FIT MANUFACTURING:
MAPPING PRODUCT COST REQUIREMENTS USING RELATIONAL DATABASE DESIGN

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ABSTRACT: Efficiency of a manufacturing system depends on the capability of production to transform customer orders into products. Elimination of seven production wastes (i.e. defects, waiting, inventory, overproduction, transportation, motion, over-processing) is the concept used in Lean Manufacturing system to improve manufacturing efficiency. In this regard, the seven production wastes cause additional costs to the total product cost. Therefore, this paper aims to introduce a data model of product cost measurement system named as Product Cost System (PCS). The PCS will compute cost of a unit product that is important to the calculation of Production Waste Index (PWI). Thus, the concept of Relational Database Design has been applied in the development of PCS architecture. As the PWI will be measured on a monthly basis, the PCS database has been designed for calculating cost of a unit product based on one month production period. In this regard, the PCS data model integrates production input (order) quantity with materials cost, packaging cost, and labor cost. However, this paper presents only the first part of PCS that focuses on material cost and packaging cost. For the second part of PCS, a system for determining labor cost per unit product will be developed which is named as Labor Cost System (LCS). Then, both parts of PCS will be integrated to determine the PWI. Result of the first part of PCS prototype shows that further improvement is required in the aspect of bugs and errors.

KEYWORDS: *System, Production, Cost, Waste, Manufacturing.*

1.0 INTRODUCTION

In the case of price competitive market, strategies in sales and marketing are not sufficient enough to maintain the profit margin. Therefore, minimizing the production costs is the only alternative to maintain the profit margin. For this reason, the application of Lean Manufacturing (LM) concept through wastes elimination has been considered as an effective approach for minimizing the total production cost [1-3]. Narasimhan et al. [4] claimed that cost efficiency is a primary performance outcome through LM concept. The LM concept had already been hailed as a cost reduction mechanism [5]. In this study, the cost efficiency can be determined by the difference between pay-in and pay out amount. The pay-in amount refers to sold amount while the pay-out amount refers to production amount. A lean production can be achieved by minimizing the pay-out amount, while at the same time maximizing the pay-in amount. In this regard, production leanness is measured through the calculation of Production Waste Index (PWI cates less production wastes encountered [6]. The PWI is a part of production fitness measure for Fit Manufacturing system. As the calculation of PWI is based on cost of unit product, it is important to have a database system that is able to trigger any changes of direct costs involved in the production (i.e. materials cost, packaging cost, and labor cost).

Therefore, the objective of this paper is to propose a data model of Production Cost System (PCS) for micro-Small Medium Enterprises (SMEs). The proposed framework presents the basic structure of a unit product cost for one product model, that is, production input (order) quantity, materials cost, packaging cost, and labor cost. Discussion on the concept of efficient production cost is presented in the next section which refers to the basic structure of PCS. In the following sections, the architecture of PCS is explained based on system requirements, system design, and system implementation.

2.0 BUSINESS REQUIREMENTS

Lean production operates on the concept of LM that enables high quality products, low production costs and on-time delivery performance. Womack et al. [7] defined lean as the input-output dimensions are used in determining effectiveness and efficiency of lean production. Chen [8] claimed that it is essential for manufacturing companies to estimate long-term cost competitiveness for three main reasons; (i) factory must be competitive on cost, (ii) companies can only survive through cost competitiveness when the economy is not good, and (iii) management pays special attention to competitiveness on financial indicators such as cost.

In the context of cost, total production cost is determined by the sum of fixed costs and variable costs. In lean production, the variable costs must be minimized in order to reduce the total production cost. Therefore, the PWI calculation only considers variable costs (i.e. materials cost, packaging costs, and labor cost) that will depend on the production input (order) quantity. In this regard, the variable costs are presented as pay-out amount whilst the sale revenue is presented as pay-in amount of lean production system. Profit margin depends on the total variables cost and the sale price. Figure 1 illustrates the inconsistency in total variable cost and sale price that has totally affected the profit margin.

