STRATEGIC PROCUREMENT PROCESS FOR MULTIPLE ITEMS IN A SUPPLY CHAIN

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ABSTRACT

Procurement, the process of acquiring goods or services from the external providers, involves strategic sourcing and purchasing. Observing the researches related to procurement finds that many researches study sourcing and purchasing separately, missing out the essence of the procurement process. This paper shows procurement process from sourcing to purchasing. The methods used to select the supplier and to determine the order quantity in the researches are reviewed. Moreover, this paper explains the procurement process through a case of an oilrigs manufacturer. AHP is applied for supplier selection, then the multiple items are purchased from the selected supplier. The 3 models of applied EOQ method for the order quantity are compared. The method of partially jointly order the items by applied EOQ method is selected with the lowest total costs.

INTRODUCTION

Procurement can be considered vital to business operations that it normally ensures availability of all necessary items for their operations. The effective procurement including the processes of sourcing and purchasing all together are essential to the supply chain (Kumar, et al. 2018). An effective supply chain can reduce supply chain cost by choosing the right supplier, an activity in sourcing process, and purchasing material with the right amount (Araz and Ozkarahan 2007; Kumar, et al. 2018; Pereira and Costa 2017). However, the procurement process in researches is normally discussed in the area of sourcing or purchasing process separately. Realistically, the firm must consider both processes in procurement. This paper, therefore, presents the whole procurement process which consider both sourcing (supplier selection) and purchasing so that the firms' procurement officers can follow. Moreover, in the purchasing process, this paper demonstrates how to purchase multiple items from a supplier adopting the applied Economic Order Quantity (EOQ) methodology. The rest of the paper is organized as follows. The next section presents the two processes in procurement: sourcing and purchasing, and related literature review. After that, the case is presented to demonstrate the whole process of procurement beginning with supplier selection by Analytic Hierarchy Process (AHP) followed by purchase ordering with applied EOQ. Finally, discussion and conclusion is presented in the last section for practical implication and possible future researches.

ESSENCE OF PROCUREMENT PROCESS

Procurement is a logistics process to obtain goods or services for the operation. It normally includes sourcing process focusing on supplier selection, and purchasing process involving a major activity of purchase ordering. To complete the essence of procurement processes from research perspectives, the studies of procurement can be depicted in Figure 1.

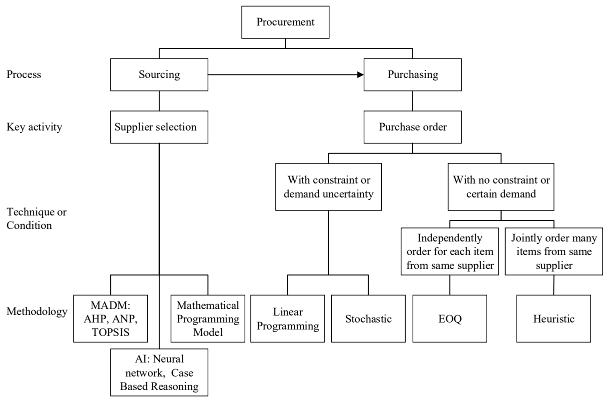

Figure 1: Essence of Procurement Process

Sourcing – Supplier Selection

Sourcing is the process of identifying source that provides goods or services. Sourcing contributes to the success of supply chain management in the way that it ensures that the company purchases from a right supplier with cost saving (Kumar, et al. 2018). Many firms form partnerships with suppliers, and involve them in the early stages of product research and development (Araz and Ozkarahan 2007; Kumar, et al. 2018). Many experts claim that supplier selection is one

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of the most important activities in sourcing process which help the firms select proper suppliers and eventually enhance the firms' performance. Considering that the supplier selection influences the firms' competitiveness, it attracts many researchers to develop methods for supplier selection. Evaluation of a supplier depends on several criteria such as price, quality, and others. These criteria influence the outcome of decision-making. Consequently, the methodologies of multi-criteria decision making are normally applied to the study. Some examples of multi-criteria methodologies used in supplier selection can be classified into 3 groups (Figure 1). The first group is the Multi Attribute Decision Making (MADM) including AHP or fuzzy AHP (Asamoah, et al. 2012; Özfirat, et al. 2014; Özkan, et al. 2011; Secundo, et al. 2017; Tahriri, et al. 2008; Yadav and Sharma 2016), ANP (Gencer and Gürpinar 2007; Hsu and Hu 2009; Rezaeisaray, et al. 2016) and mix between methods (Sevkli, et al. 2008; Yadav and Sharma 2015). The second group is Artificial Intelligent such as case based reasoning (CBR) (Jahani, et al. 2011; Zhao and Yu 2011). The last group is mathematical model (multiple objective programming) or mixed between mathematic model with others (Faez, et al. 2009; Kumar, et al. 2018; Kumar, et al. 2018; Saen 2007; Sevkli, et al. 2008; Somboonwiwat, et al. 2018). As mentioned earlier, the researches related to supplier selection rather focus on the methodology. However, this paper would like to extend the process to cover purchase order. Also reviewing a number of literature shows that one methodology which is frequently used in the supplier selection process is AHP. Hence, this paper uses AHP as the methodology for supplier selection.

