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Research Article

Improvement of Inventory Control for Defective Goods Supply Chain by Available Time Limitation of the Production Facilities

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Abstract: One of the most important competitive criteria in the global marketplace is keeping the customer satisfaction. Timely delivery and cost of finished goods are two important factors for satisfaction of customers. In this study, we proposed a mathematical model to improve inventory control of defective goods supply chain by Available Time Limitation (ATL) of the production facilities. The defective goods are reworking able parts and the rest are considered as scraps. The aim of the model is to optimize the total costs of production, maintenance, freight, reworking, the quantity of scrap goods and shortage in retailers for three level supply chains. The uniqueness is that it can anticipate the active manufacturers/distributors and the quantity of goods that must be exchanged between them. Finally, the model determines the Economic Production Quantity (EPQ) and appropriate ATL of any production facilities. Our proposed model is novel and we used CPLEX and LINGO to solve the problem. It can be ascertained that based on the results of the model validated the correctness and fine function of the model.

Keywords: CPLEX, defective goods, JIT logistic, LINGO, supply chain management

INTRODUCTION

In recent years, the Supply Chain Management (SCM) (Shib, 2011; Yung-Fu *et al*., 2007; Gwo-Hshiung *et al*., 2006; Wing *et al*., 2008; Carvalho and Costa, 2007) has been a field of study which covers a wide spectrum of research ranging from strategic issues to operational models. In the past two decades, the issue of supply chain management has drawn a great attention from manufacturers and organizations due to its optimal effects on their operations. Subsequently, the manufacturers need to find alternative means of ensuring the continuous provision of their goods and then employ appropriate strategies to meet various market demands properly and on time. In most current production system, factors such as imperfect quality and defective raw materials can affect the efficiency of productivity (Yuan-Shyi *et al*., 2010; Sarker *et al*., 2008; Arindam *et al*., 2009; Kun *et al*., 2009; Mondal *et al*., 2009). So, the manufacturers need a dedicated facility to perform the task of reworking these defective goods. Furthermore, if the raw materials are very expensive and have limited source, the reworking task can save so much cost. Several methods have been proposed for the improvement of efficiency and they showed that the correlation of simultaneous application of TQM, SCM and JIT can enhance the effectiveness of the companies (Vijay and Keah, 2005; Colledani and Tolio, 2006).

Young and Sook (2000), proposed a hybrid method for solving the problem of optimization of production-distribution planning in SCM. However, in their model, the production capacity of machine and the distribution capacity are limited. Also, Simme and Ruud(2004), considered defective products from a single-item manufacturer that used same facilities and production machines for reworking. On the other hand, mathematical models of economic order quantity (EOQ) for defective goods and the ordered amount returned as shortage have been studied and in most of their results showed that the defective goods and shortage can reduce the overall profit (Abdollah and Gultekin, 2007; Wahab and Jaber, 2010; Wee *et al*., 2007; Hung-Chi and Chia-Huei, 2010; Bjorn and Mike, 2010). For instance, Jafar and Mansoor (2008), investigated optimal amount of the order given to the supplier for the defective goods. In their model, they assumed that the defective goods can be used in other places or can be sold at a lower price. In line with that, Salameh and Jaber (2000), have extended and modified the Economic Production Quantity (EPQ) model for items with imperfect quality. Their investigation shows that the modified model can led to a reduction in the total production costs.

The implementation of Just In Time(JIT)has given such effective features on supply chain productivity because JIT can reduce inventory level, save manpower and increase service level to customers (Wang and

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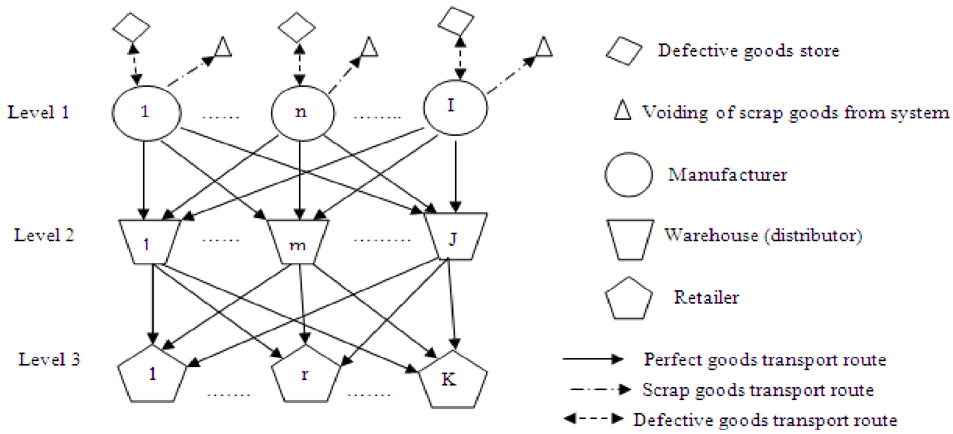

