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Integrating Discrete-Event Simulation with Activity-Based Costing for Process Improvement: FPCA Manufacturing System

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Abstract: We propose to incorporate activity based costing into a discrete-event simulation model of a flexible printed circuit board assembly line. We show how it can help identify costly value-added activities, suggest where cost reduction can be achieved, and how much price discounts we can offer to customers. In our case study, the most costly cost drivers are cleaning process and 100% final inspection, which constitute 26.5% and 22.4% of total cost, respectively. This cost reduction translates to price reduction of 2.3% and 3.2%.

Keywords: discrete-event simulation; activity-based costing; process improvement; flexible printed circuit board

1. Introduction

Because of the highly competitive nature of the electronics industry, manufacturers of flexible printed circuit board assemblies (FPCAs) need to help customers reduce costs while keeping their own profit margins. FPCAs are components in hard disk drives, mobile phones and digital cameras; Figure 1 shows the supply chain of electronic goods. The 2005-2009 data of the company under study reveal that though the sales volume has been steadily increasing, the unit price has decreased annually [1]. To survive, the FPCA manufacturers must continuously strive for process improvement and cost reduction.

The existing Traditional Cost Accounting (TCA) only focuses on financial reports and costs of materials, labors, overhead and others; however, it does not consider cost activities that generate value in each operation. Therefore, we use the Activity Based Costing (ABC) system to analyze operational work efficiency. Cooper and Kaplan [2, 3, 4] develop the ABC to assign activity costs to each product or customer. The activity cost drivers (i.e., factors) are classified into three types: transaction drivers, duration drivers and intensity drivers [5]. The transaction drivers count the number of times an activity take place, e.g., setting up a machine. The duration drivers represent the length of an activity, e.g., processing time. The intensity drivers consider the cost of using resources.

Activities are classified into four types, ranked from lowest to highest levels [4]: Examples of *unit-level activities* are direct labor, materials, machine costs and energy. *Batch-level activities* include setups, material handling, purchasing and quality inspection. *Product-sustaining activities* are concerned with process engineering and product R&D. *Facility-sustaining activities* cover plant management, building and grounds, and heating & lighting. In this study, we only consider the unit-level and batch-level activities.

We use ABC inside discrete-event simulation (DES) models in order to calculate activity based costs by multiplying the cost rates with time duration of activities, similar to the concept of time-driven activity based costing [6]. DES models naturally take into account the randomness in the processing times, and they also provide insights and answers to "what-if" questions [7]. Specifically, we consider the FPCA manufacturing system where we would like to determine the most costly value-added activities and experiment with how to reduce them.

Spedding and Sun [5] also combine DES with ABC but for a semi-automated printed circuit board assembly line. Their DES models are developed in WITNESS. Through series of scenarios (e.g., calculation of surplus capacity, improved cost allocation, quality costing), they illustrate how DES models can be a powerful analysis tool for quantifying costs. Park and Kim [8] also examine how ABC can be applied in advanced manufacturing environment, but they use it to provide costing data for investment decision models, instead of simulation models as in [5] and our work.

This paper is organized as follows: Section II summarizes our problem details and methodology. Section III describes the analysis of simulation output and what-if analysis. We conclude in Section IV.

2. Background and Methodology

A. FPCA Production Processes

The FPCA fabrication consists of 14 processes consisting of both automatic and semi-automatic lines (see Figure 2). The process begins with an operator sets the FPCs onto a carrier. As the name implies, the carrier holds the FPCs in the assembly process (one carrier contains 4 FPCs) and moves them through automatic machines. The solder printing process puts solder on the FPCs where assembly components will be added. A conveyor then sends them to the surface mounting processes number 1 and 2 where electronic components are placed onto the solder area. Then the conveyor sends them to the reflow process where the solder is heated so that electronic components are bonded to the FPCs. Subsequently, they are sent to the assembly inspection process where defects (e.g., incomplete solder, missing joints between components and solder, and misaligned components) are checked. At the Carrier A changing step, operators move the FPCs onto a carrier named "A". This is the end of the automatic line.

