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고객의 대기비용을 고려한 경제적 생산량 모델 설계

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The Design of Economic Production Quantity Model Considering Customer Waiting Cost

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제조업에서는 보다 합리적으로 생산량을 결정함으로써 고객에 대한 납기 준수는 물론, 기업 내부의 비용을 감소시키기 위한 노력을 끊임없이 하고 있다. 합리적인 생산량의 결정은 기업 내적으로는 낭비를 제거하고, 생산 흐름의 안정성을 유지하여 주며, 기업 외적으로는 공급사슬 전체의 자재흐름을 원활히 해주고 고객의 기호 변화에 빠르게 대처할 수 있도록 한다. 이에 본 논문은 보다 높은 고객 만족도와 비용의 절감을 위해서 재고 유지비용과 생산 준비비용만을 고려하는 기존의 생산량 결정 모형에 고객의 대기 비용을 추가한 다품목 경제적 생산량 모델을 제시하였다.

Keywords : EOQ(Ecinimic Order Quantity), EPQ(Economic Production Quantity), Customer Waiting Cost

1. 서 론

To gain an advantage with reducing cost in manufacturing companies and improving the reliability from customers, this paper will inquire into the economic production quantity, one of the classic models to determine production quantity, and show the problems and improvement on the method. Also, to raise the reliability from customers, we will develop an effective economic production quantity model that includes parameters indicating possible events in customers as an expansive economic production quantity model. We will also make up for limitation in the economic production quantity model to apply the method to a multi-item manufacturing system because the classic economic production quantity is confined to a manufacture system producing a single item. In this paper, we will consider the anticipated effect and practical use for identifying the improved economic production quantity. As you can see, to achieve high customer satisfaction and curtailment of cost from a manufacturing firm's point of view it is considered that a new production quantity model reflecting reality is required rather than a simple economic production quantity including inventory carrying cost and set up cost. Based on these previous researches on economic production quantity and the model with customer waiting cost, this paper will develop the economic multiple item production quantity model considering customer waiting cost.

2. Previous research

In manufacturing company, there are four major activity; (1) material supply activity from external provider, (2) manufacturing activity producing finish product with raw materials, (3) temporary storage activity of end items, and (4) delivery activity to customers. All companies are operated lying stress on these activities and these individually or cooperatively contribute to create profit. Another major activity in manufacturing company is assigning jobs at facilities and workstation that is concerned with production balancing production and minimizing cost. Thus, it has been issues how to integrate or harmonize these four major activities. As early as Goyal (1995) and Lu (1995) suggested a study about production-delivery policy between single manufacturer and multiple retailer, and Goyal and Nebebe (2002) researched a study about production-delivery policy between single manufacturer and single retailer. In manufacturing facility assembling multiple parts, Hahm (1990) showed two models by *Common cycle* approach and a model by *Basic period* approach under a single deterministic replenishment cycle length for all parts. Ramani and Narayanan presented the expansive economic lot scheduling model for Just-In-Time system and researched the effect of setup cost, setup time, and capacity variable for total profit. Bannerjee and Burton (1994) proposed the inventory replenishment policy operating cooperatively for single seller and multiple buyers. Also, they assumed that all buyers have same replenishment cycle time (*Common Delivery Cycle*), and that the production cycle length is an integer multiple of common delivery cycle. Nori and Sharker (1996) examined the cycle scheduling problem for multiple products in a single production facility under the JIT policy. Ha and Kim showed that the integrated JIT purchasing under the single setup-multiple deliver plan is more effective than the classic economic order quantity. Sarker and Parija (1996) abd Parija and Sarker (1999) developed the order policy for raw materials to satisfy customers ordering already scheduled end item quantity in fixed time period. David and Eben-Chaim (2003) attempted to unify the degree of independence and the level of flexibility converted to lot size and delivery scheduling. In establishing and discussing the partnership between manufacturer and retailers, Kelle *et al.* (2003) searched two typical cases; the supplier's dominance having large production and sporadic delivery lot size and the retailer's dominance having small and production and frequent delivery. They compared the optimal policy for both the two policy in each case.

