Performances evaluation of production system taking into account machine failure and free shipping option

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Abstract

Today many production companies are proposing free shipping as a marketing strategy to attract customers in e-commerce. In this paper we empirically examine the impacts of free shipping on the performance of a production system. Two cases of the transport services are considered: the first is a classic case in which the delivery charges are paid by the customer and the second is the case of the free shipping in which the delivery charges are paid by the company. Discrete flow model is used to describe the production system and to take into account delivery activities. The objective of this work is to provide a performance evaluation study that allows choosing the suitable case according to the indicators of interest such as delivery cost or the demand increase. Numerical results are presented to discuss the choice of the suitable case. In addition, an optimization study of the production system with free shipping option is presented.

Keywords
Free shipping, performance evaluation, machine failure, production system, transport.

1. Introduction

One of the most important sections of supply chain management is distribution. Delivery cost is one of the parts of the total price of the product, which make it engaging for consumers. That is why manufacturers and companies more often try to attract customers and encourage them to order more are increasingly offering free shipping. Moreover, different types of free shipping have greater effect on customers than discounts. In this this topic we found interesting works, Lewis et al. [1] empirically find that free shipping with or without conditions is very effective in generating additional sales. The authors say that consumers are very sensitive to shipping charges and that shipping fees influence order incidence and basket size. Promotions such as free shipping and free shipping for orders that exceed some size threshold are found to be very effective in generating additional sales. However, the lost revenues from shipping and the lack of response by several segments are substantial enough to render such promotions unprofitable to the retailer. Wen-Hsien Huang et al. [2] examine how consumers evaluate and respond to two economically equivalent but different forms of threshold free shipping (TFS) policy: They demonstrate that a piece-based TFS will result in a higher intention to shop than a dollar-based TFS. Mehmet Gäumäus et al. [3] presented study results which showed that the optimal strategy for retailers with a large segment of shipping-charge-skeptics is to offer free shipping to their customers. Michael Lewis [4] empirically studied the effects of shipping fees on customer acquisition and customer retention. It was found that shipping fees greatly influence order incidence rates and graduated shipping fees significantly affect average expenditures. Furthermore, a profitability analysis suggests that shipping policies that provide incentives for larger order sizes may outperform free shipping promotions. Guowei Hua et al. [5] examined a new free shipping problem in business context where the demand faced by the retailer is stochastic and the retail price affects the demand distribution. They numerically examine the impacts of free shipping, quantity discount, transportation cost, and demand variance on the newsvendor's optimal order quantity and pricing decisions. However, these works didn't consider some important characteristics of supply chain systems such as the manufacturing unreliability and unsatisfied demands. In this paper, we will study the impact of the free shipping on the performance of a manufacturing system with the take into account the machine failures, random demands and transport activities.

Realizing the importance of transport, Van Ryzin et al. [6] considered the impact of the transport for optimal flow control of job shops in order to minimize the discount and infinite-horizon average cost. Dolgui and Ould-Louly [7] proposed a model for supply planning under random lead time with the take into account the inventory and the lost sale costs. Turki et al. [8] studied a manufacturing system with transport activities with the consideration of the machine failures and the delivery time. The authors studied the impact of the transport cost on the optimal inventory level. Also Hajej et al. [9] considered the transport activates between the manufacturing store and purchase warehouse. The authors studied the influence of the transport time on the production delivery and maintenance planning. In this work we will consider two cases of production companies: the first is a production company without free shipping option and the second is with free shipping option. For modelling both cases, we will use discrete flow model which is the most realistic.

Discrete flow model (Turki et al. [10], [14]) is widely used for design, simulation, control and optimization of production systems. This model is considered as an alternative paradigm to queuing network for analysis and synthesis of discrete event systems. Hence, it allows to consider easily the transported parts and to describe the behavior of both cases of the transport service. Indeed, discrete flow model is the most realistic for discrete supply chain systems the fact it allows tracking individual products product by product in flow control and is easier to simulate. In this paper we will use a suitable simulation for discrete flow model which is the simulation based discrete event system.