The semi-automatic line begins with the cleaning process, after which they are transferred to a new carrier named "B" and to the next process. To bond the components onto the FPCs, adhesive is applied to the electronic components. The FPCs are cured in the curing oven to strengthen adhesive. After curing, they are sent to quality control X-ray tests to ensure that the soldering under the components is complete. Then their electrical properties are inspected. In the forming process, the FPCs are shaped according to customer's specifications and are sent to the second cleaning process. During the final inspection, operators carefully inspect all FPCs. Products that meet requirements are shipped out; else, they are scrapped.

B. ABC Implementation

Spedding and Sun [5] incorporates ABC into their simulation models by estimating the cost of making a product C as follows:

$$C = TR + M, \tag{1}$$

where T is the time that the resources are occupied, R is the cost rates, and M is the cost of materials. The processing time T will be estimated from DES models. The cost drivers (or factors) include direct labor and manufacturing overhead which consists of electricity and maintenance. The depreciation costs are not considered since all of the machines in the process have been in use for over 12 years. Due to the proprietary nature of the data, we will not show the cost rate data here (See [1] for details).

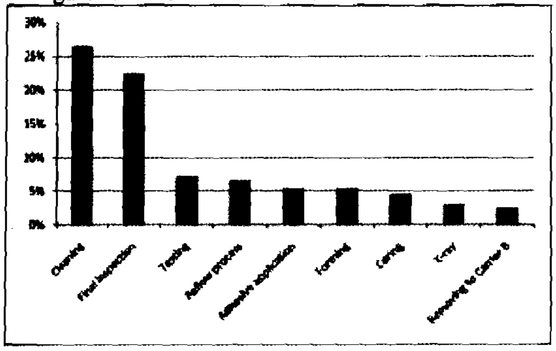
C. DES Model Development

We implement our DES models in Arena (v.12) software [9], where models are constructed by creating a flow chart of logic modules through graphic user interface. To model randomness in processing times of each step in the FPCA fabrication, the actual data are collected and fit with probability distributions (see [1] for complete details). Other important input parameters are the number of resources used and cost rates that we have estimated in Section B. Our ABC simulation model consists of two sets of logic modules: production processes and the ABC. We validate our simulation model by comparing empirical flow time of one lot (92 FPCAs) with simulation outputs. A two-sample t-test is designed to assess if the means of two samples are statistically different, assuming unequal and unknown variances [7]. The p-value of the test is 0.39, so we can conclude that our simulation model is adequately representing the actual system. The simulation run length is 500 hours (1 month).

3. Analysis of Outputs and what-if analysis

The activity costs come from resource usage and material costs. Figure 3 shows that the top two most costly activities are cleaning and the final inspection (26.5% and 22.4% of the total cost, respectively). When we identify each activity in terms of operation (value added cost), inspection, and transportation (non-value added cost). The total cost consists of 52.4% value added cost, 33.3% inspection cost and 14.3% non-value added cost.

Figure 3. Fraction of total costs of cost activities.



The cleaning process is the most costly activity. It is identified as a value added cost because customers require that the FPCAs are washed so that they pass the cleanliness control specifications before being assembled into a hard disk drive. The cost of busy cleaning machine is 189,549 THB/month (79%); whereas it is 51,362 THB/month (21%), when idle. This suggests that this cleaning machine can be shared with other assembly lines. Recall that FPCAs go through the cleaning process twice: The first time is after assembly inspection, and the second time is after the forming process. The first cleaning is done to remove the flux and solder stemming from the solder printing and surface mounting processes. The second cleaning is to ensure that the FPCAs meet the cleanliness specifications. One possible way to reduce costs is to eliminate the first cleaning. Before offering this change to customers, we need to assess its financial benefits. The simulation results show that the cost reduction gained is 6.8%, translated to a potential price reduction of 2.3% that we can offer to customers, given that we keep the same profit margin.