3. The Economic Production Quantity in Multiple Items

Most industrial countries including Korea are keeping large volume production system in that the system can get low cost and the economies of scale. However, as customer is more changeable and exporting channel is wider, it is necessary to convert into multiple items production system. These changes are related with changes of social environment as follows ;

① The raise of income and various customer needs
② The higher education and graying
③ The productive use of limited resources
④ The international division of labor and diversification of product
⑤ The intensification of the company competition

The characteristics of multiple items small production are as follows ;

- *The diversity of production item*

The type of item and the delivery period are diverse and the production quantity is small.

- *The diversity of process*

The conversion process from raw materials to product is various and the flow of materials or the process is also diverse each product.

- *The lack of production capacity*

It is possible to occur over and short because of various demand and the change of demand and companies should be depend on overtime work or subcontract if the production capacity is lack.

- *The uncertainty of customer demand*

The standard and delivery of product ordered by customer are often changed and the delivery delay of supply is frequently occurred.

It is important to determine the economic production quantity each item to run multiple item small production effectively. However, it is possible that the individual economic production quantity can not meet customer demand. Although the production for each item follows a certain sequence, it can be possible for demand to be unsatisfied on time when production planning sets depending on the individual economic production quantity because there is customer demand in anytime. Thus, it is important to determine economic production quantity to meet customer demand as well as the economic production quantity.

The notation we will require is as follows ;

TC = annual total cost
i = the index for item, $t=0,\cdots,i$
k = the number of production
D_i = the annual demand for item i
p_i = the annual production rate for item i
t_{pi} = the production period for item i
C_{bi} = the setup cost for item i
C_{pi} = the production cost per unit for item i
C_{hi} = the holding cost per unit for item i
C_{sbi} = the setup cost for item i with shortage
C_{spi} = the production cost per unit for item i with shortage
$S_i = \left\{ \begin{matrix} S_i = 1, & if\ shortage\ occur \\ S_i = 0, & otherwise \end{matrix} \right\}$
P_{si} = the average number of shortage for item i
L_{wi} = the length of delivery delay period for item i
R_{wi} = the rate of compensation for customer waiting for item i

If each item having annual demand D_i produces k times, we can express D_i/k for the production quantity a time. According to that, the average inventory level can be indicated as follows ;

The average inventory level of item $t = \frac{D_i/k}{2}(1-\frac{d_i}{p_i})$

Here, d_i is the daily demand and p_i indicates the daily capacity for item i when all facilities only produce item i. In addition, we can define annual setup cost as kC_{si} because item i should be setup k times a year and the annual total cost TC including inventory carrying cost can be expressed as follows ;

$$TC = \sum_{i=0}^{I} kC_{si} + \sum_{i=0}^{I} \frac{\frac{D_i}{k}}{2}(1-\frac{d_i}{p_i})C_{hi}$$

Here, C_{si} is the setup cost a time for item i and $C_{hi}$is the inventory carrying cost per unit. We can calculate the k minimizing TC by differentiating by k because TC is a function for k. Hence, the production frequency, quantity, and total cost can be expressed as follows ;

$$k^* = \sqrt{\frac{\sum_{i=0}^{I} C_{hi} D_i (\frac{1-d_i}{p_i})}{2\sum_{i=0}^{I} C_{si}}}$$

$$Q^* = \frac{D_i}{k^*}$$

$$TC^* = \sqrt{2\sum_{i=0}^{I} C_{si} C_{hi} D(1-\frac{d_i}{p_i})}$$

We can get the economic production quantity each item through the classic economic production quantity model. It is effective to calculate the economic production quantity for individual item under the mass production system using special-purpose-tool, while it is not under the multiple item production system. It is because that each setup time and production time are required to make multiple items, producing other items is suspended while an item is produced and customer demand is generated. The demand during production period in order should be also satisfied, so that the production sequence and frequency should be determined considering possibility of shortage. The customer waiting cost is a compensation for delivery delay, and a kind of fine. However, it is necessary to classify into the penalty for delivery delay and the order cost for later delivery. The fine for flaking delivery should be used for a method of reconsideration on the firm's image and on the recovery of reliability. The later order cost should be also applied to the product that did not keep the delivery time and earmark to minimize complaint of customer. Thus, the new economic production quantity is required, including the later set up cost as well as the fine of delivery delay.