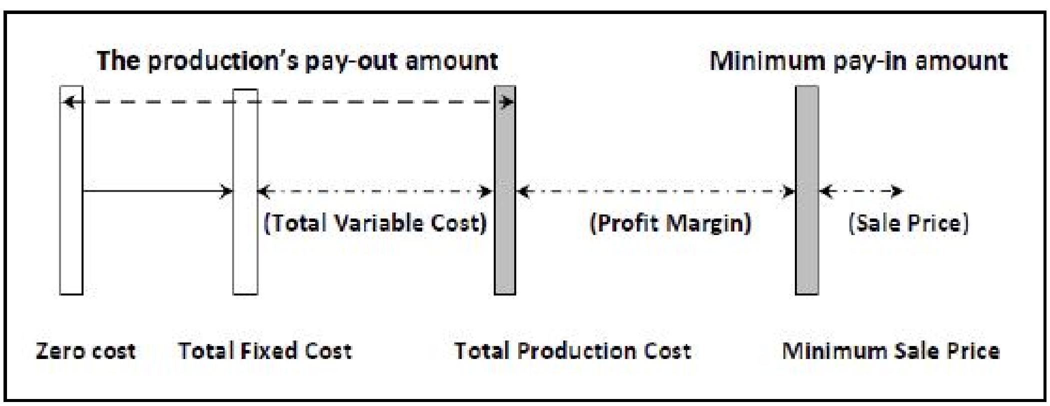

Figure 1: Affected profit margin due to variable costs and inconsistent sale price [6]

Cost of a unit product is determined by dividing the total production cost with the total number of unit products produced. The cost of a unit product is reduced by increasing the production input (order) quantity provided the same amount of resources has been used (i.e. operator and operating hour). However, the calculation of the cost of a unit product becomes complicated when high product variety is involved in the same production line. The cost of a unit product will be different for each product model due to different materials and different packaging. Packaging costs have a significant impact to the total product cost [9].

Thus, the PCS data model is developed to provide the cost of a unit product for different product models which is based on one month period. The cost of a unit product will be different as it depends on four variables: (i) production input (order) quantity, (ii) changes in material price, (iii) changes in packaging price, and (iv) changes in labor cost. Figure 2 illustrates the relationship between PCS, LCS, and PWI system. Theoretically, Mayer et al. [10] concluded that the change in product mix driven by the trading environment has important repercussions on firm productivity. Thus, the changes of product model have been considered in the PCS model.

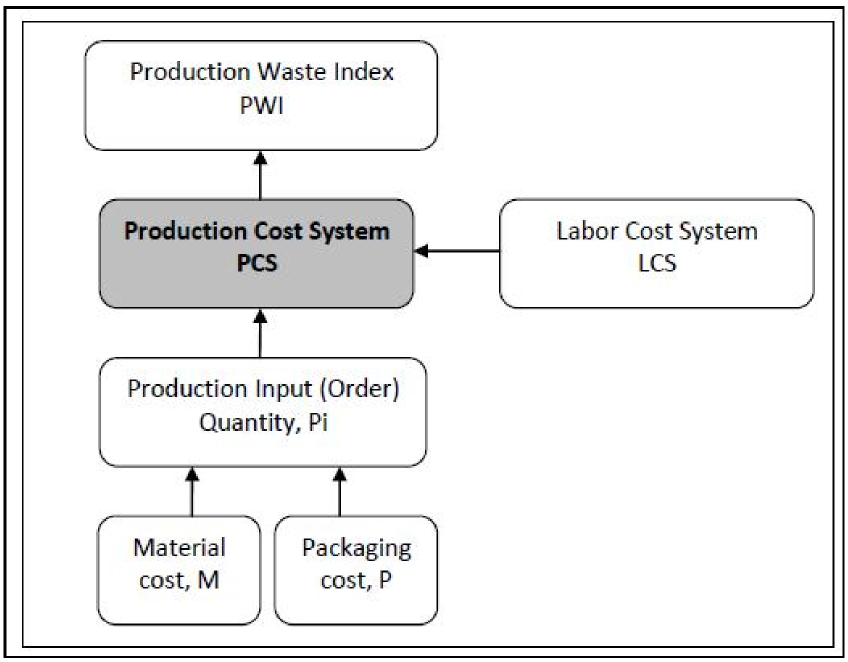

Figure 2: Relationship between PCS, LCS and PWI

In other words, the PCS model accounts for the latest update of any changes made to the variable costs. Thus, the cost of a unit product, PCS can be written as:

$$PCS = \frac{\sum(\mathrm{M} + \mathrm{P} + \mathrm{L})}{Pi} \qquad (1)$$

Where,
M is total material cost for one month
P is total packaging cost for one month
L is total labor cost for one month
Pi is total production input (order) for one month