Purchasing – Purchase Order

The selected supplier will be reserved for material purchasing. Purchasing process basically involves with inventory management in determining when and how many materials to purchase. Efficiency purchasing process normally order with the amount that minimize or balance between costs of inventory and purchasing (Jiao, et al. 2017; Pereira and Costa 2017; Rezaeisaray, et al. 2016). To determine the purchasing process, the problems related to purchasing must be clarified. Generally, the problems relating to purchasing process can be classified into two main problems. One is to purchase under demand uncertainty or order with other constraints and the other is to purchase under demand certainty with no constraints. To solve the former kind of purchasing problems, the researchers apply mathematical modelling, deterministic or stochastic methodologies (Jiao, et al. 2017; Somboonwiwat, et al. 2018; Yu and Tsai 2008), while the latter kind of problem must be further distinguished. A company normally purchase many items from a supplier. When ordering from a single supplier, the company either determine to order each item separately or jointly order multiple items at the same time. The EOQ model is widely used to calculate the quantity of purchased material when ordering independently (Pereira and Costa 2015; Pereira and Costa 2017). The issue with independently order from the same supplier is that it might not ensure minimum total cost. Therefore, there are researchers attempt to reduce the total cost by jointly ordering the items from the same supplier (Chopra and Meindl 2016). Heuristic approach is applied to the joint order purchasing. The next section will demonstrate the process of supplier selection and order purchasing.

METHODOLOGY

This section briefly presents the methodologies for both supplier selection and purchasing.

AHP for supplier selection

AHP is introduced by Saaty in the year 1980, is one of the most used for supplier selection. AHP benefits the decision makers in reducing complex decisions by providing a structure of decision in form of a multilevel hierarchic structure of integrated decision criteria that reflects the objectives of the decision maker.

AHP Methodology.
The process of AHP can be summarized into 4 steps.

Step 1: Construct the hierarchic structure of decision criteria and sub-criteria as well as the alternatives at the bottom level as presented in Figure 1.

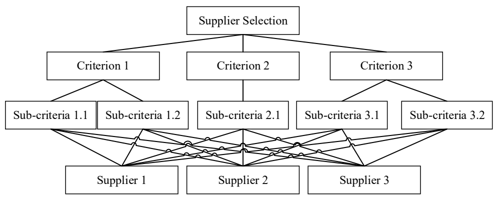

Figure 2: AHP decision structure

Step 2: Create comparative judgment through pairwise m x m comparison matrix A where m is the number of evaluation criteria.

Step 3: Normalize the pairwise comparison. Once the matrix A is built, derive the normalized matrix A_n by making the sum of a_{jk} on each column equal to 1, a_{lk}, the members of matrix A_n ($\bar{a}_{jk}$) is computed as follow.

$$\bar{a}_{jk} = \frac{a_{jk}}{\sum_{l=1}^{m} a_{lk}} \quad (1)$$

Step 4: Calculate criteria weight vector w by averaging the entries on each row of A_n

$$w_j = \frac{\sum_{l=1}^{m} \bar{a}_{jl}}{m} \quad (2)$$

Step 5: Estimate an measure local priorities which refers to both criteria weights and rating scores indicating preference among the alternatives.

Step 6: Synthesize local priorities into global priorities. Obtain a total aggregate score for each alternative by combining the calculated weights of each decision criterion with rating scores of alternatives through a weighted sum of the type:

$$R(k) = \sum_{i=1}^{n} w_i \times r_i(k) \quad (3)$$

where $R(k)$ = overall score of kth alternative
w_i = important weight of ith criterion
$r_i(k)$ = relative score of kth alternative respect to ith criterion.