Fig. 1: Three-level supply chain network

Sarker, 2006; Reza and Mahsa, 2008). Amasaka (2002) presented a new JIT concept for producers which was not limited only to Toyota Production System (TPS) and Total Quality Management (TQM), but also included the software and hardware systems. The findings show the JIT has had a definitely positive impact on sales, design, improvement and production in Toyota factory.

In this study, we presents a comprehensive model including JIT logistics, Available Time Limitation (ATL) of production facilities, maintenance cost for the defective goods, cost of production of scrap products and cost of shortage in retailers due to the production of defective goods.

MATHEMATICAL MODEL

We proposed a mathematical model for optimizing the global costs of the defective goods. The model investigates three-level of supply chain network as shown in Fig. 1. The first level designates the manufacturers; the second level represents the distributors while the third level shows the retailers. The model can be adapted to optimize costs such as production, maintenance, shipping, reworking on the defective goods, scrap products and shortage in retailers due to the production of defective goods.

Assumptions and limitations of the model: The following assumptions are made to develop the mathematical model:

- The amount of demand was given to the manufacturers at the beginning of the period and duration of each period is fixed and clear.
- Duration of each period is equal to the total of production time and rework time.
- Shortage in retailer is allowed.
- The model is designed for multi-manufacturer, multi-distributor and multi-retailer.
- Parameters used are fixed which means the demand rate, reworking time, production time, percentage of defective products, percentage of scrap products and prices are fixed.
- The inspection operation is perfect and inspection time is zero.

We also consider limitations for our model:

- The manufacturers supply capacities and total warehouse capacities are limited.
- The storage capacities for each perfect product are limited.
- Store capacities and storage allocated capacities are limited for defective goods.
- For each period, the customer demand should be provided.
- Limited production and reworking times.

Indices and sets: In order to facilitate our model, the following indices are introduced.

Manufacturer's index $i = 1, 2, 3,..., I$
Distributor's index $j =1, 2, 3,..., J$
Product's index $l = 1, 2, 3,...., L$
Period's index $t = 1, 2, 3, \dots, T$
Retailer's index $k = 1, 2, 3, \dots, K$

Parameters and decision variables: The parameters and decision variables that used in cost optimization are defined as follows:

p_{ilt} : Percentage of defective goods l produced by manufacturer i during period t

γ_{ilt} : Rework cost of per defective goods l by manufacturer i during period t
h_{jlt} : Holding cost of product l in distributor j during period t
h'_{ilt} : Holding cost of product l in defective goods store inside the manufacturer i during period t
θ_{ilt} : Time required to production of per goods l by manufacturer i during period t
$T\theta_t$: Total of production time during period t
μ_{ilt} : Time of reworking required for goods l by manufacturer i during t
$T\mu_t$: The total of reworking time during period t
Pc_{ilt} : Production cost of per item by manufacturer i during period t
TC_{ijlt} : Shipping cost each product l from manufacturer i to distributor j during period t
$T'C_{jklt}$: Shipping cost each product l from distributor j to retailer k during period t
$T''C_{ilt}$: Shipping cost each defective goods l inside manufacturer I during period t (from production process to defective goods store and inverse)
α_{ilt} : Percentage of scrap product l produced by factory i during period t
f_{ilt} : Production cost of per scrap goods *l* by factory *i* during period *t*
β_{klt} : Shortage cost for each product l in retailer k during period t
B_{klt} : Amount of the shortage of product l in retailer k during period t
X_{ijlt} : Amount of product l transported from factory i to distributor j during period
Q_{ilt} : Economic production quantity of product l by factory i during period t
Def_{ilt} : Amount of defective goods l produced by factory i during period t
Sc_{ilt} : Amount of scrap goods l produced by factory i during period t
Co_{ilt} : Amount of perfect products l produced by factory i during t before reworking
TCo_{ilt}: Amount of perfect products l produced by factory i during t after reworking
Y_{jklt} : Amount of product l transported from distributor j to retailer k during period t