Provided,

$Pi \neq 0$

The total production input (order) quantity, Pi depends on sales order and inventory of that particular month. In this regard, there will be no production for some product models if inventory is more than sales order. Hofer et al. [11] confirmed that the effect of lean production on financial performance and inventory performance is partially mediated by inventory leanness. Therefore, Pi has been considered in the PCS system. But, the Pi also depends on production rate. Production rate refers to standard production capacity that is presented in number of batch per month. For instance, a bakery firm is capable to produce four batch of loafs per month at standard operating hour (e.g. eight hours per day) where one batch consists of 500 loaves. Thus, the Pi can be determined by using equation (2):

$$Pi = r(S - I) \qquad (2)$$

Where,
r is production rate
S is sales order for a particular month
I is beginning inventory for a particular month

Once the Pi is determined, the total variables cost such as materials, M, packaging, P, and labor, L will be calculated according to the Pi. For material cost, M, the required material quantity is determined by quantity needed for one production batch. For instance, one batch production of Product A consists of 2kg material X, 10 liter material Y, and 5kg material Z. Thus, if 10 batches product A are produced, the total material cost of one batch will be multiplied by 10. For that particular month, the PCS will account for the latest update of material price.

For packaging cost, P, if more than one packaging types are used in one product model, there will be allocated percentage of demand for each packaging type. For instance, there are three types of packaging for mineral water; 0.5 liter, 1 liter, and 5 liters. 60% of the demand is for 0.5 liter while 30% for 1 liter, and 10% for 5 liters. Thus, the required packaging quantity can be determined by multiplying the production input (order) quantity with allocated percentage of each packaging type. In this regard, equation (3) can be used to determine the packaging quantity, Pq.

$$Pq_k = a_k(Pi) \qquad (3)$$

Where,
a_k is allocated percentage for k th packaging type.
Pi is production input (order) quantity.

Thus, P is determined by multiplying packaging quantity with the latest update of packaging price that is written as:

$$\text{P} = \sum_{k=1}^{k} Pq_k\,(Cp_k) \qquad (4)$$

Where,
Pq_k is quantity of K_{th} packaging type
Cp_k is price of K_{th} packaging type

For labor cost, L a separate data model is needed as it involves relations between the architectural components. Operator and payment rates are two major components of labor cost. Thus, a Labor Cost System (LCS) database will be developed to compute total labor cost for one month period. Tian etc al. [12] has included labor cost as one of the important variables in the probability analysis method for modeling the product disassembly cost that they proposed. Therefore, labor cost is an important part of the PCS. The calculation of total labor cost is based on changes in; (i) number of operator; (ii) payment rate due to seniority/experience/level; (iii) overtime hours, (iv) paid hours (i.e. annual leave, sick leave, and public holidays); v) unpaid leave; and (vi) payment rate during public holidays and overtime. The PCS data model will import the total labor cost of a particular month from the LCS data model to compute the cost of a unit product.

3.0 DATA MODEL REQUIREMENTS

3.1 Scope of PCS

As a prototype version for measuring PWI at manufacturing companies, the PCS data model is designed for micro-SME manufacturing companies. Verheugen [13] defines micro-SME as a company that has less than 10 workers with an annual turnover of less than $2M. Most of micro-SME practice manual method in their production operations and also in data management. Thus, the components of the PCS architecture are based on major practice in the micro-SME industry (i.e. standard operating hours and the number of operators). Technically, the PCS data model can be run at any platform but requires a web browser that has java installed in it and a server. The PCS data model operation is best for production staff who are familiar with production system (i.e. production engineer and production clerk).

