Integrated Quality and Material Flow Cost Accounting (MFCA) Analysis of Production System

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***Abstract*—Material Flow Cost Accounting (MFCA) is one of the environmental management accounting methods aims to assess and reduce both environmental impact and product costs. Product quality is a crucial factor that significantly affects customer's satisfaction and many organizations emphasize and invest large amounts in designing and assuring quality system to prevent flow of defectives along the process. This research applied the Material Flow Cost Accounting (MFCA) technique first to trace material and energy used both in terms of physical quantity and monetary units in order to analyze efficiency of process and then to design the lot size and quality inspection that maximize of the total positive product cost with respect to the total cost obtained from the MFCA concept. Based on the case study data, the results of MFCA analysis showed that the highest portion of negative product cost was material accounting for 78.54% and following by System cost of 7.61% comparing with the total product cost. The analysis revealed that the loss cost can be reduced by improving the process quality which depends on the lot size. In the future the researcher will use artificial bee colony algorithms to determine the proper design by designing the optimal sampling plan and Optimal Lot Sizing that minimize both total cost, quality cost and negative cost.**

***Index Terms*—sampling inspection, serial multi-stage process, optimal lot size, Material flow cost accounting**

I. INTRODUCTION

The current global trade economy situation has changed over time. The sustainability has been increasingly demanded to increase the competitiveness and decouple the environmental problem from economics. The product quality, the main feature expected by customer, becomes very important in designing the production system to prevent flow of detectives along the process. Therefore, in order for the organization to compete sustainably in the enterprise industry, there must be a potential quality management policy and resource-based optimal a quality inspection system. Inspection of products to prevent nonconforming items from reaching the customer is performed in virtually every production system. In particular, the determination of inspection strategy in a Multi-stage Production System (MPS), where raw material is transformed into a product in a series of distinct processing stages, has been recognized as one of the major issues on methods of inspection in production systems.

Generally reducing waste in a production can be achieved by, i.e., reducing process variation, resources usage and eliminating causes of defects to achieve higher quality and output. In this study, reducing waste means implementing an efficient inspection strategy to detect defective items as soon as possible, ensure the required output quantity while minimizing costs. The inspection only at the last stage may not prevent non-conforming products submitted to the next stage, resulting in penalty costs, losing customer trustworthiness and market share, etc. Therefore, a cost trade-off is important to select the efficient economic inspection strategy that balance quality and cost.

Another interesting factor is lot size impact. During past few decade, inventory management has been important for the most manufacturing industries. Previously, most organizations use Economic Order Quantity (EOQ) model to identify the optimal lot size considering set up and holding costs. There are many researchers who extend the EOQ model concept for better solution and more suitable for each manufacturing environments. The lot size has direct impact on work in process, inventory level which affect directly on inventory holding costs. The study on optimal lot size will help design an economic order quantity and increase the organization's profitability.

Therefore this research aims to apply Material Flow Cost Accounting (MFCA) to calculate and analyze the cost associated with whole production system. This research incorporates the concept of MFCA and Quality cost to determine the effects lot size and sampling inspection at incoming, in-process and outgoing stage on the total cost of system. This research focuses on the total positive cost compared with the traditional total cost plus the cost of quality.

II. PROBLEM STATEMENT

This research extended the serial multi-stage production system studied by Bai and Yun (1996) with 2 stages as shown in Fig. 1. by considering the lot of material (Q_i) consisting of both good and bad quality

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entering the process. Each process has 2 stages $j = 1,2$ as shown in Fig. 2.