4. The Economic Production Quantity Model Considering Customer Waiting Cost

Mass production system usually uses special- purpose-facilities, or it is unfavorable to the flow of materials and the productivity. With the special-purpose-tools, however, the unit cost is lower, moving length shorter and the flow of materials faster.

4.1 The assumption for model

As you can see above, using the general-purpose -tools is more appropriate in the production flexibility and the facility investment. The plan and sequence for each item and facilities should be arranged with general-purpose-tools. The customer waiting cost should be also included considering shortage because it is possible for all demand to be unsatisfied spite of economic production quantity. Thus, the assumptions to establish the economic production quantity model with customer waiting cost for multiple item production system are as follows including the assumptions from EOQ by Harris ;

① It is for multiple item production
② Products are gradually filled in production period.
③ Shortage is allowed and shortage cost and waiting cost are caused when shortage occur. But, if there is no shortage, these costs are not considered.
④ The length of delivery delay period is known.
⑤ The customer waiting cost is directly proportional to the waiting period and the purchasing volume.

4.2 The model

With these assumptions, we can establish the economic production quantity model considering customer waiting cost. In the economic production quantity model under the multiple item production system, total cost can be expressed as

Total cost = the total amount of each manufacturing cost
+ the holding cost for each item
+ the shortage cost for individual item
+ the waiting cost for each product

Manufacturing cost is classified into setup cost and production cost, and production cost is directly proportional to the unit production cost and the amount of production. By calculating manufacturing cost each item, total manufacturing cost can be expressed as

$$\text{Total manufacturing cost} = \sum_{i=0}^{I} kC_{bi} + \sum_{i=0}^{I} C_{pi}Q_i$$

Besides, total holding cost can be also computed by sum up individual's holding cost because holding cost is depend on the average inventory level and the holding cost for each item. Because the average inventory level can be denoted as $\frac{1}{2}\frac{D_i}{k}(1-\frac{d_i}{p_i})$, we can express total holding cost as follows ;

$$\text{Total holding cost} = \sum_{i=0}^{I}\frac{1}{2}\frac{D_i}{k}(1-\frac{d_i}{p_i})C_{hi}$$

Here, to calculate the quantity a time dividing the annual demand for each product by same number of production is why all items are produced in the same times because it is a cycle for each item to produce a time. Shortage cost is a kind of crash cost that is used for the order to be unsatisfied for delivery, so that the setup cost and the manufacturing cost for the crash order should be distinguished. Here, because the crash order would be delivered to customer as soon as the product done, total shortage cost can be expressed as follows ;

$$\text{Total shortage cost} = \sum_{i=0}^{I} S_i \cdot k(C_{sbi} + C_{spi} \cdot P_{si})$$

It is necessary to use binary variable S for including shortage cost only when shortage occur. Binary variable S is also required to customer waiting cost because the waiting cost is also required with occurring shortage. Because the waiting cost is directly proportion to the length of waiting period and the quantity of order in dollar, we can express customer waiting cost as

$$\text{Total customer waiting cost} = \sum_{i=0}^{I} S_i \cdot k \cdot L_{wi} \cdot R_{wi} \cdot C_{pi} \cdot P_{si}$$

Thus, total cost can be expressed as

$$TC = \sum_{i=0}^{I} k \cdot C_{bi} + \sum_{i=0}^{I} C_{\pi}Q_i + \sum_{i=0}^{I}\frac{D_i \cdot C_{hi}}{2k}(1-\frac{d_i}{p_i}) + \sum_{i=0}^{I} S_i \cdot k(C_{sbi} + C_{spi} \cdot P_{si}) + \sum_{i=0}^{I} S_i \cdot k \cdot L_{wi} \cdot R_{wi} \cdot C_{pi} \cdot P_{si}$$

TC is a function for k, so that TC should be differentiated by k.