3.2 Functional Requirements

Nine functional requirements of the PCS data model have been determined through a study on Data Flow Diagram (DFD) developed based on Context Diagram (CD) as shown in Table 1. According to Cysneiros and Leite [14], the Non-Functional Requirements (NFR) integration into data models does help in achieving better understanding of what is being modeled. In this study, integration of the NFR into the PCS is based on two aspects; (i) Standard coding, and (ii) System qualities. Table II summarizes nine aspects of PCS qualities.

Table 1: PCS functional requirements

No.	Functions	Description
1.	Authenticate user	User verification using username and password
2.	Manage product	Old and new product model record
3.	Manage production	Calculation of production input (order) quantity
4.	Manage material	Old and new material record
5.	Manage material batch	Old and new batch size record for old and new material
6.	Manage packaging	Old and new packaging record
7.	Calculate	Calculation of material cost per batch

	material cost	
8.	Calculate packaging cost	Calculation of packaging cost for each packaging type
9.	Calculate product cost	Calculation of cost or unit product

Table 2: PCS qualities

No.	PCS System Qualities	Characteristics
1.	System response time	2 seconds for data processing and screen loading
2.	Hardware scalability	Multi-tier architecture
3.	Data integrity	Consistent data without redundancy
4.	Manageability	Central hub to administer
5.	Security	Information security across companies
6.	Usability	Graphic User Interface (GUI)
7.	Maintainability	Independent components (modular design)
8.	Flexibility and extensibility	Configurable and easy to deploy
9.	Reusability	Generic services (extend and reuse)

4.0 DATA MODEL DESIGN

The design of PCS data model covers four important aspects; (i) Main frame of PCS programming, (ii) Business rules applied to the major components of PCS, (iii) conceptual database design, and (iv) Logical database design.

First, in the aspects of programming, the PCS programming is divided into three parts; (i) Client scripting, (ii) Server scripting, and (iii) Database scripting. Figure 3 presents the main frame of the PCS programming.

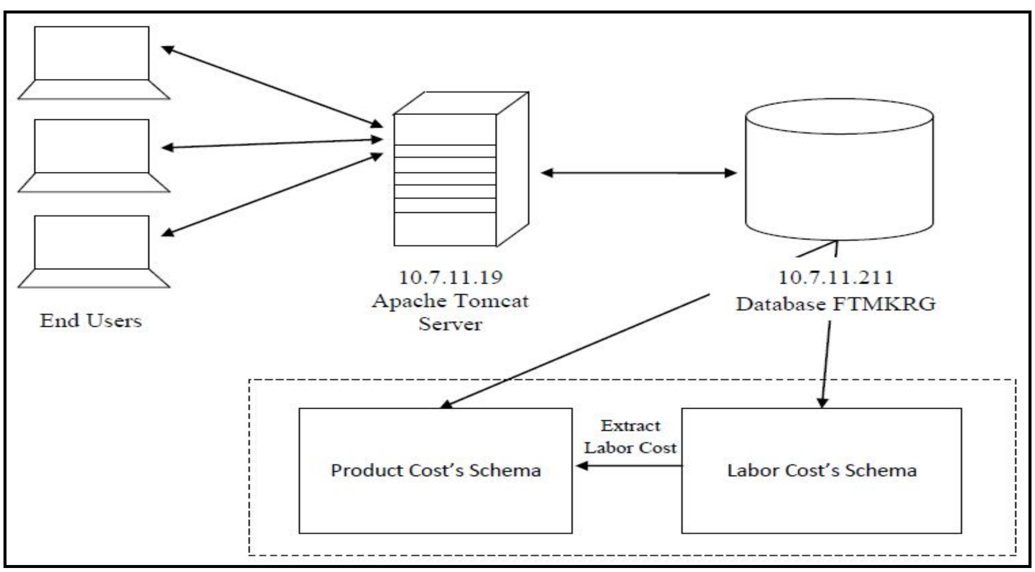

Figure 3: The Main Frame of PCS Programming

Client scripting interprets HTML, CSS, and Javascript codes that is done at client workstation. On the other hand, the Server scripting interprets Java and JSP codes whilst Database scripting interprets PL/SQL and SQL in stored procedure. The stored procedure enables faster processing of Data Manipulation Language (DML) as it has been stored in the shared memory pool. Coding system in PCS is built using JSP, Java, Javascript, HTML, CSS and Ajax whilst the database coding is built using SQL and PL/SQL.