The contribution of this paper is to provide a performance evaluation study that allows comparing both cases of delivery services, and then to evaluate the suitability of the free shipping according to the delivery charges and the customer demand.

The paper is organized as follows. We present the production system with delivery activities in section 2. In section 3 we will present the performance evaluation study with the numerical results. We present an optimization study of the production system in the section 4. Finally, the last section concludes the paper and gives some perspectives to our work.

2. Production System with Delivery Activities

We consider a manufacturing system that produces one type of product. The manufacturing system is composed of a single machine M, a stock S and a customer. We denote by $D(t)$ the customer demand which is random and given by a truncated Normal distribution. The demand $D(t)$ is satisfied from the stock S. The stock S is filled up by the machine M (see Fig. 1).

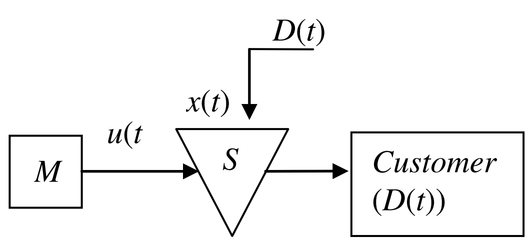

Figure 1: Production system.

It assumes that the machine will be never starved. It is either up or down. The state of the machine at time t, denoted $\alpha(t)$, is given by:

$$\alpha(t) = \begin{cases} 1 & \text{if machine is up} \\ 0 & \text{if machine is down} \end{cases}$$

While the machine is up, the production rate of M, denoted by $u(t)$, take a value between 0 and its maximum rate U, i.e., $0 \leq u(t) \leq U$. in the case when the machine is down, we have $u(t)=0$. The times to failure and times to repair are stochastic. We note $x(t)$ the stock inventory level at time t. The material outgoing from stock S at time t denoted by $y(t)$ and that corresponds to the number of products that will be satisfied.
Furthermore, we assume in this paper that:

- If the demand is unsatisfied, the demand is lost with a corresponding cost (lost sales cost).
- For building the stock S and for avoiding to have always unsatisfied demands, we assume that the maximal production rate permits to satisfy the demand, i.e. $U \geq D(t) \ \forall t$.
- At time $t = 0$, we suppose that we have enough parts in the stock to satisfy the first demand, i.e. $x(0) \geq D(t)$.
- The delivery time t is known and constant, with $t > 0$ and corresponds to a delivering cost.
- We assume that, the average system capacity is larger than the demand, i.e., $[(U.\ (MTBF))/(MTBF+MTTR)] > D(t)$, where MTBF and MTTR are, respectively, mean time between failure and mean time to repair.

We consider the case of finite stock inventory capacity, where the stock inventory level at time t ($x(t)$) is given by:

$$x(t) = x(t\text{-}dt) + u(t\text{-}dt) - y(t)$$

Where $y(t)$ is the number of products that will be satisfied. The value of $y(t)$ can be described as follows:

$$y(t) = \begin{cases} D(t) & \text{if } x(t - dt) \geq D(t) \\ 0 & \text{if } x(t - dt) = 0 \\ x(t - dt) & \text{if } x(t - dt) < D(t) \end{cases}$$

The control policy is defined as follows:

$$u(t) = \begin{cases} U & \text{if } a(t) = 1 \text{ and } x(t) < S^* \\ D(t) & \text{if } a(t) = 1 \text{ and } x(t) = S^* \\ 0 & \text{if } a(t) = 0 \end{cases}$$

This control policy is a hedging point policy (Mokou and Porter [15]) which ensures that the material does not exceed the stock capacity denoted by S^*. The hedging point has been proved to be the optimal policy (Akella and Kummar [16]), when the delivery time is not considered, and then uses for our system.

