trade credit and lot size policies in economic production quantity models with learning curve production costs[J]. International Journal of Production Economics, 2014, 155:318-323.

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202001_2(12).0001

[20] Teng J T , Thompson G L . Oligopoly Models for Optimal Advertising When Production Costs Obey a Learning Curve[J]. Management Science, 1983, 29(9):1087-1101.