EOQ for Purchase Ordering

The purchase ordering normally relates to determination of the amount and time to purchase the multiple items from the selected supplier. To do so, the company must first determine whether or not the purchasing is under constraints. If the purchasing is under constraints, the mathematical model is applied to find the optimal order quantity (Jiao, et al. 2017; Somboonwiwat, et al. 2018). For those without constraints, EOQ is used to solve the amount of raw materials to be ordered (for EOQ applicable items). However, when ordering with EOQ for multiple items from a supplier, the company must decide whether each item will be determined separately or jointly with other items.

Three alternatives are presented for ordering stocked items from the same supplier as follows.

(1) Independently order each stocked item
(2) Jointly order for all stock items
(3) Partially jointly order for selected stocked items varied by order

Independently order each stoked item.

Basic EOQ is one of the most frequently used method to determine the quantity of items to be ordered. The economic order quantity (Q*) of each item can be calculated by Equation (4).

$$Q^* = \sqrt{\frac{2DH}{S^*}} \quad (4)$$

Where D = Annual demand of each item
H = Holding cost of each item
S* = Total ordering cost to order which is the summation of fixed ordering cost (S) and item ordering cost (x)

Jointly order for all stocked items.

To jointly order all the items from the same supplier, the applied EOQ can be used (Chopra and Meindl 2016; Pereira and Costa 2015). In basic EOQ, the quantity to order can be straightforwardly calculated an then the numbers of order per year are to be determined. However, for applied EOQ, the suitable number of orders per year must firstly be determined and then the number of orders will be used to calculate the quantity to order (Q*) by the following equations.

$$n^* = \sqrt{\frac{\sum_{i=1}^{k} D_i H_i}{2S^*}} \quad (5)$$

$$S^* = S + \sum_{i=1}^{k} x_i \quad (6)$$

$$Q_i^* = \frac{D_i}{n^*} \quad (7)$$

Where n^*= No. of joint orders for all items
D_i = Annual demand of each item i
H_i = Holding cost of each item i
S^*= Total ordering cost
S = Fixed ordering cost for each time of order
x_i = Ordering cost for each item i

Partially jointly order for selected stocked items varied by order.

Similar to jointly order for all stocked items, partially jointly order the stocked items needs to use the applied EOQ.The suitable number of orders can be determined by the following steps.

Step 1: Calculate the number of orders for each stocked item independently by Equation (8) and then determine which stocked item requires the most frequent orders.

$$\bar{n}_i = \sqrt{\frac{D_i H_i}{2(S + x_i)}} \quad (8)$$

Step 2: After getting the stocked item that requires the most number of orders (*mf*), the other items are to be jointly order with that particular item. The number of order for the remaining stocked items are to be determined again ($\bar{\bar{n}}_i$) by Equation (9). However, the ordering cost used in the equation will be only the item ordering cost for extra stocked item ordered.

$$\bar{\bar{n}}_i = \sqrt{\frac{D_i H_i}{2(x_i)}} \quad (9)$$

Step 3: Compare the number of orders for each stocked item from step 2 with that of the item required the most frequent orders to obtain the order cycle (m_i) in conjunction with the item required the most frequent orders by using Equation (11).

$$m_i = \left\lceil \frac{\bar{n}_{mf}}{\bar{\bar{n}}_i} \right\rceil \quad (10)$$

Step 4: Re-calculate the number of orders for all welding rods (n) using the Equation (11). This number of orders takes into consideration all the annual demand for every item.

$$n = \sqrt{\frac{\sum_{i=1}^{k} D_i H_i m_i}{2(S + \sum_{i=1}^{k} \frac{S_i}{m_i}}} \quad (11)$$

Step 5: Calculate the annual number of orders for each stocked item by using the Equation (12). This calculation determines the number of orders for each stocked item considering jointly order with the most ordered item.

$$n_i = \frac{n}{m_i} \quad (12)$$

PROBLEM DESCRIPTION

The problem in this study is raised from an oilrigs manufacturer whose maximum production capacity is 60,000 – 80,000 metric tons a year. The production of oilrigs demands welding rods of various sizes with the usage in the year 2016 and 2017 presented in Table 1.