The number of unsatisfied demands (lost) at time t is defined as follows:

$$D^0(t) = D(t) - y(t)$$

We call case1 the case in which the delivery charges are paid by the customer. This case corresponds to a production system or company without free shipping option. We call case2 the case in which the delivery charges are paid by the company. This case corresponds to a company with free shipping option. The difference between both cases is not only the delivery charges, but also the demand customer. Indeed, as it mentioned in the introduction that when a company proposes free shipping option (case2), the customer demand increases and usually becomes upper than to which in the case1. Therefore in this study and in order to consider real cases, we will take into account the characteristics of the free shipping. In the following parts, we will present both cases of the profit function.

2.1. Profit function in the case that the company without free shipping option

In this part we will present the profit function in the case1. Thus, we need to denote $y(t)$, $u(t)$, $x(t)$, $D(t)$ and $D^0(t)$ respectively by $y_1(t)$, $u_1(t)$, $x_1(t)$, $D_1(t)$ and $D^{01}(t)$.

The stock inventory level at time t in case1 is given by:

$$x_1(t) = x_1(t-dt) + u_1(t-dt) - y_1(t)$$

The number of products that will be satisfied in case1 is given by:

$$y_1(t)= \begin{cases} D_1(t) & \text{if } x_1(t-dt) \geq D_1(t) \\ 0 & \text{if } x_1(t-dt) = 0 \\ x_1(t-dt) & \text{if } x_1(t-dt) < D_1(t) \end{cases}$$

The control policy in case1 is defined as follows:

$$u_1(t) = \begin{cases} U & \text{if } a(t) = 1 \text{ and } x_1(t) < S^* \\ D_1(t) & \text{if } a(t) = 1 \text{ and } x_1(t) = S^* \\ 0 & \text{if } a(t) = 0 \end{cases}$$

The number of unsatisfied demands at time t in case1 is defined as follows:

$$D^{01}(t) = D_1(t)-y_1(t)$$

The profit function for the case1 denoted by $P_1(t)$ and which is composed by the sales cost, production cost, inventory cost and lost sales cost, is given by:

$$P_1(t) = y_1(t).\ C_1 - u_1(t).C_2 - x_1(t).C_3 - D^0(t).\ C_4$$

Where:

C_1 - unit sales cost;
C_2 - unit production cost;
C_3 - unit inventory cost;
C_4 - unit lost sales cost;

The total profit function for the case1 denoted by $CT_1(S^*)$ depending on S^* is given by :

$$CT_1(S^*) = \sum_{t=0}^{t=T} P_1(t)$$

Where T is the total simulation time

2.2. Profit function in the case that the company with free shipping option

In this part we will present the profit function in the case2. Thus, we need to denote $y(t)$, $u(t)$, $x(t)$, $D(t)$ and $D^0(t)$ respectively by $y_2(t)$, $u_2(t)$, $x_2(t)$, $D_2(t)$ and $D^{02}(t)$.

The stock inventory level at time t in case2 is given by:

$$x_2(t) = x_2(t\text{-}dt) + u_2(t\text{-}dt) - y_2(t)$$

The number of products that will be satisfied in case2 is given by:

$$y_2(t)= \begin{cases} D_2(t) & \text{if } x_2(t - dt) \geq D_2(t) \\ 0 & \text{if } x_2(t - dt) = 0 \\ x_2(t-dt) & \text{if } x_2(t - dt) < D_2(t) \end{cases}$$

The control policy in case2 is defined as follows:

$$u_2(t) = \begin{cases} U & \text{if } a(t) = 1 \text{ and } x_2(t) < S^* \\ D_2(t) & \text{if } a(t) = 1 \text{ and } x_2(t) = S^* \\ 0 & \text{if } a(t) = 0 \end{cases}$$

The number of unsatisfied demands at time t in case2 is defined as follows:

$$D^{02}(t) = D_2(t)\text{-}y_2(t)$$

The profit function for the case2 denoted by $P_2(t)$ and which is composed by the sales cost, production cost, inventory cost, lost sales cost and delivery cost, is given by:

$$P_2(t) = y_2(t).\ C_1 - u_2(t).C_2 - x_2(t).\ C_3 - D^{02}(t).\ C_4 - y_2(t).\ C_5$$

$$= y_2(t).\ (C_1 - C_5) - u_2(t).C_2 - x_2(t).\ C_3 - D^0(t).\ C_4$$

Where: C_5 is the unit delivery cost.

