THE FRAMEWORK DEVELOPMENT OF MULTI MACHINE - MULTI PRODUCT EPQ MODEL FOR OPTIMIZING QUANTITY OF SODIUM SILICATE PRODUCTION: CASE STUDY CHEMICAL MANUFACTURER

Chusain and Nurhadi Siswanto
Master’s Program in Management of Technology, Institut Teknologi Sepuluh Nopember
Jl. Cokroaminoto 12A, Surabaya, 60264, Indonesia
e-mail: chusain14@mhs.mmt.its.ac.id; siswanto@ie.its.ac.id

ABSTRACTS
This research deals with a chemical manufacturer whose vision to be the best chemical manufacturer in the country. To reach their vision, this manufacturer has built an expansion plant which began the production activities in 2015. The new plant produces both solid and liquid sodium silicate. However, the production of this manufacturer still has challenges in particular for determining the production quantity. The current policy of the management is to produce the maximum capacity. The management assumes that the maximize quantity of production would be given the minimum of COGM (Cost of Goods Manufacturing). But in reality, it is the opposite. The COGM still increase because of inventory cost and production damages. This paper is discussed the framework how to calculate the optimal production quantities. The paper consists of the introduction, literature review and creation of the framework. The framework is to conduct literature reviews related how to determine the economic production quantity (EPQ) and to identify the flow process of production (there are any machines with any different products) which create the cost. The expected outcome for this paper is the framework for development multi machine-multi product EPQ model.

Keywords: Base Chemical Manufacturer, Sodium Silicate Production, Multi Machine-Multi Product EPQ.

INTRODUCTION
This paper considered a chemical products based industry which have a vision to be the best chemical manufacturer in Indonesia. The Key Performance Indicator (KPI) of this manufacturer is to achieve efficient production cost. In order to achieve this vision, the manufacturer has built a sodium silicate plant which produces solid sodium silicate and liquid sodium silicate. The plant has started to produce the products in 2015.

Since it is running, the plant still has a problem in determining the production quantity. The plant existing approach is to produce based on the maximum production quantity. The manufacturer assumes that the maximum production is the best solution (efficient) for minimizing the Cost of Goods Manufacturer (COGM) because the fixed cost component within the COGM can be decreased by larger quantity of production. Meanwhile, during January to
December the last 12 months, the sales quantities are not as much as the maximum of production quantity. This condition has impact on inventory accumulation which is over inventory capacity.

The current condition of this plant is that the maximum capacity of solid sodium silicate production is 35 MT/day with the average sales in 2015 is 20 MT/day. If the manufacture produces using the maximum capacity, there is inventory accumulation. This condition not only happen in solid sodium silicate plant but also in liquid sodium silicate plant hence in the sodium silicate liquid the maximum capacity of sodium silicate liquid is 36 MT/day with the average sales in 2015 for the sodium silicate liquid is 33 MT/day.

The other negative impact of this policy is poor (inefficient) inventory performance which is detected by lower in the inventory turnover ratio. It means that the manufacturer must have big investment (capital) either for buying the raw materials or inventory finish products. Also, finish product inventories have possibility to be damage. Based on data in the Fig. 2, the average number of inventory turnover ratio is no more than 2.5 times. This means that the manufacture must spent more investment 2.5 times as average for inventory operational.

In the Fig.2 the differences of COGM in sodium silicate solid and liquid depends on raw material factor and utilities unit which used in the production activities. Hence the sodium silicate solid consumption more expensive in raw material and gas consumption. Sodium silicate liquid has decreased COGM on April 2015 it happen because the sodium silicate liquid production use different raw material which cheaper and it is supplied from own production plant.

From this phenomenon, we can infer that the decision of production quantity is influenced by COGM. Based on the problem above, we can conclude that the determination of economic production quantity is important for manufacturers to increase their competitiveness. Thus, in this paper we develop a framework or methodology to determine the economic production quantity of sodium silicate with multi machine and multi product in a production system. The ultimate goal or purpose of this paper is to create a framework or methodology for future research for development multi machine – multi product EPQ model to determine economic production quantity of sodium silicate production which can reach the optimum COGM of the system.