Second, application of business rules on the PCS data model has referred to five major components of cost for a unit product; (i) Product, (ii) Production, (iii) Material, (iv) Packaging, and (v) Labor. For product, the PCS data model allows multiple product models. Each product model can have more than one material order that is presented in one batch size of material. However, the PCS data model limits one batch size of material for each product model. For material cost for one batch of material, the PCS will use the latest update of material price. As the total material cost refers to production input (order) quantity, only one production rate is allowed for a particular month in each product model. For packaging, the PCS data model allows more than one packaging styles for each product model. The quantity used for each packaging style will be computed based on allocated percentage which is constant for a period of time. The PCS will use the latest update of packaging price. For labor, the PCS will import total labor cost of the same month.

Next, the Conceptual Database of PCS is designed based on five components of cost of a unit product. As can be seen in Figure 4, the relation between the five components have been clarified through their sub-components (e.g. material prices, packaging prices, material order, material batch, packaging type, etc.).

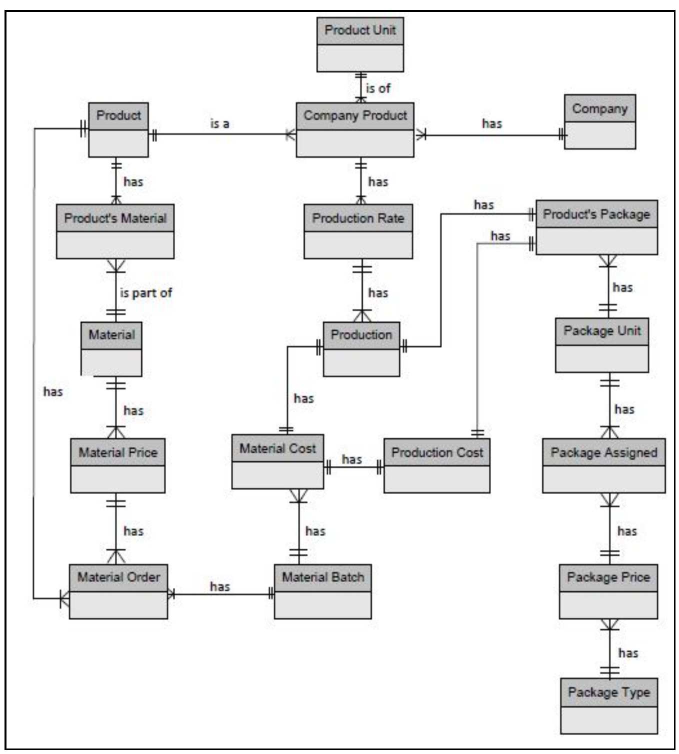

Figure 4: Conceptual Database Design

Next, the Logical Database (LD) of PCS is developed based on the Conceptual Database designed. LD or also known as data dictionary provides ID for each components in the Conceptual database. Here, the field size of input data is speficied such as total number of letter for product name is 50 while for product description is 100.

Finally, the Physical Database (PD) is designed according to the LD design so that the usage of data in terms of its size and frequency can be checked. Finkelstein et al. [15] claimed that designers may know how often the application will be run, but may find it difficult to predict the frequency of execution of a statement due to the complexity of program logic. Furthermore, Skogen [16] promotes simplicity in designing a model that involves complicated user-interface applications. In this study, production input, material batch, and packaging quantity are the most complicated part in PD design. Thus, null number is not allowed in determining production input, material batch, and packaging quantity.

5.0 DATA MODEL IMPLEMENTATION

The PCS data model is purposely developed to integrate with LCS for determining cost of a unit product based on one month's production. Then, the PWI will be computed based on the cost of unit product determined by the PCS data model. Therefore, data such as new price of materials and packaging, and new payment rate of labor have to be updated as soon as the effective date is confirmed. At the end of the month, sale quantity and inventory are needed for the PCS operation. Thus, only authorised personnel is allowed to access the PCS database for security purpose. Therefore, username and password will be required upon login to the PCS database. In addition, the PCS data model allows only one time key-in through a confirmation message before proceeding to next pages. The PCS data model operation is divided into two categories; (i) New product model, and (ii) New production.