The total profit function, for the case2, denoted by $CT_2(S^*)$ depending on S^* is given by:

$$CT_2(S^*) = \sum_{t=0}^{t=T} P_2(t)$$

3. Study of Production System with Free Shipping Option

In this section we stimulate both proposed cases to study the impact of free shipping on the production system performance. We aim to find balance point from which we can decide suitability of the company with free shipping option compare with company without this delivery option. We present two studies that allow comparing both cases of production system. First one is total profit with respects percentage increase in demand and second is with respects the ratio between unit sales cost and unit delivery cost.

We have developed two simulation algorithms based on discrete event system to simulate both case of the profit function. In what follows we present the algorithm which help to find solutions.

3.1. Algorithm for simulating the profit function

Step 1: Initialize the system.

Step 2: Determine the next event which could be: machine failure, repair, demand event, stock inventory full stock inventory empty.

Step 3: Change the state of the system.

Step 4: Time advance: $t = t + \Delta t$.

Step 5: If the simulation time is achieved, stop the simulation.

Else, go to Step 2.

3.2. Study of the free shipping according to the demand increase

In this part, we aim to study the performance of the system when the demand increases in case2. Indeed, as the company in case2 proposing the free shipping option, the demand increases. Thus, we vary the demand in case2 ($D_2(t)$) and we determine the corresponding total profit. To compare both cases of profit, we determine also the profit in case1 and then we can determine the balance point that indicates the suitability of the free shipping option. In what follows, we present the total profit in function of the percentage increase in demand. This study shows conditions with which company who offer free shipping can be a winner.

The following parameters are used for the simulation and which are arbitrary chosen:

- U = 15 products /time unit;
- The stock capacity S^*= 30 products;
- The average demand in case1 equals to 10 products /time unit;
- For the demand in case2 ($D_2(t)$), we vary the average value from 10 to 15 products /time unit. These values are presented by percentage increasing in demand. Indeed, we consider that the initial average value of $D_2(t)$ is equals to10 products /time unit as in case1, then it increases till to 15, for example when the percentage increasing in demand is equals to 30%, the average value of $D_2(t)$ is equals to13 products /time unit;
- The total simulation time is equal to T=10E+07 time units;
- *MTBF* is equal to 10 and *MTTR* is equal to 3;
- C_1 = 10;
- C_2 = 2;
- C_3 = 1;
- C_4 = 5;
- C_5 = 1.

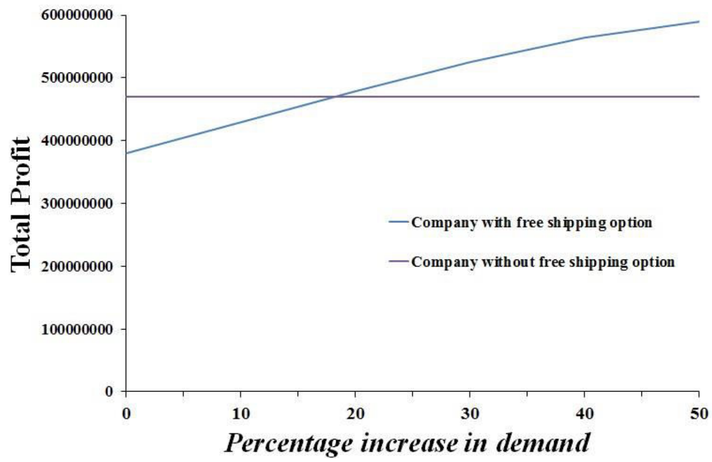

Figure 2: Total profit according to the demand increase

From the figure 2 we can determine the balance point of increasing demand which correspond to 18 percent of increasing. Indeed, if the company has more that 18 percent of increase in demand, the free shipping option will be profitable for company. Besides, if the company has less than 18 percent of increasing in demand, the case of the company without free shipping option is more profitable. Hence, this study allows to a manager to take decision about offering the free shipping option according to the demand increase.