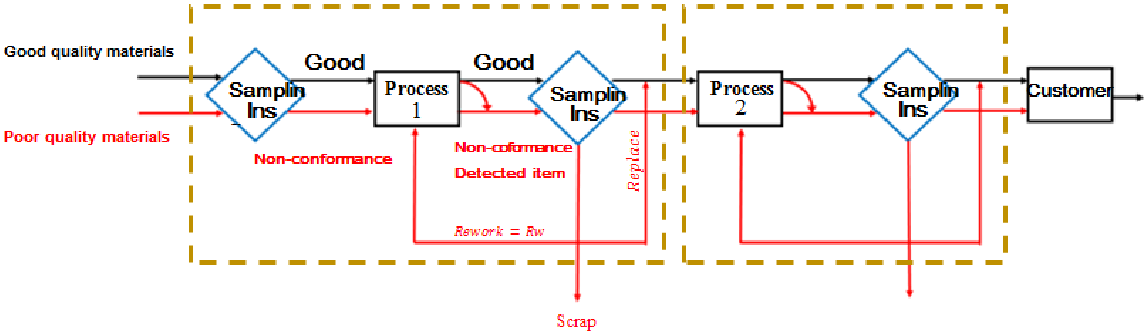

Figure 1. Serial multi-stage process

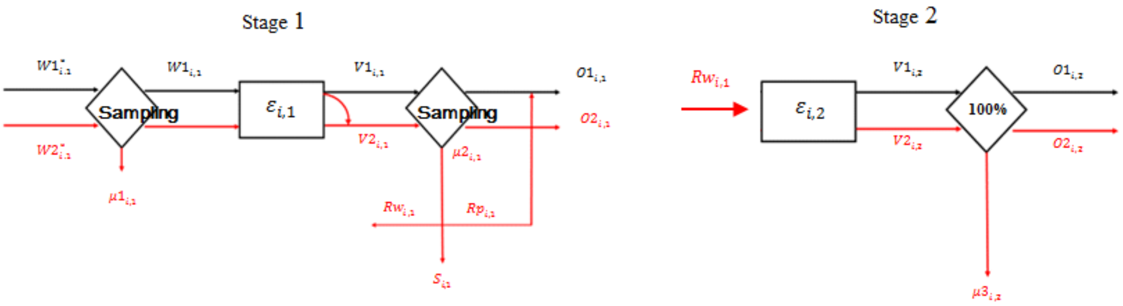

Figure 2. Processing during stage1 and stage2

After the 1^{st} stage, the production transforms the lot of material into WIP under imperfect production condition. Those inspected items are identified as good quality products and non-conforming products. Non-conforming products are classified into three categories: replaceable items, rework able items and reject items with constant proportion $f1_{i,j}$, $f2_{i,j}$ and $f3_{i,j}$ respectively. The 2^{nd} stage represent the rework cycle of the production. At both stage the materials and WIP will be inspected both before entering and after passing to the next process. The results of inspection and defectives affects the total production time and cost. There are following assumptions on this study:

1. Demand are pre-determined and constant
2. Non-conforming products are produced with constant proportion in each process
3. Each process adopts the acceptance sampling plan as quality inspection.
4. The amount of waste ($\mu_{i,j}$) that has been detected based on the probability of the sampling inspection
5. Rework operation can occur only once
6. The 2nd Stage will have 100% quality inspection

III. Modeling

A. Serial Multi-stage Production Model

From the serial multi-stage process model, suppose that each item must go through i processes and each of process has 2 stages. Then mass balance are calculated as follows:

Stage $j = 1$

(a) Probability for receiving production lot size

$$Accept = Pa = (1 - f)^n$$

$$Reject = 1 - Pa$$

(b) Production lot size that out of the sampling process before entering Stage 1 of process i

$$Q^*_{1,1} = Q(Pa) + W1^*_{i,1}(1 - Pa)$$

(c) Amount of good quality products that out of the sampling process before entering Stage 1 of process i

$$W1_{i,1} = W1^*_{i,1}$$

(d) Amount of non-conforming products that out of the sampling process before entering Stage 1 of process i

$$W2_{i,1} = W2^*_{i,1}(Pa)$$

(e) Amount of good quality products produced from process i stage $j = 1$

$$V1_{i,j} = W1_{i,1}(1 - \varepsilon_{i,1})$$

(f) Amount of non-conforming products produced from process i stage $j = 1$

$$V2_{i,j} = W2_{i,1} + W1_{i,1}(\varepsilon_{i,1})$$

(g) Amount of non-conforming detected from sampling plan before entering stage 1 of process i

$$\mu1_{i,1} = W2^*_{i,1}(1 - Pa)$$

(h) Amount of non-conforming detected from sampling plan after out of stage 1 of process i