Total cost: The global optimal cost Z_{min} of the model is represented by the following equation:

$$Z_{\min}=\sum_{i=1}^{I}\sum_{l=1}^{L}\sum_{t=1}^{T}Pc_{ilt}.Q_{ilt}+\sum_{j=1}^{J}\sum_{l=1}^{L}\sum_{t=1}^{T}h_{jlt}.\left(\sum_{t'=1}^{t'\neq T}\sum_{i=1}^{I}X_{ijlt'}-\sum_{t'=1}^{t'\neq T}\sum_{k=1}^{K}Y_{jklt'}\right)+\sum_{i=1}^{I}\sum_{l=1}^{L}\sum_{t=1}^{T}h'_{ilt}.Def_{ilt}+$$
$$\sum_{i=1}^{I}\sum_{l=1}^{L}\sum_{t=1}^{T}\gamma_{ilt}.Def_{ilt}+\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{l=1}^{L}\sum_{t=1}^{K}TC_{ijlt}.X_{ijlt}+\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{l=1}^{L}\sum_{t=1}^{T}T'C_{jklt}.Y_{jklt}+\sum_{i=1}^{I}\sum_{l=1}^{L}\sum_{t=1}^{T}T''C_{ilt}.Def_{ilt}+$$
$$\sum_{i=1}^{I}\sum_{l=1}^{L}\sum_{t=1}^{T}f_{ilt}.Sc_{ilt}+\sum_{k=1}^{K}\sum_{l=1}^{L}\sum_{t=1}^{T}B_{klt}.\beta_{klt} \tag{1}$$

This equation determines the objective function to minimize total cost of supply chain. It includes:

- Cost of production
- Cost of maintenance in the distributors and defective goods stores
- Cost of defective goods reworking
- Cost of logistic from manufacturers to distributers
- Cost of logistic from distributers to retailers
- Cost of logistic from manufacturers to defective goods stores
- Cost of logistic from defective goods stores to manufacturers
- Cost of scrap goods production
- Cost due to shortage in retailers because of defective goods production

Constraints of the model: Due to the assumptions and limitation given to the mathematical model, few constraints need to be made to facilitate the model as the following equations.

$$Q_{ilt} \le S_{ilt} \qquad \forall \; i,l,t \tag{2}$$

Constraint (2) shows the restriction of the EPQ capacity in manufacturers:

$$\sum_{i=1}^{I}\sum_{l=1}^{L}X_{ijlt} \le W_{jt} \qquad \forall \quad j,t$$
$$\sum_{i=1}^{I}X_{ijlt} \le W_{jlt} \qquad \forall \quad j,l,t \tag{3}$$

Limitations (3) are delivery capacity constraint for distributors:

$$\sum_{j=1}^{J}\sum_{l=1}^{L}Y_{jklt} \le W'_{kt} \qquad \forall \quad k,t$$
$$\sum_{j=1}^{J}Y_{jklt} \le W'_{klt} \qquad \forall \quad k,l,t \tag{4}$$

Limitations (4) describe capacity constraint for retailers

$$Def_{ilt} = p_{ilt}.Q_{ilt} \qquad \forall \quad i,l,t \tag{5}$$

Equation (5) shows the amount of defective goods:

$$Sc_{ilt} = \alpha_{ilt}.Def_{ilt} \qquad \forall \quad i,l,t \tag{6}$$

Equation (6) represents the amount of scrap goods:

$$Co_{ilt} = (1-p_{ilt}).Q_{ilt} \qquad \forall \quad i,l,t \tag{7}$$

The amount of perfect goods before reworking describes by Eq. (7):

$$TCo_{ilt} = Co_{ilt} + Def_{ilt} - Sc_{ilt} \qquad \forall \quad i,l,t \tag{8}$$