METHODOLOGY

In this section, literature review to develop the framework or methodology to the problem is discussed. Hansen and Mowen (2004) explained the basic concept of COGM and defined it as the total cost of goods which is released in the certain period. Further, the component of COGM has been defined by Bustami and Nurlela (2006) as the total component costs of direct raw material cost, direct labor cost, factory overhead cost, initial and ending inventory value within certain period.

The development of EPQ model, from the basic concept to the latest model are discussed as below.

Classical EPQ Model

The following EPQ model is recognized as the classical EPQ model. The model was developed Ford Whitman Harris (1913) in paper which have published in the A.W. Shaw Company’s magazines factory with the title is how many parts to make at once. Actually, the ISBN :
EPQ model likes inventory model, but without instantaneously assumption. In the EPQ model, the production rate \((p)\) which is assume relatively constant is higher than the demand rate \((d)\). So, in this case, \(p > d\). The goal or objective function of EPQ is to determine the production quantity so that it can minimize the total cost. The formulation to determine the \(Q\) in this classical model as

\[
Q^* = \sqrt{\frac{2CsD}{(Ch . (1-D/P)}}
\]

with

- \(Q^*\): Economic production quantity (unit or Kg)
- \(Cs\): Set-up Cost (USD)
- \(Ch\): Holding Cost (USD/unit/year)
- \(D\): Demand rate (unit/day)
- \(P\): Production rate (unit/day)

**Single Machine-Multi Item EPQ model**

Tersine (1983) has extended the classical EPQ model into multi items problem. In this model, the problem assumed that the production is intermittent (batch production) for any products. So, the first step in this EPQ method is to determine the optimal frequency during production period for the all of products type, after that the optimal production quantities are determined.

To determine the optimal production quantity, there are four steps needs to be followed:

1. Calculate and make sure that the annual demands are produced no more than the available time (e.g \(N=250\)) so that \(\sum D_n/P_n \leq 250\), if this requirement is satisfied, continues on the next step.

   Hence:
   - \(N\): Number of days (days)
   - \(D_n\): Demand rate for \(n\) Product (Unit/day)
   - \(P_n\): Demand rate for \(n\) Product (Unit/day)

2. Calculate the optimal frequency by using the formulation below:

   \[
f = \sqrt{\frac{\sum D_n Ch_n}{(1-D_n/P_n)/2 \sum Cs_n}}
   \]

   the assumption of this model is to ignore of the length of set-up time, so there is enough time for each production cycle. This assumption is declared in this formulation:

   \[N/f \geq \sum Q_n/P_n\]

   Hence:
   - \(f\): Optimal frequencies of production \(n\) product (cycle or times)
   - \(Q_n\): Production quantity of \(n\) product (Unit)
   - \(Ch_n\): Holding cost for \(n\) product (USD)
   - \(Cs_n\): Set-up cost for \(n\) product (USD)

3. Calculate the \(Q^*\) as the production optimal quantity for single machine-multi item problem with followed formulation:

   \[
   Q^* = D_n/f
   \]

   Hence:
   - \(Q^*\): Economic Production quantity of \(n\) product

   Calculate the total cost \((TC)\) with following formulation:

   \[
   TC = \sum D_n Ch_n + 2f \sum Cs_n
   \]
Hence:
TC : Total cost

An EPQ Model with Imperfect Production System with Rework of Regular Production and Sales Return

The next research was elaborated by C. Khrisnamoorthi and S Panayappan (2012). This kind of EPQ model deals with the production plant is not perfect so that it exists scrap, defect or nonconforming products. Because of imperfect quality of product, there is any additional cost in the objective function which has different from the one of EPQ classical model.

Simplified Approach to the Multi-Item Product Quantity Model with Scrap, Rework, and Multi Delivery

This kind of EPQ model was develop by Chiu (2014) as the extension of Khrisnamoorthi (2012) by considering multi delivery for multi items. The method to solve the problem is by using algebraic derivation method of cost function for finding the optimal cycle time and simple approach to solve real case more effective.

Production Lot Sizing With Quality Screening and Rework

The next EPQ reviewed model was represented by Lama Musawwi Haidar (2015). This kind of EPQ model has a screening process to find the defect products. This EPQ model also assumes that the inventory cost of defective products in the screening process or rework are higher than the inventory cost of non-defective products. The other assumption is that the screening rate is higher than demand rate. Lastly, the next assumption is that the screening cost during production time is higher than the one of screening process after production time.