For the first category, the PCS operation begins at product component where all product models have to be registered as 'Company Product'. With the function of Start date, a new product model will be activated in the PCS database whilst the End date function will de-activate the obsolete product model. Each product model is linked to material component, packaging component, and production component. Once the new product model is registered, data such as quantity and price per unit materials and packaging types are needed for the PCS operations. Quantity for materials refers to quantity needed for one batch production of particular product model whilst quantity for packaging types refers to percentage of packaging demand.

Thus, the total quantity used can be computed based on the production input (order) quantity determined. Then, the price of each material needs to be included with the function of start date and end date. In this way, the PCS data model will account for the latest price updated. Similar process flow applies to product packaging types. The packaging volume (e.g. liter, gram, meter, etc.) is required in order to compute total quantity of each packaging type that is based on allocated percentage. It is presented as packaging demand. Figure 5 shows a summary of PCS process flow for New Product Model.

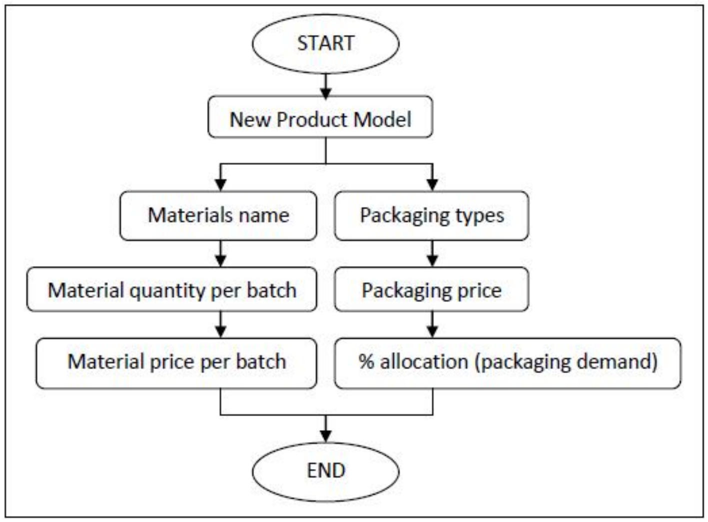

Figure 5: PCS process flow for New Product Model

For the second category, the PCS data model provides two options for the user; (i) Create new production input, and (ii) Retrieve existing production input. Here, the production input operation refers to process of determining production input (order) quantity of selected product model for a particular month. Data of production (i.e. production rate, sale quantity, and beginning inventory) for the particular month are needed to compute production input (order) quantity. Production input (order) quantity, Pi is computed using equation (2). Figure 6 shows an example of output for new production input with the PCS database programming.