$$\mu2_{i,1}$$

(i) Amount of non-conforming detected from process i stage $j = 2$

$$\mu3_{i,2} = V2_{i,2}$$

(j) Amount of replaceable items from process i stage $j = 1$

$$Rp_{i,1} = \mu2_{i,1}(f1_{i,1})$$

(k) Amount of rework able items from process i stage $j=1$

$$Rw_{i,1} = \mu 2_{i,1}(f2_{i,1})$$

(l) Amount of reject items from process i stage $j = 1$

$$S_{i,1} = \mu 2_{i,1}(f3_{i,1})$$

(m) Total good quality outcomes from i stage $j = 1$

$$O1_{i,1} = V1_{i,1} + Rp_{i,1}$$

(n) Total good non-conforming outcomes from i stage $j=1$

$$O2_{i,1} = V2_{i,2}(Pa)$$

Stage $j = 2$

(a) Amount of good quality products entering to process i stage $j = 2$

$$W1_{i,2} = 0$$

(b) Amount of non-conforming products entering to process i stage $j = 2$

$$W2_{i,2} = Rw_{i,1}$$

(c) Amount of good quality products produced from process i stage $j=2$

$$V1_{i,2} = Rw_{i,1}(1\text{-}\varepsilon_{i,2})$$

(d) Amount of non-conforming products produced from process i stage $j=2$

$$V2_{i,2} = Rw_{i,1}(\varepsilon_{i,2})$$

(e) Amount of non-conformance products detected from process i stage $j = 2$

$$\mu 3_{i,2} = V2_{i,2}$$

(f) Amount of replaceable items from process i stage $j=2$

$$Rp_{i,2} = 0$$

(g) Amount of rework able items from process i stage $j=2$

$$Rw_{i,2} = 0$$

(h) Amount of reject items from process i stage $j=2$

$$S_{i,2} = \mu 3_{i,2}$$

(i) Total good quality outcomes from i stage $j = 2$

$$O1_{i,2} = V1_{i,2}$$

(j) Total good non-conforming outcomes from i stage $j=2$

$$O2_{i,2} = 0$$

Therefore, the total outcomes reach into next process where $W1_{i+1,1} = O1_{i,1} + O1_{i,2}$ and $W2_{i+1,1} = O2_{i,1} + O2_{i,2}$

Reject items are waste $Scrap_i = \mu 1_{i,1} + S_{i,1} + \mu 3_{i,2}$

B. Modeling of MFCA Analysis

MFCA technique was proposed to trace all material used and calculate all activities in monetary term. There are four types of costs i.e. material cost, system cost, energy cost and waste treatment cost. These costs are distributed into positive and negative product cost based on the attribution of activities to generation of product and waste. This research proposes the following steps:

1. Draw the material flow diagram and identify the quantity center (QC).
2. Quantity the flow of material: Quantify input and output of each work center.
3. Evaluate flow in terms of cost which consists of material cost (MC), cost of production (SC), energy cost (EC), and waste management cost (WC) are the costs.

1) Material cost of process i

$$: MC_i = C_i^{mat} \quad (1)$$

2) System cost of process i

$$: SC_i = C_i^{setup} + C_i^{processing} + C_i^{Q_i} + C_i^{insp} + C_i^{IH} + C_i^{WIP} \quad (2)$$

3) Energy cost of process i

$$: EC_i = C_i^{Energy} \quad (3)$$

4) Waste treatment cost of process i

$$: WC_i = C_i^{treat} \quad (4)$$

5) These costs are distributed as positive product costs and negative product costs

Therefore, concluding overall production system:

Total cost (TC)

$$TC_i: TC_i = MC_i + SC_i + EC_i + WC_i \quad (5)$$

Total positive product cost(PC)

$$PC = PMC_I + PSC_I + PEC_I \quad (6)$$

Total negative product cost (TNC)

$$TNC = \sum_{i=1}^{I} NMC_I + \sum_{i=1}^{I} NSC_I + \sum_{i=1}^{I} NEC_I + \sum_{i=1}^{I} WC_I \quad (7)$$

Cost of Quality(COQ)

$$COQ_i = C_i^Q = \sum C_L^{Prev} + \sum C_L^{Appraisal} + \sum C_L^{Failure} \quad (8)$$

C. Mathematical Model

Decision variables

$W1_{1,1} \in [200{,}3000]$: Amount of good quality materials feed into process $i = 1$

$W2_{1,1} \in [200]$: Amount of poor quality materials feed into process $i = 1$

n_i: Samples of sampling plans

f_i: Proportion of waste in production lot

Objective function

$$Maximize \quad \frac{Positive\ Product\ Cost}{Total\ Cost + COQ} \quad (9)$$

Subject to

$$\frac{W1_{I,1} + W2_{I,1}}{t_c} \geq d \quad (10)$$

where Eq. (10) is the total products delivered to customer constraint. Note that the limited inspection resource constraint i.e. inspection persons, inspection time are not mentioned in this study.