The second is that the cost of imperfect product which is not compensate in the cost which is not covered in the first formulation.

Economic Production Quantity in Batch Manufacturing With Imperfect Quality, Imperfect inspection, and Destructive and Non Destructive Acceptance Sampling in A Two – Tier Market.

This EPQ which is develop by Muhammad al Salamah (2015) considers the imperfect inspection and imperfect production on the single acceptance. As we know, the manufacturing has two models or characterize of material inspection: destructive and non destructive tests.

Generally, the testing material has two possibilities of type errors. When a lot of products are rejected, the lot will contribute to the cost of related screening and rework. The formulation of this model considers the imperfect inspection which has been explained from type of error in inspection.

A Multi Machine Multi product EPQ Problem for an imperfect manufactured system considering utilization and allocation decision

The sophisticated research of EPQ problem are represented by Nobil (2016) which considers multi machine and multi product for determining the optimal production quantity. The formulation of this EPQ model is solved as MNLP (mixed integer non-linear programming). The convexity of this model is proven by changing the problem into bi-level decision making problem form.
On the first level, decision is made by considering machine utilization and allocation of production. After that, the second level decision is made to determine the length of cycle time.

For solving this problem, this research uses integration approach between hybrid genetic algorithm and derivatives method.

The formulation to determine the optimal production lot size from the inventory model fluctuation is given as follow:

$$Q_j = \frac{D_j T_j}{1 - \theta_{ij}}$$

To determine the optimal cycle time length, the formulation is as follow:

$$T_i = T_{Pi} + T_{ai} = \frac{(1 - \theta_{ij}) Q_j}{D_j}$$

The total cost function can be formulated as follow:

$$TC = CU + CA + CP + CH + CD$$

The constraints of this model are as follow:

- Allocation of producing product i in machine j
- Machine utilization
- Semi-finished goods Inventory
- Machine capacity

The final EPQ model for this problem is given as follow:

$$\text{Min } TC = \sum_{i=1}^{n} \sum_{j=1}^{m} y_{ij} + \sum_{i=1}^{n} \sum_{j=1}^{m} x_{ij} \left[ \frac{A_{ij}}{T_i} + \frac{h_{ij} D_j}{2(1 - \theta_{ij})} \left( 1 - \theta_{ij} - \frac{D_j}{R_{ij}} \right) T_i \right]$$

$$+ \frac{c_{ij} D_j + d_{ij} \theta_{ij} D_j}{1 - \theta_{ij}}$$

s.t. 

$$\sum_{i=1}^{n} \alpha_{ij} x_{ij} = 1 \quad j = 1, 2, \ldots, m$$

$$x_{ij} \leq y_{ij} \quad i = 1, 2, \ldots, n; j = 1, 2, \ldots, m$$

$$\sum_{i=1}^{n} f_{ij} y_{ij} \leq B$$

$$\sum_{i=1}^{n} r_{ij} y_{ij} \leq R$$

$$T_i \geq \left( \frac{\sum_{j=1}^{m} x_{ij} S_{ij}}{1 - \sum_{j=1}^{m} x_{ij} S_{ij} / (1 - \theta_{ij})} \right) ; \quad i = 1, 2, \ldots, n$$

$$T_i > 0 \quad i = 1, 2, \ldots, n$$

$$y_{ij}, x_{ij} \in \{0, 1\} \quad i = 1, 2, \ldots, n; j = 1, 2, \ldots, m$$
From the all of literature review above, gap of research and the future research position can describe as follow:

<table>
<thead>
<tr>
<th>no</th>
<th>Research title</th>
<th>Approach</th>
<th>research object</th>
<th>Goal</th>
<th>assume and constrain</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Economic production quantity single machine multi product (tersine, 1982)</td>
<td>√</td>
<td>single machine single product</td>
<td>√</td>
<td>√ √ √ √ √ √ √</td>
</tr>
<tr>
<td>2</td>
<td>An EPQ Model With Imperfect Production System With Rework of Regular Production and Sales Return (C. Khrisnamoorthi and S. Panayappan, 2012)</td>
<td>√</td>
<td>single machine multi product</td>
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<tr>
<td>3</td>
<td>Simplified Approach to The Multi-item Product Quantity Model With Scrap, Rework, and Multi Delivery (Chiu, 2014)</td>
<td>√</td>
<td>multi machine multi product</td>
<td>√</td>
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<tr>
<td>4</td>
<td>Production Lot Sizing With Quality Screening and Rework (lama mussawi haidar, 2015)</td>
<td>√</td>
<td>multi machine multi product</td>
<td>√</td>
<td>√ √ √ √ √ √ √</td>
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<td>Economic Production Quantity in Batch Manufacturing With Imperfect Quality, Imperfect Inspection, and Destructive and Non Destructive Acceptance Sampling in A Two – Tier Market (Muhammad al salamah, 2015)</td>
<td>√</td>
<td>single machine multi product</td>
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<tr>
<td>6</td>
<td>A Multi Machine Multi product EPQ Problem for an imperfect manufactured system considering utilization and allocation decision (amir hossein nobil, 2016)</td>
<td>√</td>
<td>single machine multi product</td>
<td>√</td>
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<tr>
<td>7</td>
<td>Development Multi Machine - Multi Product EPQ Model for Optimization Quantity of Sodium Silicate Production; Base Chemical Manufacturer Cases (Chusain, 2016)</td>
<td>√</td>
<td>single machine multi product</td>
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</tr>
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Research Position

We reviewed six journals in which they have several similarities. From the table above, the similarities are that they have algebraic approach with derivative method. The basic foundation of the research came from EPQ classical model to determine the optimal production quantity. All of them assumed that the models are for single machine-single product with no defective products and no capacity constraints. Based on that, we will elaborate and develop the mathematical model for determining the optimal quantity with consider any assumptions not covered in the classical model.

From the table above, we can also identify the basic research gaps within future research and previous researches. The object of previous researches are that to generally explore the EPQ problem for single machine single product case or single machine multi product case. Meanwhile the future research would focus on model development of multi machine multi product case in base chemical manufacturer which have any process and product variation in there. The other gap within future research and previous research are from the research goal. In the previous research the research goal as generally is to determine Q optimal for reaching the minimum total cost. Meanwhile in the future research, determining the optimal production quantity is calculated by model to minimize COGM.

The research position is given as follow:

![Fig. 3 Research position](image)

**Fig. 3** describes the connectivity between the previous and the future research. The classical EPQ model has been developed by Krishnamorthi and Panayappan (2012) which have different assumption from the classical one. The research considered the imperfect production system issues and also rework in regular production and sales return. Meanwhile, the classical EPQ model developed by tersine is used for single machine multi products. Chiu (2014) who extended the tersine’s model combined the tersine’s model with the outcome research from Krishnamorthi and Panayappan (2012) and become a new model for solving single machine - multi item problem with considering product quality, scrap, rework, and multi delivery. The research from chiu still was not yet covered for multi machine multi product problem. So, Amir Hossein Nobil extended the model into multi machine –multi product problem. The research also considered the system utilization and allocation decision. Although the model seems complete and almost coverage the all of type of problem, the objective function does not cover COGM formulation. This gap become our opportunity to develop the multi machine multi item model with the COGM as the objective function. This becomes the contribution of our research to enrich in development model and case problem.
RESULTS AND DISCUSSION

From the methodology above, the purpose of this paper will create the framework for model development. The detail of framework for model development multi machine –multi product EPQ model can be described as flowchart bellow:

The first step of the framework begins with data collection. The data would be collected are each component and values of COGM, production process and capacity, and lastly the demand rate. The next step is to use the output from data collection to represent the problem and develop the EPQ model by using derivative approach for the COGM objective function. Then, the model would be tested with convexity to make sure that the model would be given optimum global solution. After the test, the value of the optimal production quantity (Q) for sodium silicate production is calculated, followed by the calculation of COGM. The optimal value of COGM would be compared with the real manufacturing costs for analysis and interpretation. The analysis will also investigate the factors which influence the COGM value, from which would be the the conclusion for this research.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of all literature review and framework / methodology, this paper concluded that there are three main steps in the framework for EOQ model development. The first step is data collection phase, the second is data process phase which in there include derivative activity of objective function, convexity test and determination of the optimal production quantity. The third phase or final phase is to compare the result between the optimization calculation and existing manufacturing costs.

REFERENCES