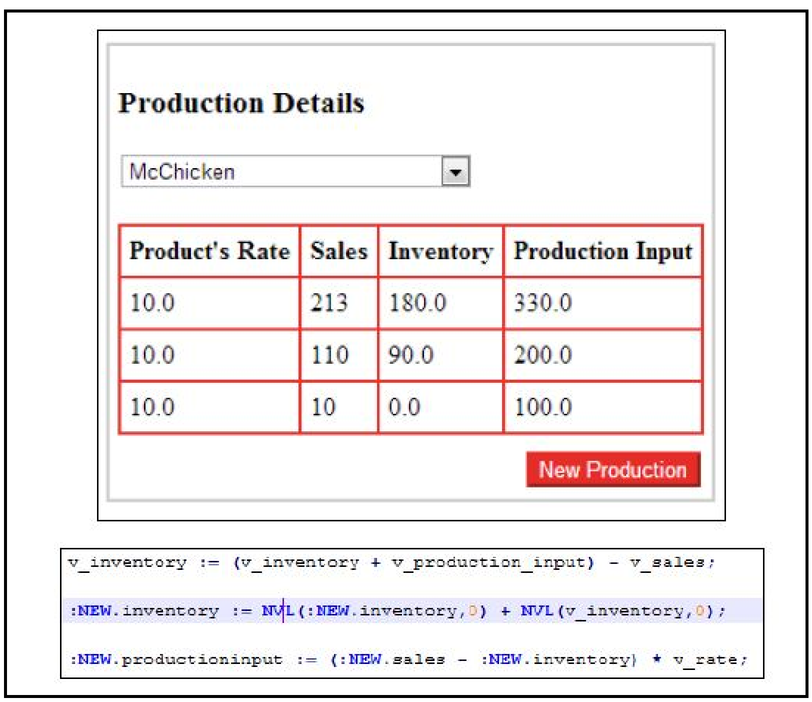

Figure 6: Production input (order) quantity

Then, the total number of production batch, PB can be calculated through production input (order) quantity, Pi and production rate, r which can be written as below:

$$PB = \frac{Pi}{r} \qquad (5)$$

Where,
Pi is production input (order) quantity
r is production rate

For material component, data of material (i.e. quantity of raw materials for one production batch) is required in order to calculate the total number of material batch needed for the production input (order) quantity, Pi. Here, the measurement unit (e.g. liter, pcs, meter, etc.) for each material is necessary. Data of price per unit material is needed so that the cost of one batch material can be computed. The PCS is capable to update the price through the confirmation of start date and end date of the material price. In this regard, the latest updated price will be used in the calculation of cost of material. Hence, the material cost will be multiplied with the total number of material batch needed for production batch, PB. In short, the PCS data model applies equation (6) for the calculation of total material cost. Figure 7 presents the page for material cost output.

$$\mathrm{MC} = PB \sum_{n=1}^{n} \mathrm{M_n} * \mathrm{P_n} \qquad (6)$$

Where,
MC is Material Cost
PB is total number of production batch
$\mathrm{M_n}$ is n th Material
$\mathrm{P_n}$ is cost of n th Material.