Table 1: Usage of Each Welding Rod

Welding Process	Welding rod	Code	Usage amount (kg.)		
			2016	2017	Average
FCAW	DW-100KS 1.2 mm	W1	65,375	57,919	61,647
SMAW	LB-52U 3.2 mm	W2	14,680	15,660	15,170
	LB-52 3.2 mm	W3	41,470	48,760	45,115
	LB-52 4.0 mm	W4	166,580	145,940	156,260
	LB-52NS 3.2 mm	W5	5,980	5,991	5,986
	LB-52U 4.0 mm	W6	32,030	28,260	30,145

It can be seen that the demands of welding rods vary. Some demands more in 2016, while others do in 2017. This causes a problem in procurement process. The firms normally order welding rods from 3 different suppliers. These 3 suppliers can provide all the types of welding rods used. In the recent years, the management would like to strategically form a relationship with one supplier for future expansion. Moreover, the company normally applies the basic EOQ method to manage the inventory of each welding rod. The use of EOQ seems proper when separately considering each welding rod.

Supplier Selections for Welding Rods

Supplier Selection Criteria.

To select the suppliers for welding rods applying AHP methodology, the selection criteria must be identified. The common criteria used to select the suppliers include the following. The first criteria for supplier selection is Quality of purchased items (Liu and Hui 2004; Tam and Tummala 2001). Quality can be considered the most important criteria to for supplier selection, especially in steel industry (Tahriri, et al. 2008). They claim that poor quality of raw materials or supplies directly affect the quality of finished products. Not only the quality of the purchased material, but the quality of the supplier's production process and the quality of packaging should be considered also. It is because the good packaging can protect raw materials during delivery. The next criterion to be included is Price (Asamoah, et al. 2012; Gencer and Gürpinar 2007; Ghodsypour and Brien 1998; Khurrum and Faizul 2002; Kumar, et al. 2009; Özkan, et al. 2011). Delivery of raw material is another criterion to be considered (Ghodsypour and Brien 1998; Liu and Hui 2004; Tahriri, et al. 2008; Tam and Tummala 2001). Flexibility is the criterion added to supplier selection in the steel industry (Tahriri, et al. 2008). Similarly, Jamil, et al. (2013) asserts another 2 criteria to select supplier in automotive industry: flexibility and information technology. Sometimes, there may be some urgent requests from the company due to the adjustment of the production. The supplier must be capable of responding to the urgency (Jamil, et al. 2013; Tahriri, et al. 2008). The use of information technology is required to ensure timeliness of receiving the information regarding orders, changes, and others. Apart from the information technology, suppliers must be responsive to new technologies to be more competitive (Jamil, et al. 2013). Moreover, the suppliers must be able to cope with rush orders or changes in order which require production capability. In addition to the production capability, the supplier must be able to maintain sufficient production capacity. To do so, the supplier should be financial stable (Jamil, et al. 2013) which is the last criterion included.

The assertion of the supplier selection criteria as well as their sub-criteria can be presented as the AHP methodology framework in Figure 3.

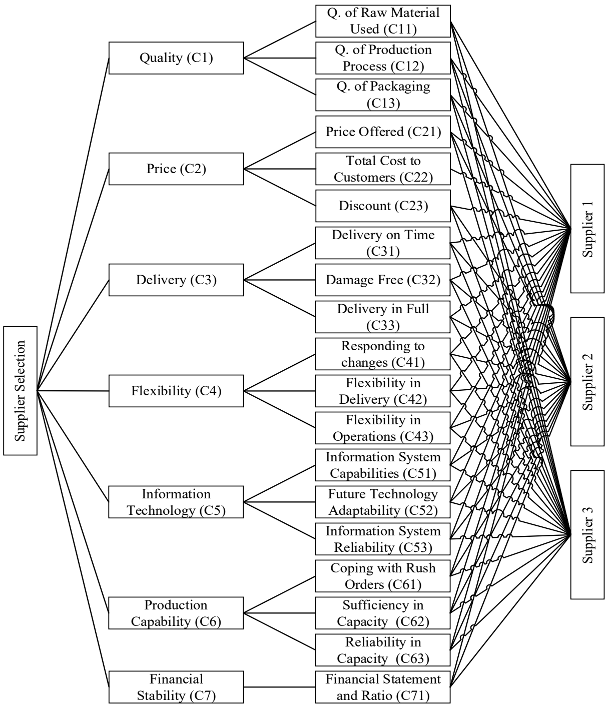

Figure 3: AHP Framework for Supplier Selection

Supplier Selection Process.

Following the process of AHP methodology, the experts are asked to compare and score each criterion. The weight obtained is then checked for consistency of the responses by using the Consistency Ratio, CR. The result derived from each expert yields CR less than 0.1. Therefore, the weight determined by these experts are consistent and reliable, and can be applied to select supplier for welding rods. Following the aforementioned AHP methodology for all the criteria and sub-criteria from all the six experts, the weight of criteria and sub-criteria can be presented in Table 2.