Equation (8) explains the total of perfect goods after reworking:

$$Q_{ilt} = Co_{ilt} + Def_{ilt} \qquad \forall \quad i,l,t \tag{9}$$

The total of produced products by manufacturers in each period is shown with Eq. (9):

$$\sum_{k=1}^{K} d_{klt} + \sum_{i=1}^{I} Sc_{ilt} \le \sum_{i=1}^{I} Q_{ilt} \qquad \forall \quad l,t,$$

$$\sum_{k=1}^{K} d_{klt} \le \sum_{i=1}^{I} TCo_{ilt} \qquad \forall \quad l,t \tag{10}$$

Equation (10) assures that the total demands to each manufacturer in per period do not exceed the production capacity of those manufacturers; also, the all demands are covered by perfect products:

$$\sum_{k=1}^{K} B_{klt} = \sum_{k=1}^{K} d_{klt} - \sum_{i=1}^{I} Co_{ilt} \qquad \forall \quad l,t \tag{11}$$

$$\sum_{i=1}^{I} Co_{ilt} \le \sum_{k=1}^{K} d_{klt} \qquad \forall \quad l,t \tag{12}$$

Constrains (11) and (12) show the amount of shortage in retailer due to production of defective products:

$$\sum_{i=1}^{I} X_{ijlt} = \sum_{k=1}^{K} Y_{jklt} \qquad \forall \quad j,l,t \tag{13}$$

Equation (13) investigates the final inventory balance for per warehouse and it shows that the inventory for each warehouse is zero at the end:

$$\sum_{j=1}^{J} Y_{jklt} = d_{klt} \qquad \forall \quad k,l,t \tag{14}$$

The inventory of retailers is not more than demands; it shows by Eq. (14):

$$\sum_{k=1}^{K} \sum_{t'=1}^{t' \ne T} Y_{jklt'} \le \sum_{i=1}^{I} \sum_{t'=1}^{t' \ne T} X_{ijlt'} \qquad \forall \quad j,l,t \ne T \tag{15}$$

Limitation (15) explains that the amount of goods shipped by each warehouse to the retailers in per period do not exceed the inventory of that warehouse:

$$\sum_{j=1}^{J} X_{ijlt} \le TCo_{ilt} \qquad \forall \quad i,l,t \tag{16}$$

Constraint (16) describes the exit of scrap products from system and the total perfect product cover the demands:

$$\sum_{i=1}^{I} \sum_{l=1}^{L} \theta_{ilt} . Q_{ilt} \le T\theta_t \qquad \forall \quad t \tag{17}$$

Constraint (17) represents the limitation of available times of production facilities:

$$\sum_{i=1}^{I} \sum_{l=1}^{L} \mu_{ilt} . Def_{ilt} \le T\mu_{ilt} \qquad \forall \quad t \tag{18}$$

Eq. (18) shows the limitation of available times for reworking:

$$T\theta_t + T\mu_t = T_t \qquad \forall \quad t \tag{19}$$

Eq. (19) explains the required time for production and reworking in each period is equals with the length of that particular production period:

$$X_{ijlt}, Y_{jklt}, Q_{ilt}, B_{klt}, Def_{ilt}, Sc_{ilt}, Co_{ilt}, TCo_{ilt} \ge 0 \qquad \forall \quad i,j,k,l,t \tag{20}$$

Equation (20) explains the amount of productions, delivery to warehouses and etailers, shortage in retailers, scrap goods, defective goods, perfect goods before reworking and perfect goods after reworking should all have positive values.

Theoretically, the relation between production and time in any particular period is shown in Fig. 2.

- Total production during a period (Q_{opt})
- Perfect products produced during a period before reworking:

  $Co = (1-p).Q_{opt}$

- Defective goods produced for reworking during a period:

  $Def = p.Q_{opt}$

- Scrap products produced during a period:

  $Sc = \alpha.p.Q_{opt} = \alpha.Def$

- Perfect goods produced during a period after reworking:

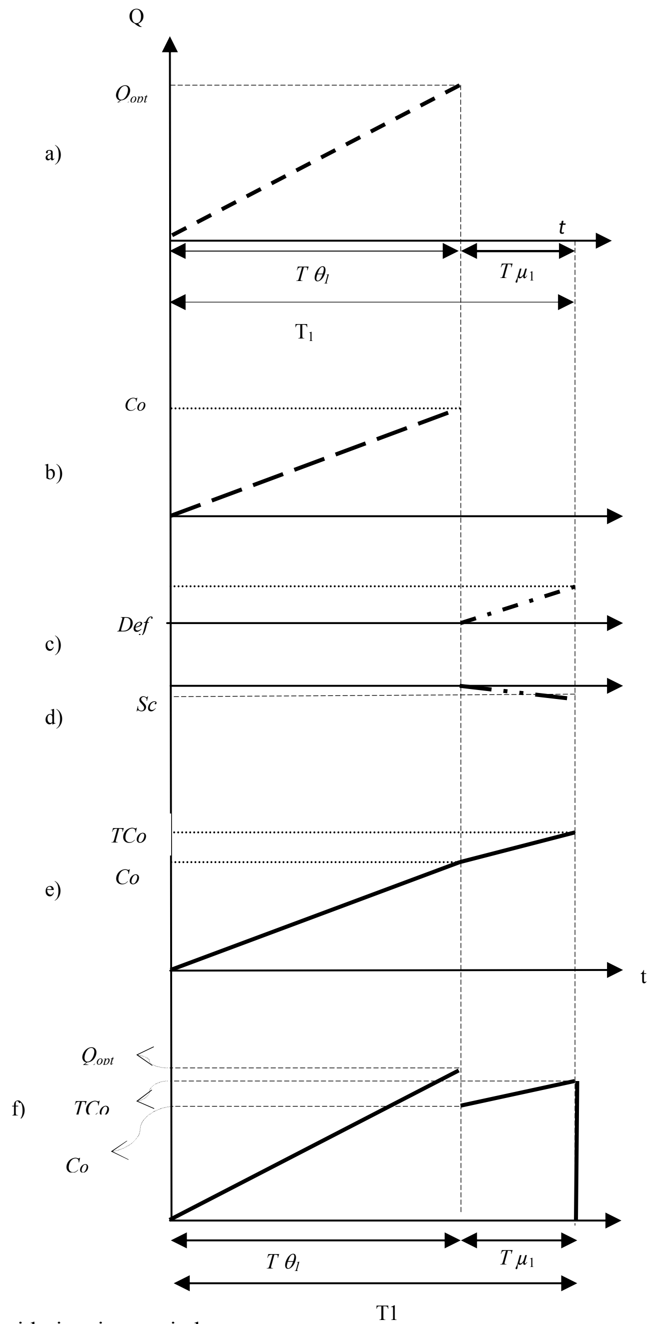

Fig. 2: Relation of production with time in a period

Table 1: Comparison of five sample problems solved by CPLEX and LINGO

Sample problems	Dimensions I	J	K	L	T	CPLEX Z_{min}	LINGO Z_{min}
1	1	1	1	1	1	88012	86341
2	2	2	1	1	1	95438	89941
3	2	2	2	1	1	187390	179883
4	2	2	2	1	2	360177	359767
5	2	1	1	2	3	320548	305768

$$TCo = Co + Def - Sc$$

- The total process of production in a period T_1

METHODOLOGY

The proposed mathematical model of three-level supply chain for defective goods by available time limitation of the production facilities and application of JIT logistics is solved by using a mathematical

Table 2: LINGO simulation for Tθ = 26750

Z_{min} = 321936

B_{klt}	Q_{ilt}	Def_{ilt}	Sc_{ilt}	Co_{ilt}	TCo_{ilt}	X_{ijlt}	Y_{jklt}
						X_{1111} = 3486	Y_{1111} = 0
						X_{1211} = 3000	Y_{1211} = 3500
B_{111} = 0	Q_{111} = 6666	Def_{111} = 600	Sc_{111} = 180	Co_{111} = 6066	TCo_{111} = 6486	X_{2111}= 14	Y_{2111}= 3000
B_{211} = 420	Q_{211} = 14	Def_{211}= 1	Sc_{211} = 0	Co_{211} = 13	TCo_{211} = 14	X_{2211} = 0	Y_{2211} = 0
∑ B = 420	∑ Q =6680	∑ Def =601	∑ Sc =180	∑ Co=6079	∑ TCo =6500	∑ X=6500	∑ Y=6500