3.3. Study of the free shipping according to the sales and delivery costs

In this part, we study the performance of the system in function of the ratio between the unit sales cost and the unit delivery cost. Thus, for both cases, we vary this ratio and the algorithm determines the corresponding total profit. We use the same simulation parameters that are in the previous part, the average demand in case2 is fixed to13 products /time unit. In what follows, we present the total profit in function of the ratio between the unit sales cost and the unit delivery cost.

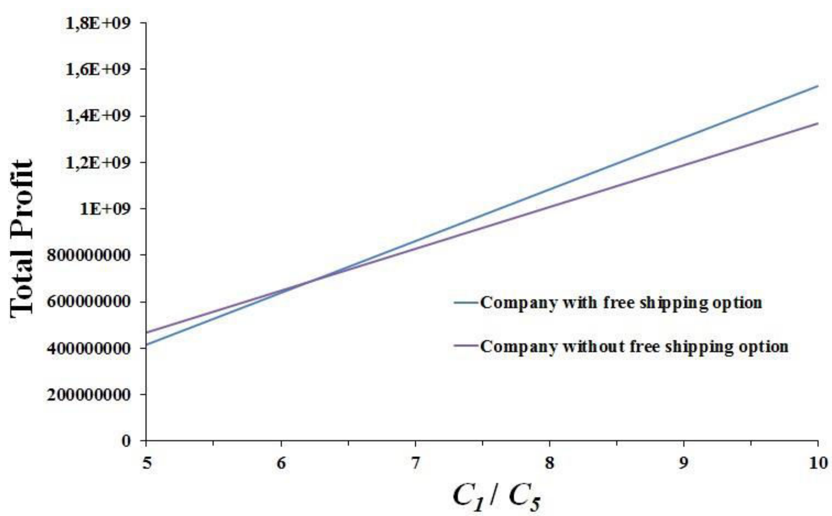

Figure 3: Total profit according to the demand increase

As we see in the figure 3, when the ratio between the unit sales cost and the unit delivery cost is more than 6.5, the free shipping option will be profitable for company. Hence, this study allows to a manager to take decision about offering the free shipping option according to the sales cost and delivery cost.

In the next section we will study the optimization of the production system with free shipping.

4. Optimization of Production System with Free Shipping.

In this section we have the interest to optimize the production system with free shipping option. Indeed, we will determine the optimal capacity of the stock inventory that maximizes the total profit function $CT_2(S^*)$. To determine the optimal value of the capacity, we use an optimization algorithm based simulation ([17]-[25]). We use the same simulation parameters that are in the section III. The average demand in case2 is fixed to13 products /time unit. In what follows the results.

Table 1. Optimal capacity of the stock inventory

S^*	$CT_2(S^*)$
11	661669056

The optimal capacity of the stock inventory is equals to 11 with the total profit is 661669056 monetary units. According to the figure 2, when the capacity of the stock is equals to 30 and the average demand equals to 13 products /time unit the total profit equals to 525682624 monetary units (which correspond to 30% increasing in demand). Hence to optimize the production system that offers the free shipping option, the manager should to reduce the capacity of the stock level to 11.

5. Conclusion

In this paper we studied two cases of the delivery services in production system: the first is a classic case in which the delivery charges are paid by the customer and the second is the case of the free shipping in which the delivery charges are paid by the company. To describe the system in both cases, discrete flow model is adopted and which take into account the delivery activities. We provided a performance evaluation study that allows choosing the suitable case according to delivery cost and the demand increase. Numerical results are presented and analyzed to discuss the choice of the suitable case. We studied the optimization of the production system with free shipping option with respect to the stock level capacity.

For future work we will consider a production system with several types of products. Then we will treat a lot size problem in the case of free shipping.

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