Table 2: Weight of Criteria and Sub-criteria

Main Criteria	Weight	Sub-Criteria	Weight
Quality, C1	0.326	Q. of RM used, C11	0.431
		Q. of Production, C12	0.431
		Q. of Packaging, C13	0.138
Price, C2	0.195	Price Offered, C21	0.438
		Total Cost to Cust., C22	0.438
		Discount, C23	0.124
Delivery, C3	0.195	Delivery on Time, C31	0.414
		Damage Free, C32	0.171
		Delivery in Full, C33	0.414
Flexibility, C4	0.109	Respond to Changes, C41	0.443
		Flex. in Delivery, C42	0.443
		Flex. in Operations, C43	0.115
Info. Technology, C5	0.062	Info. Sys. Capability, C51	0.145
		Future Tech Adapt., C52	0.388
		Info. Sys. Reliability, C53	0.467

Table 2: Weight of Criteria and Sub-criteria (cont.)

Main Criteria	Weight	Sub-Criteria	Weight
Pdt. Capability, C6	0.084	Cope with Rush Ord., C61	0.437
		Sufficient Capacity, C62	0.437
		Reliable Capacity, C63	0.127
Fin. Stability, C7	0.029	Fin. Statement, Ratio. C71	1.000

For each criteria, sub-criteria and weights obtained in Table 2, the experts are asked to compare the 3 existing suppliers for welding rods in pairs in order that the importance score of each supplier is eventually determined. The result of the importance score of each supplier can be presented in Table 3. Then the total score of each supplier can be determined by multiplying the important score with the weights (Table 3). According to the total score, the supplier X is selected.

Table 3: Important Score for Each Supplier

Main Criteria	Sub-Criteria	Score of each supplier		
		X	Y	Z
Quality, C1	Q. of RM used, C11	0.200	0.600	0.200
	Q. of Production, C12	0.200	0.600	0.200
	Q. of Packaging, C13	0.167	0.667	0.167
Price, C2	Price Offered, C21	0.424	0.132	0.434
	Total Cost to Cust., C22	0.526	0.192	0.282
	Discount, C23	0.536	0.194	0.271
Delivery, C3	Delivery on Time, C31	0.623	0.104	0.274
	Damage Free, C32	0.637	0.101	0.263
	Delivery in Full, C33	0.634	0.098	0.268
Flexibility, C4	Respond to Changes, C41	0.183	0.622	0.195
	Flex. in Delivery, C42	0.127	0.627	0.246
	Flex. in Operations, C43	0.132	0.625	0.243
Info. Tech., C5	Info. Sys. Capability, C51	0.135	0.443	0.422
	Future Tech Adapt., C52	0.135	0.443	0.422
	Info. Sys. Reliability, C53	0.554	0.253	0.193
Pdt. Cap., C6	Cope with Rush Ord., C61	0.608	0.213	0.179
	Sufficient Capacity, C62	0.616	0.226	0.158
	Reliable Capacity, C63	0.624	0.223	0.153
Fin. Stability, C7	Fin. Statement, Ratio. C71	0.429	0.143	0.429
TOTAL SCORE		0.383	0.363	0.254

Purchasing Welding Rods

The selected supplier X provides all the welding rods and wires for the company as presented in Table 3. According to the methodology of purchase ordering presented earlier and the demand of each welding rod (Table 1), all the welding rods for the firm can apply EOQ to determine how much and when to order. According to EOQ method, the information required for EOQ calculation can be presented in Table 4.

Table 4: Information Required for EOQ Calculation

Items	W1	W2	W3	W4	W5	W6
Unit price (Thai Baht)	78	92	60	58	215	207
Lead Time (days)	30	30	30	30	30	30
Holding cost (THB/Kg.): H	8.17	9.63	6.28	6.07	22.51	21.67
Fixed Ordering cost (THB): S	109	109	109	109	109	109
Item Ordering cost (THB): x	52	52	52	52	52	52

As mentioned earlier, three alternatives for ordering welding rods from the same supplier will be used to select which is the most proper method to use for welding rod ordering. In order to compare the three methods, total relevant costs for each method are to be compared. The total cost can be calculated as follows.

Annual holding cost = $(Q^*/2) \times H$ (13)

No. of yearly orders = D/Q^* (14)

Annual ordering cost = $(D/Q^*) \times S$ (15)

Total Cost = Holding cost + Ordering cost (16)

Independently Order Each Welding Rod.