Table 3: LINGO simulation for Tθ = 34000

Z_{min} = 248930

B_{klt}	Q_{ilt}	Def_{ilt}	Sc_{ilt}	Co_{ilt}	TCo_{ilt}	X_{ijlt}	Y_{jklt}
						X_{1111} = 0	Y_{1111} = 0
B_{111} = 0						X_{1211} = 2970	Y_{1211} = 3500
B_{211} = 344	Q_{111} = 3052	Def_{111} = 274	Sc_{111} = 82	Co_{111} = 2777	TCo_{111}= 2970	X_{2111}= 3500	Y_{2111}= 3000
	Q_{211} = 3632	Def_{211}= 255	Sc_{211} = 102	Co_{211} = 3378	TCo_{211} = 3530	X_{2211} = 30	Y_{2211} = 0
∑ B = 420	∑ Q = 6680	∑ Def = 529	∑ Sc = 184	∑ Co = 6155	∑ TCo = 6500	∑ X = 6500	∑ Y = 6500

Table 4: LINGO simulation for Tθ = 40150

Z_{min} = 196102

B_{klt}	Q_{ilt}	Def_{ilt}	Sc_{ilt}	Co_{ilt}	TCo_{ilt}	X_{ijlt}	Y_{jklt}
						X_{1111} = 0	Y_{1111} = 0
B_{111} = 0						X_{1211} = 0	Y_{1211} = 3500
B_{211} = 284	Q_{111} = 0	Def_{111} = 0	Sc_{111} = 0	Co_{111} = 0	TCo_{111}= 0	X_{2111}= 3500	Y_{2111}= 3000
	Q_{211} = 6687	Def_{211}= 468	Sc_{211} = 187	Co_{211} = 6219	TCo_{211} = 6500	X_{2211} = 3000	Y_{2211} = 0
∑ B = 280	∑ Q = 6687	∑ Def = 468	∑ Sc = 187	∑ Co = 6219	∑ TCo = 6500	∑ X = 6500	∑ Y = 6500

programming solver for linear programming called CPLEX and an optimization modelling software for linear, nonlinear and integer programming called LINGO.

In order to ascertain the correctness and fine function of the model, both of the solvers have been used. We simulate five sample problems with different dimensions and amount of parameters for validate the model. Furthermore, the finding of the most appropriate Available Time Limitation (ATL) was carried out by using three sample problems with same dimensions and amount of parameters with different available time of production facilities.

RESULTS AND DISCUSSION

The results of five sample problem solved using CPLEX and LINGO is shown in Table 1. From that, it can be seen that the maximum different between both solver is only 6.11%. It shows the correctness of our proposed model. On the other hand, the results of appropriate of available time limitation of production facilities for three sample problems are shown in Table 2, 3 and 4 and plotted in Fig. 3.

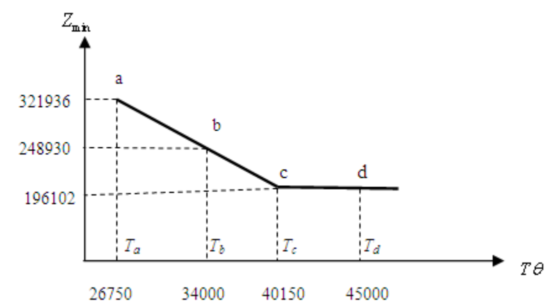

Fig. 3: Available time of production facilities and total cost relation

In Fig. 3, it shows the total cost Z_{min} of the supply chain related to available time of production facilities. It can be concluded that the Z_{min} will be reduced together with the increment of available time of production facilities. The total cost before T_a were infeasible and it showed constant value after T_c. Usually by increment the available time of production facilities, the indirect costs such as stagnant capital, maintenance cost will affect the total cost. From this simulation, it can be found that the most appropriate available time of production facilities is between T_a and T_c.

CONCLUSION

In this study, a solvable mathematical model through linear programming software LINGO and CPLEX have been proposed for the optimization of the costs of the supply chain of the defective goods. The proposed model can find the most appropriate of available time of production facilities and useful to optimize the costs such as production, maintenance, shipping, reworking on the defective goods, scrap products, shortage in retailers due to the production of defective goods and also it determines the economic production quantity of each manufacturer. The results of the model for some sample problems showed the correctness and fine function of the model.

According to the data of parameters, this model can also determines which manufacturer and distributor are active and at what period of the production to be active. Finally, it shows what amount of goods must be exchanged between them in order to optimize the costs.

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