$$\frac{\partial TC}{\partial k}=\sum_{i=0}^{I}C_{bi}+\frac{1}{k^2}\sum_{i=0}^{I}\frac{D_i\cdot C_{hi}}{2}(1-\frac{d_i}{p_i})+\sum_{i=0}^{I}S_i(C_{sbi}+C_{spi}\cdot P_{si})$$
$$+\sum_{i=0}^{I}S_i\cdot L_{wi}\cdot R_{wi}\cdot C_{pi}\cdot P_{si}=0$$

$$\therefore k^*=\sqrt{\frac{\sum_{i=0}^{I}\frac{D_i\cdot C_{hi}}{2}(1-\frac{d_i}{p_i})}{\sum_{i=0}^{I}C_{bi}+\sum_{i=0}^{I}S_i(C_{sbi}+C_{spi}\cdot P_{si})+\sum_{i=0}^{I}S_i\cdot L_{ui}\cdot R_{ui}\cdot C_{pi}\cdot P_{si}}}$$

If k^* is computed, $Q^*$is also calculated as

$$Q^*=\frac{D_i}{k^*}$$

Thus, the minimized TC^* can be leaded as

$$TC^*=k\left\{\sum_{i=0}^{I}C_{bi}+\sum_{i=0}^{I}S_i(C_{sbi}+C_{spi}\cdot P_{si}+\sum_{i=0}^{I}S_i\cdot L_{wi}\cdot R_{wi}\cdot C_{pi}\cdot P_{si}\right\}$$
$$+\frac{1}{k}\left\{\sum_{i=0}^{I}2C_{pi}\cdot D_i+\sum_{i=0}^{I}\frac{D_i\cdot C_{hi}}{2}(1-\frac{d_i}{p_i})\right\}$$
$$=\sqrt{\sum_{i=0}^{I}2D_i\cdot C_{hi}(1-\frac{d_i}{p_i})}$$
$$\sqrt{\sum_{i=0}^{I}C_{bi}+\sum_{i=0}^{I}S_i(C_{sbi}+C_{spi}\cdot P_{si})+\sum_{i=0}^{I}S_i\cdot L_{wi}\cdot R_{wi}\cdot C_{pi}\cdot P_{si}}$$
$$+\sum_{i=0}^{I}C_{pi}\cdot D_i\cdot\sqrt{\frac{\sum_{i=0}^{I}C_{bi}+\sum_{i=0}^{I}S_i(C_{sbi}+C_{spi}\cdot P_{si})+\sum_{i=0}^{I}S_i\cdot L_{wi}\cdot R_{wi}\cdot C_{pi}\cdot P_{si}}{\sum_{i=0}^{I}\frac{D_i\cdot C_{hi}}{2}(1-\frac{d_i}{p_i})}}$$

We can compare the number of production and total cost with customer waiting cost with/without customer waiting cost in <Table 1>.

5. Case Study for Model

In reality, a small computer company, M, has 10 items and the days operated is 300days a year. We can see the demand and cost each item in <Table 2>.

In <Table 2>, it seems like there is idle production capacity because total production period is 243 days of the days operated 300 days. However, it is possible to meet all demand for each item when production planning is set according to the economic production quantity for individual item. Although it is enable to calculate economic production quantity for each product using the classic economic production quantity model, item 1, 3, and 4 cannot meet their demand using one production as described <Table 3>. In this case, it is necessary to compute the production quantity a time considering production schedule. Thus, the production cycle and production quantity for each item should be determined to minimize setup cost and holding cost assuming a cycle means that all type of product is produced one time. <Table 4> describes more detail data of the related cost for each item.

<Table 1> The comparison the number of production and total cost with/without customer waiting cost