In this case, each welding rod is ordered independently without any other consideration than EOQ. Therefore, welding rods W1 – 6 which are ordered from the same supplier are ordered with the EOQ as presented in Table 5. According to Equations (13) to (16), the calculation of total cost from each welding rod can be determined as presented in Table 5.

Table 5: Total cost of independently order with EOQ
(Unit for amount of welding rods: Kg.; Cost: 1,000 THB)

Items	W1	W2	W3	W4	W5	W6
Q*	1,560	687	1,513	2,879	293	670
Approx. No. of orders per year	39	65	20	29	54	20
Annual ordering cost	6.36	10.53	3.30	4.75	8.74	3.29
Annual holding cost	6.37	10.54	3.31	4.75	8.74	3.30
Total cost per item	12.73	6.61	9.50	17.48	6.59	14.50
Total Cost	**67.41**					

Jointly order for all welding rods.

In this case, all the welding rods from the same supplier are to be ordered all together in every order, thus the fixed ordering cost is paid just only once for all the welding rods (S = THB109, x = THB52; S* = 109 + 6*52). Therefore, the suitable number of orders for every welding rod in a year and the order quantity amount of each welding rod can be determined. Accordingly, if the welding rods are ordered together, the company must order all the welding rods approximately 56 times each year which bring up the total ordering cost, holding cost, and Total cost as presented in Table 6.

Table 6: Total cost of jointly order for all welding rods
(Unit for amount of welding rods: Kg.; Costs: 1,000 THB)

Items	W1	W2	W3	W4	W5	W6
No. of orders per year	56.17					
Q*	1,098	251	795	2,782	107	537
Annual ordering cost	23.65					
Annual holding cost	4.81	1.21	2.50	8.45	1.20	5.82
Total Cost	**47.29**					

Partially jointly order for selected welding rods varied by order.

In this case, the welding rods with similar character of demands are to be grouped and ordered together, i.e. the ones with high demands and need frequent order. From the calculation steps for this applied EOQ presented earlier the result from each step can be described as follows.

Step 1: The number for independent order for W1 – 6 equal to 39.54, 20.53, 29.50, 54.29, 20.46 and 45.04 times respectively. Therefore, the welding rod W4 requires the most frequent orders of 54.29 times a year.

Step 2: The number of joint orders ($\bar{\bar{n}}_i$) for welding rods W1, 2, 3 5 and 6 joint with equal to 69.58, 36.12, 51.91, 36.00, and 79.26 times, respectively.

Step 3: The order cycle (m_i) for W1 – 6 equal to 1, 2, 2, 1, 2 and 1, respectively. For m_i equals to 1, it means that that welding rod are to be jointly order with every single order of W4.

Step 4: Re-calculate the number of orders for all welding rods (n) for this company which is 68 times.

Step 5: The annual number of joint orders for each welding rod W1 – 6 equal to 68.38, 34.19, 34,19, 68.38, 34.19 and 68.38 times per year respectively. With these numbers of orders, total cost of this method and the order quantities can be determined (Table 7).

Table 7: Total cost for Partially Jointly Order for Selected Welding Rods
(Unit for amount of welding rods: Kg.; Costs: 1,000 THB)

Items	W1	W2	W3	W4	W5	W6
No. of orders per year	68	34	34	68	34	68
Annual fixed ordering cost	7.45					
Annual variable ordering cost	3.56	1.78	1.78	3.56	1.78	3.56
Q*	902	412	1,305	2,285	175	441
Annual holding cost	3.68	1.97	4.10	6.94	1.97	4.78
Total Cost	**46.91**					

Comparing the Total Cost of Three Ordering Methods. As presented in previous sections, it can be seen that the ordering method that partially jointly order for welding rods varied by order yield the least total costs of 46.91 (THB1,000) or exactly THB46,905.18 per year. Therefore, the company should adopt this ordering method to order the welding rods from the same supplier. Figure 4 demonstrates the flow of usage and orders for welding rods which are jointly ordered. The welding rod W1, 4 and 6 are jointly ordered in every ordering cycle, while W2, 3 and 5 are ordered every two ordering cycles. For example, ordering no. 1 (cycle 1) include only W1, 4 and 6, then ordering cycle 2 include all the welding rods W1 – 6.