IV. Experimental Results

In this study, the experimental data was obtained from the case study manufacturer. Since the present production has no replacement and rework process ($f1_{i,1} and\ f2_{i,1} = 0$) the detected items in stage1 will categorized as reject or scrap. The production parameters used in the mass balance calculation are shown in Table I. All material costs are kept confidential. Assuming that the customer demand (d) = 15,000 units per year, electrical rate (En) = \$0.11 per kWh, operating person each process = 1, inspection person (in case inspection) = 1, labor cost (Lc) = \$12 per day and labor hour (h) = 8 hours per day.

TABLE I. Production Data

Parameter	Process i														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
f	0.01	0.004	0.005	0.004	0.003	0.003	0.005	0.004	0.004	0.009	0.006	0.005	0.004	0.008	-
$\varepsilon_{i,1}$	0.00%	0.18%	0.02%	0.00%	0.00%	2.50%	0.00%	6.60%	1.20%	0.18%	0.24%	0.14%	1.73%	0.00%	-
n	40	40	30	50	40	60	50	40	35	50	55	60	45	50	-
Pa	78.37%	76.86%	85.40%	79.87%	86.62%	18.16%	77.01%	5.55%	56.68%	57.61%	61.73%	66.40%	37.18%	66.26%	-
(1-Pa)	21.63%	23.14%	14.60%	20.13%	13.38%	81.84%	22.99%	94.45%	43.32%	42.39%	38.27%	33.60%	62.82%	33.74%	-
$f3_{i,1} = f3_{i,2}$	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	-
$\varepsilon_{i,2}$	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	-
Inspec2	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	-
${t_s}_i$	4.00	8.00	0.00	0.25	0.00	0.25	0.50	4.00	0.50	1.00	1.00	0.00	0.00	0.00	-
${t_{insp}}_i$	2.30	8.22	10.70	2.00	0.00	0.63	4.00	3.89	1.71	1.00	2.63	11.47	0.00	0.00	-
${t_m}_i$	42.00	42.00	0.00	0.00	0.00	0.00	0.00	42.00	0.00	0.00	0.00	0.00	0.00	42.00	-
${t_{rw}}_i$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
${P_{mc}}_i$	25.00	40.00	0.75	5.60	0.00	15.00	5.60	30.00	1.50	1.50	1.50	0.75	0.00	0.00	-
${P_{insp}}_i$	2.00	2.00	0.00	0.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	0.10	2.00	-
W_i	0.4344	0.0910	0.0412	0.0401	0.0401	0.0401	0.0401	0.0401	0.0401	0.0401	0.0401	0.0401	0.0400	0.0400	0.0400

TABLE II. MFCA Analisis of A Present Case Study Manufacturing

	Total cost (฿/year)	Positive cost (฿/year)	Negative cost (฿/year)
MC	8,696,171.75 79.16%	68,017.85 0.62%	8,630,153.91 78.54%
SC	2,259,558.70 20.56%	1,423,680.98 12.96%	835,877.72 7.61%
EC	37,088.90 0.34%	28,916.47 0.26%	8,172.44 0.07%
WC	1,244.44 0.01%	0 0.00%	1,244.44 0.01%
TC	10,987,719.98 100.00%	1,520,615.29 13.84%	9,467,104.69 86.16%

Table II shows the calculated positive and negative product cost of the current production process for a given set of parameter and variables. Only 13.84% of the total cost is the positive product cost, while 86.16% becomes negative product cost in which 78.85% is the material loss cost. The result shows that this manufacturing incurs high wastage of using materials in production.

V. Conclusion and Discussion

MFCA technique helps identify the waste and its cost with respect to the detective items being processed unnecessarily during manufacturing operations and the inefficient inspection strategy. This study provides mechanism to find an efficient design strategy with optimal inspection strategy and production lot size. The objective of the optimization problem are the maximum ratio of positive product cost to total cost (PC/TC). Therefore, in the future, the researcher will use artificial bee colony algorithms to determine the proper design by designing the optimal sampling plan and Optimal Lot Sizing that minimize both total cost, quality cost and negative cost. In conclusion, the proposed approach is helpful for designing the production and inspection systems especially for the serial production process environment.

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