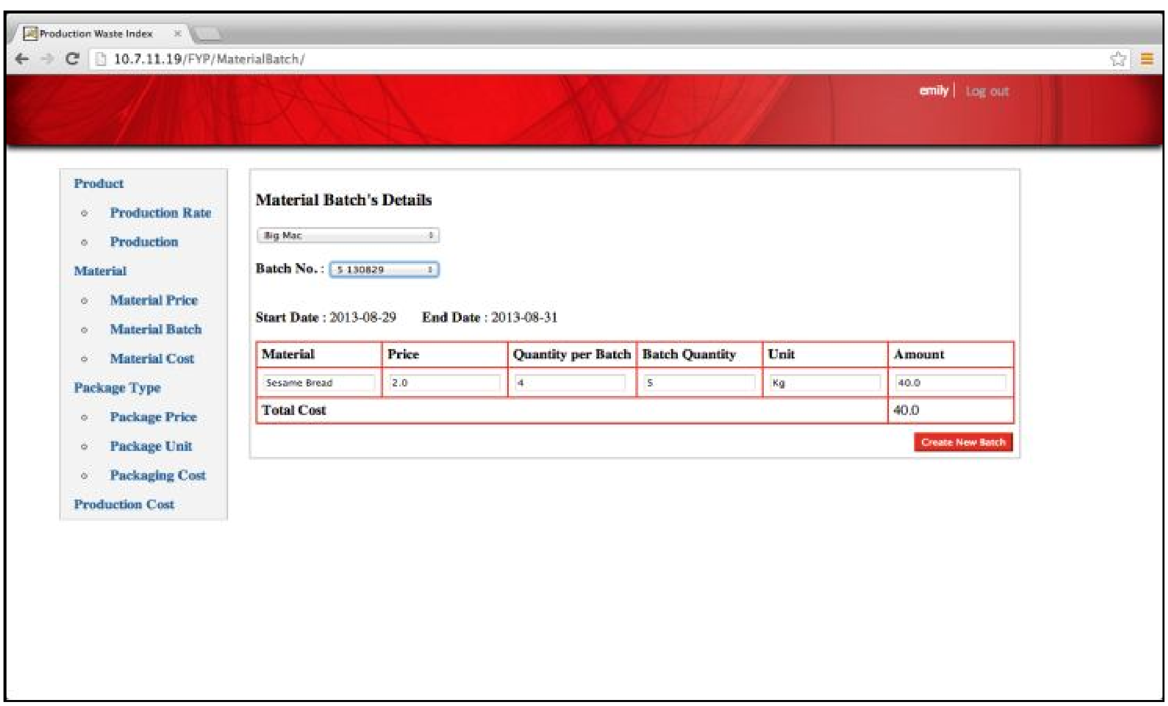

Figure 7: Output of material cost

At packaging component, the quantity of each packaging style is computed by equation (3) and the total packaging cost is computed by equation (4). Note that the PCS data model will be integrated with the Labor Cost System (LCS) data model to compute the cost of a unit product for each product model. In this regard, only labor cost of a particular month can be imported by the PCS data model. Figure 8 presents the process flow for creating new production input.

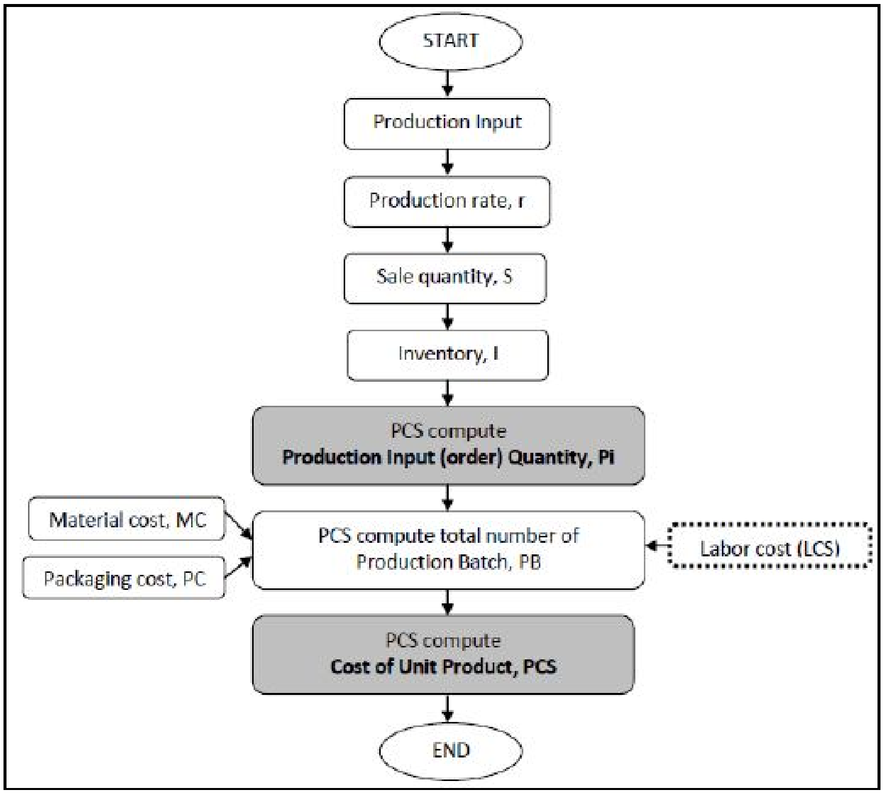

Figure 8: The PCS Process Flow for Creating New Production Input

In summary, effective production rate, material price, packaging price, and payment rate are the important variables that can affect the cost of a unit product. Thus, the start date and end date in PCS data model and LCS data model determine the effective date for these variables.

6.0 CONCLUSION

This paper presents a framework for Product Cost System (PCS) data model that has been designed based on micro-SME practices. The proposed PCS data model consists of four major components; (i) material cost, (ii) production input, (iii) packaging cost, and labor cost. However, the data model for labor cost need to be developed separately as it involves quite complicated architecture. In this case, the PCS data model will import the labor cost for a particular month. Cost of a unit product is the main output of the PCS data model that will be used to compute the Production Waste Index (PWI). Thus, PCS prototype testing with further improvement on minimizing bugs and errors will be the next phase in the development of PWI measurement system. In addition, development of LCS will be done in parallel with the PCS prototype testing.

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