DISCUSSION AND CONCLUSION

This paper portrays the complete procurement process including sourcing: supplier selection and order purchasing, the process which are normally performed by the firms' procurement officers. This paper can be used as a reference for procurement processes in the industries. The criteria for supplier selection in the case can simply be applied with alterations in the weight of the criteria depending on the type of industries. AHP would aid the procurement officers in determining the weight of the criteria.

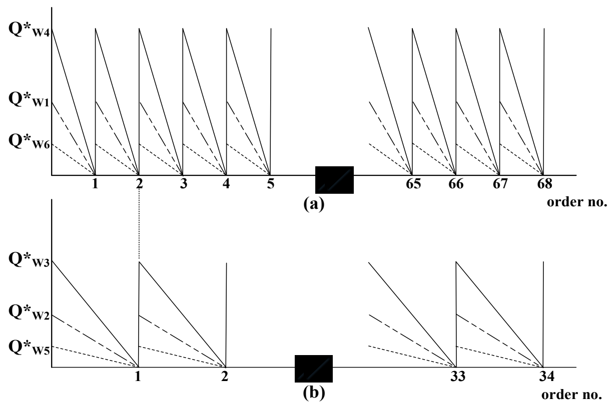

Figure 4: Flow of usage and order using applied EOQ (a) for W1, W4, W6 (b) for W2, W3, W5

In the purchasing, this paper presented the order of multiple products from a single supplier: independently, jointly, or partially jointly. The result from the case shows that partially jointly order from the same supplier yield the least total cost. In order to determine joint ordering, the method of applied EOQ is used in the paper. In the basic EOQ, the order quantity must firstly be determined, followed by determination of the number of order. The number of purchase order in the basic EOQ is the division between annual demand and the order quantity. However, in the applied EOQ, the optimal number of purchase orders must firstly be determined to encompass the demand for every item ordered from the same supplier. Later, the order quantities are calculated. This study provides the future works. For example, the applied EOQ may integrate material quantity discount or partial delivery of the ordered material into the model. The model can also be extended by considering the fuzziness of demand and delivery of the materials.

REFERENCES

Araz, C. and Ozkarahan, I. 2007. "Supplier evaluation and management system for strategic sourcing based on a new multicriteria sorting procedure", *International Journal of Production Economics*, Vol. 106, No. 2, pp. 585-606.

Asamoah, D., Annan, J. and Nyarko, S. 2012. "AHP Approach for Supplier Evaluation and Selection in a Pharmaceutical Manufacturing Firm in Ghana", *International Journal of Business and Management*, Vol. 2, No. 10, pp. 49-62.

Chopra, S. and Meindl, P. 2016. *Supply Chain Management: Strategy, Planning, and Operation*, 6th edition, Pearson.

Faez, F., Ghodsypour, S.H. and O'Brien, C. 2009. "Vendor selection and order allocation using an integrated fuzzy case-based reasoning and mathematical programming model", *International Journal of Production Economics*, Vol. 121, No. 2, pp. 395-408.

Gencer, C. and Gürpinar, D. 2007. "Analytic network process in supplier selection: a case study in an electronic firm.", *Applied Mathematical Model*, Vol. 31, No. 11, pp. 2475-2486.

Hsu, C.W. and Hu, A.H. 2009. "Applying hazardous substance management to supplier selection using analytic network process", *Journal of Cleaner Production*, Vol. 17, No. 2, pp. 255-264.

Jahani, A., Azmi Murad, M.A., Sulaiman, M.N., Selamat, H. 2011. An Agent-Based Supplier Selection Framework: A Case-Based Reasoning Approach. In: Ariwa E., El-Qawasmeh E. (eds) *Digital Enterprise and Information Systems. DEIS 2011. Communications in Computer and Information Science*, vol 194. Springer, Berlin.

Jamil, N., Besar, R. and Sim, H.K. 2013. "A Study of Multicriteria Decision Making for Supplier Selection in Automotive Industry", *Journal of Industrial Engineering and Management*, Vol. 2013, No., pp. 1-22.

Jiao, W., Zhang, J.-L. and Yan, H. 2017. "The stochastic lot-sizing problem with quantity discounts", *Computers and Operations Research*, Vol. 80, No., pp. 1-10.

Khurrum, S.B. and Faizul, H., 2002. "Supplier Selection Problem: a comparison of the total cost of ownership and analytic hierarchy process approaches", *Supply Chain Management: An International Journal*, Vol. 7, No. 3, pp. 126-135.