	Without customer waiting cost
The number of production	$\sqrt{\frac{2DC_s}{C_h}(\frac{P}{P-D})}$
Total cost	$\sqrt{2DC_sC_h(\frac{P-D}{P})}$
	With customer waiting cost
The number of production	$\sqrt{\sum_{i=0}^{I}\frac{2DC_{bi}}{C_{hi}}}\cdot\sqrt{\frac{1+\sum_{i=0}^{I}\frac{S_i(C_{sbi}+C_{spi}\cdot P_{si})}{C_{bi}}+\sum_{i=0}^{I}S_i\cdot L_{wi}\cdot R_{wi}\cdot C_{pi}\cdot P_{si}}{P-D}}$
Total cost	$\sqrt{\sum_{i=0}^{I}2D_i\cdot C_{hi}(1-\frac{d_i}{p_i})}\sqrt{\sum_{i=0}^{I}C_{bi}+\sum_{i=0}^{I}S_i(C_{sbi}+C_{spi}\cdot P_{si})+\sum_{i=0}^{I}S_i\cdot L_{wi}\cdot R_{wi}\cdot C_{pi}\cdot P_{si}}$ $+\sum_{i=0}^{I}C_{pi}\cdot D_i\cdot\sqrt{\frac{\sum_{i=0}^{I}C_{bi}+\sum_{i=0}^{I}S_i(C_{sbi}+C_{spi}\cdot P_{si})+\sum_{i=0}^{I}S_i\cdot L_{wi}\cdot R_{wi}\cdot C_{pi}\cdot P_{si}}{\sum_{i=0}^{I}\frac{D_i\cdot C_{hi}}{2}(1-\frac{d_i}{p_i})}}$

<Table 2> The data of demand and cost for each item in M company

Item	Annual demand (unit)	Average daily demand (unit)	Average daily capacity (day)	Production time (day)	The rate of unit holding cost	Setup cost (dollars)
1	9,000	28	500	18	0.4	37
2	15,000	55	600	25	0.02	45
3	9,000	32	900	10	0.3	27
4	10,000	38	200	50	0.1	16
5	5,000	15	250	20	0.35	20
6	12,000	42	300	40	0.05	18
7	20,000	40	1,000	20	0.1	14
8	5,000	18	50	10	0.15	45
9	10,000	32	400	25	0.02	50
10	15,000	52	600	25	0.05	55
Total				243		

<Table 3> The economic production quantity with considering as individual item

Item	Quantity per time (unit)	The number of annual setup	The day required for production(day)	The day required for spending the production (day)
1	297	30.31	0.59	10.61
2	1,724	8.70	2.87	31.35
3	324	27.78	0.36	10.13
4	629	15.91	3.14	16.54
5	276	18.14	1.10	18.38
6	915	13.11	3.05	21.79
7	764	26.19	0.76	19.09
8	368	13.59	0.74	20.44
9	1,346	7.43	3.36	42.06
10	1,063	14.12	1.77	20.43
계			17.76	

<Table 4> Cost data for each item

Item	production cost ($)	setup cost with shortage ($)	The production cost with shortage ($)	The length of waiting (day)	The waiting rate
1	20	74	40	0.30	0.1
2	25	90	50	1.44	0.1
3	16	54	32	0.18	0.1
4	10	32	20	1.57	0.1
5	8	40	16	0.55	0.1
6	12	36	24	1.52	0.1
7	10	28	20	0.38	0.1
8	23	90	46	0.37	0.1
9	30	100	60	1.68	0.1
10	32	110	64	0.89	0.1
계				8.88	

(1) Without customer waiting cost

We can show the information will be require to calculate k^* in <Table 5> Thus, k^* is expressed as

$$k^* = \sqrt{\frac{207,165.5}{2 \times 327}} \cong 17.8$$

We can also provide the essential data for TC^* in <Table 6>. Thus, we can get TC^* value as

$$TC^* = \sqrt{2 \times 6,949,267.5} \cong 3,728.07$$

(2) With customer waiting cost

In the case with customer waiting cost, the waiting cost and the number of production should be included in total cost because the issue of customer waiting should be considered a production. <Table 7> describes the information required to calculate k^* with customer waiting cost.

Thus, we can obtain the result as

$$k^* = \sqrt{\frac{103{,}583}{17{,}256.23}} \cong 2.45$$

You can see the data needed to get TC^* with customer waiting cost in <Table 8>.