Kumar, A., Pal, A., Vohra, A., Gupta, S., Manchanda, S. and Dash, M.K. 2018. "Construction of capital procurement decision making model to optimize supplier selection using Fuzzy Delphi and AHP-DEMATEL", *Benchmarking: An International Journal*, Vol. 25, No. 5, pp. 1528-1547.

Kumar, K., M. SrinivasaRao and S, K.V.V. 2018. "Supplier Selection and Order Allocation in Supply Chain", *Materials Today: Proceedings*, Vol. 5, International Conference on Materials Manufacturing and Modelling (ICMMM - 2017), pp. 12161–11217.

Kumar, S., Parashar, N. and Haleem, A. 2009. "Analytical Hierarchy Process Applied to Vendor Selection Problem: Small Scale, Medium Scale and Large Scale Industries", *Business Intelligence Journal*, Vol. 2, No. 2, pp. 355-362.

Liu, F.H.F. and Hui, L.H. 2004. "The Voting Analytic Hierarchy Process Method for Selecting Supplier", *Production Economics: An International Journal*, Vol. 97, pp. 308-317.

Özfirat, P.M., Taşoglu, G.T. and Memiş, G.T. 2014. "A fuzzy analytic hierarchy process methodology for the supplier selection problem", *Journal of Enterprise Information Management*, Vol. 27, No. 3, pp. 292-301.

Özkan, B., Başlıgil, H. and Şahin, N. 2011. "Supplier Selection Using Analytic Hierarchy Process: An Application from Turkey", World Congress on Engineering.

Pereira, V. and Costa, H.G. 2015. "A literature review on lot size with quantity discounts: 1995-2013", *Journal of Modelling in Management*, Vol. 10, No. 3, pp. 341-359.

Pereira, V. and Costa, H.G. 2017. "A multiproduct economic order quantity model with simulated annealing application", *Journal of Modelling in Management*, Vol. 12, No. 1, pp. 119-142.

Rezaeisaray, M., Ebrahimnejad, S. and Khalili-Damghani, K. 2016. "A novel hybrid MCDM approach for outsourcing supplier selection: A case study in pipe and fittings manufacturing", *Journal of Modelling in Management*, Vol. 11, No. 2, pp. 536-559.

Saen, R.F. 2007. "A new mathematical approach for suppliers' selection: Accounting for non-homogeneity is important", *Applied Mathematics and Computation*, Vol. 185, No. 1, pp. 84-95.

Secundo, G., Magarielli, D., Esposito, E. and Passiante, G. 2017. "Supporting decision-making in service supplier selection using a hybrid fuzzy extended AHP approach: A case study", *Business Process Management Journal*, Vol. 23, No. 1, pp. 196-222.

Sevkli, M., Koh, S.C.L., Zaim, S., Demirbag, M. and Tatoglu, E. 2008. "Hybrid analytical hierarchy process model for supplier selection", *Industrial Management & Data Systems*, Vol. 108, No. 1, pp. 122-142.

Somboonwiwat, T., Klomsae, S. and Atthirawong, W. 2018. "Optimal planning for purchase and storage with multiple transportation types for concentrated latex under age-dependent constraint", *Proceedings of the 32nd European Conference on Modelling and Simulation*.

Tahriri, F., Osman, M.R., Ali, A., Yusuff, R.M. and Esfandiary, A. 2008. "AHP Approach for Supplier Evaluation and Selection in a Steel Manufacturing Company", *Journal of Industrial Engineering and Management*, Vol. 1, No. 2, pp. 54-76.

Tam, M.C.Y. and Tummala, V.M.R. 2001. "An application of the AHP in vendor selection of a telecommunications system", *Omega-International Journal of Management Science*, Vol. 29, No., pp. 171-182.

Yadav, V. and Sharma, M.K. 2015. "An application of hybrid data envelopment analytical hierarchy process approach for supplier selection", *Journal of Enterprise Information Management*, Vol. 28, No. 2, pp. 218-242.

Yadav, V. and Sharma, M.K. 2016. "Multi-criteria supplier selection model using the analytic hierarchy process approach", *Journal of Modelling in Management*, Vol. 11, No. 1, pp. 326-354.

Yu, J.R. and Tsai, C.C. 2008. "A Decision Framework for Supplier Rating and Purchase Allocation: A Case in the Semiconductor Industry", *Computers & Industrial Engineering*, Vol. 55, No., pp. 634-646.

Zhao, K. and Yu, X. 2011. "A case based reasoning approach on supplier selection in petroleum enterprises", *Expert Systems with Applications* Vol. 38, No., pp. 6839-6847.

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