<Table 5> The required information to compute k^*

Item	Annual demand (unit)	The unit holding cost ($)	The total holding cost($)	$1-\frac{d_i}{p_i}$	The setup cost($)
1	9,000	8.00	72,000	0.94	37
2	15,000	0.50	7,500	0.91	45
3	9,000	4.80	43,200	0.96	27
4	10,000	1.00	10,000	0.81	16
5	5,000	2.80	14,000	0.94	20
6	12,000	0.60	7,200	0.86	18
7	20,000	1.00	20,000	0.96	14
8	5,000	3.45	17,250	0.96	45
9	10,000	0.60	6,000	0.92	50
10	15,000	1.60	24,000	0.91	55
계	110,000	24	221,150	9	327

<Table 6> Required information to compute TC^*

Item	Annual demand (unit)	The unit holding cost($)	$1-\frac{d_i}{p_i}$	The setup cost ($)	$C_{bi} \cdot C_{hi} \cdot D_i(1-\frac{d_i}{p_i})$
1	9,000	8.00	0.94	37	2,514,816.00
2	15,000	0.50	0.91	45	306,562.50
3	9,000	4.80	0.96	27	1,124,928.00
4	10,000	1.00	0.81	16	129,600.00
5	5,000	2.80	0.94	20	263,200.00
6	12,000	0.60	0.86	18	111,456.00
7	20,000	1.00	0.96	14	268,800.00
8	5,000	3.45	0.96	45	748,305.00
9	10,000	0.60	0.92	50	276,000.00
10	15,000	1.60	0.91	55	1,205,600.00
계	110,000	24	9	327	6,949,267.50

<Table 7> The required information to calculate k^* with customer waiting cost

Item	$\frac{D_i C_{hi}}{2}$	The setup cost ($)	The shortage cost $(S_i(C_{sbi}+C_{spi} \cdot P_{si}))$	The customer waiting cost $(S_i \cdot L_{wi} \cdot R_{wi} \cdot C_{pi} \cdot P_{si})$
1	36,000	37	8,084.39	6
2	3,750	45	0.00	0
3	21,600	27	7,869.90	4
4	5,000	16	957.33	7
5	7,000	20	0.00	0
6	3,600	18	0.00	0
7	10,000	14	0.00	0
8	8,625	45	0.00	0
9	3,000	50	0.00	0
10	12,000	55	0.00	0
계	110,575	327	16,911.62	18

<Table 8> The required data to lead to TC^* with customer waiting cost

Item	The shortage cost $(S_i(C_{sbi}+C_{spi} \cdot P_{si}))$	The customer waiting cost $(S_i \cdot L_{wi} \cdot R_{wi} \cdot C_{pi} \cdot P_{si})$	$C_{pi} \cdot D_i$
1	8,084.39	6	180,000
2	0.00	0	375,000
3	7,869.90	4	144,000
4	957.33	7	100,000
5	0.00	0	40,000
6	0.00	0	144,000
7	0.00	0	200,000
8	0.00	0	115,000
9	0.00	0	300,000
10	0.00	0	480,000
계	16,911.62	18	2,078,000

Thus, TC^* can be calculated as follows ;

$$TC^* = \sqrt{414,331} \times \sqrt{17,256.23} + 2,078,000 \times \sqrt{372,682.74} \cong 804,269.97$$

We can compare the both cases in the number of production and total cost in <Table 9>.

<Table 9> the comparison the number of production and total cost with/without customer waiting cost

	Without customer waiting cost	With customer waiting cost
The number of production	17.8	2.45
Total cost	$3,728.07	$804,269.97

As you can see in <Table 9>, although the number of production with customer waiting cost is smaller than that without customer waiting cost, total cost with customer waiting cost is considerably increased. That is because inventory should include more products to meet demand that may occur in no-production period as many as the reduced times of production.

6. Conclusion

As the information network technology has developed, we have been undergoing high industrial society. These changes have had direct effects on not only human beings but also manufacturing companies. Especially, these enormous effects are also on the product plan and inventory and material managements. Besides, as the internal and external customer needs become various and the environment of industry becomes diversification of export markets, it is under the necessary of converting to small quantity batch production. The product plan and inventory and material managements is the core in manufacturing system, and strategically managing these plans is linked directly with the survival of a manufacturing company. Recently, the recognition of the competition has been transforming from the competition of between individual firms to the competition of the whole supply chain. In addition, of the supply chain, procurement and production of parts and the logistics actives is the most important part. Therefore, to high customer satisfaction and reduction of cost, this study will show the new model reflecting more concrete on the classic economic production quantity that only concern with inventory cost and order cost.

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