If we are going to eliminate the first cleaning in practice, we still need to assess the resulting yield. It may or may not cause more defects than the current approach. Monitoring the yield closely when running the first prototype and then adjusting machine parameters accordingly should be done to circumvent this problem.

The final inspection is the second most costly activity. Currently, FPCs are inspected 100%. It requires 17 operators and thus incurs high labor costs. We propose to adopt a sampling plan. The reference sampling plan method that we use here is the MIL STD 105E as recommended in [10]. We need to specify Acceptable Quality Level (AQL), which represents the poorest level of quality for the vendor's process that the consumer would consider to be acceptable as process average. In addition to the AQL, the sample size is then determined by the lot size and the choice of inspection level (I, II, III). In this study, we assume an AQL of 0.01% (fraction of defective), level II inspection, sample size code letter "F", a single and normal sampling plan. From the lot of 92 FPCAs, the MIL STD 105E specifies that we should inspect 20 pieces from a lot of 92 pieces. Under the acceptance sampling scheme, the cost is reduced by 9.3%, translated to a price reduction of 3.2% that we can offer to customers, given that the same profit margin is kept.

The MIL STD 105E is by no means the only sampling standard. Future studies are needed to determine a more appropriate sampling plan for this production line. What we aim to show in this work is how to financially quantify the effect of making process improvement changes.

4. Conclusions

Manufacturers are constantly under pressure from customers to improve their operations in order to reduce costs and thus to offer price discount. We propose an ABC simulation model that can be used to identify costly value-added activities and to do what-if analysis. Together, we can estimate the financial outcomes of making process changes.

The cleaning process and the 100% final inspection are found to be the main cost drivers in this manufacturing system; 26.5% and 22.4% of total cost, respectively. We propose to reduce costs by eliminating the first of the two cleaning and doing an acceptance sampling of finished goods. These two proposals yield the cost reduction of 6.8% and 9.3%, respectively. Given that the profit margins are kept the same, and we transfer all the cost savings to customers, the maximum price reduction that we can offer is 2.3% and 3.2%.

5. Acknowledgment

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6. References

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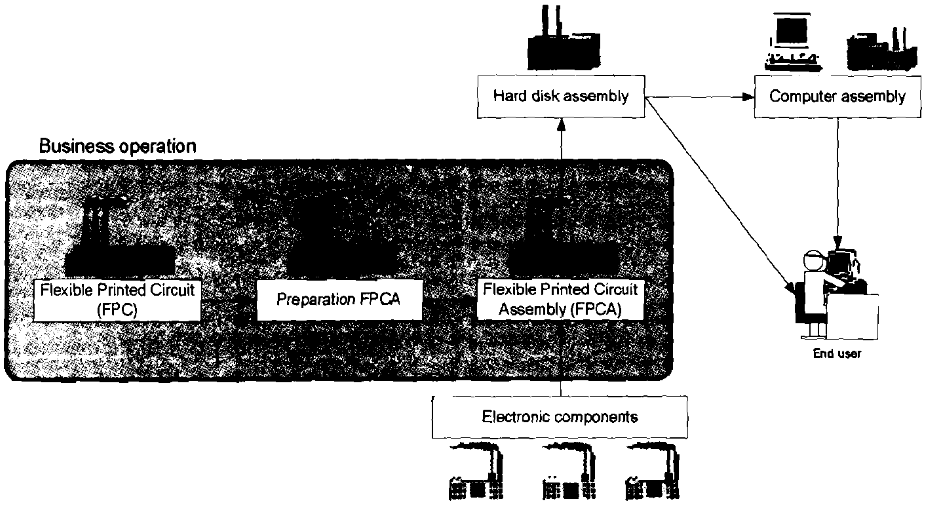

Figure 1. Supply chain of electronic goods.

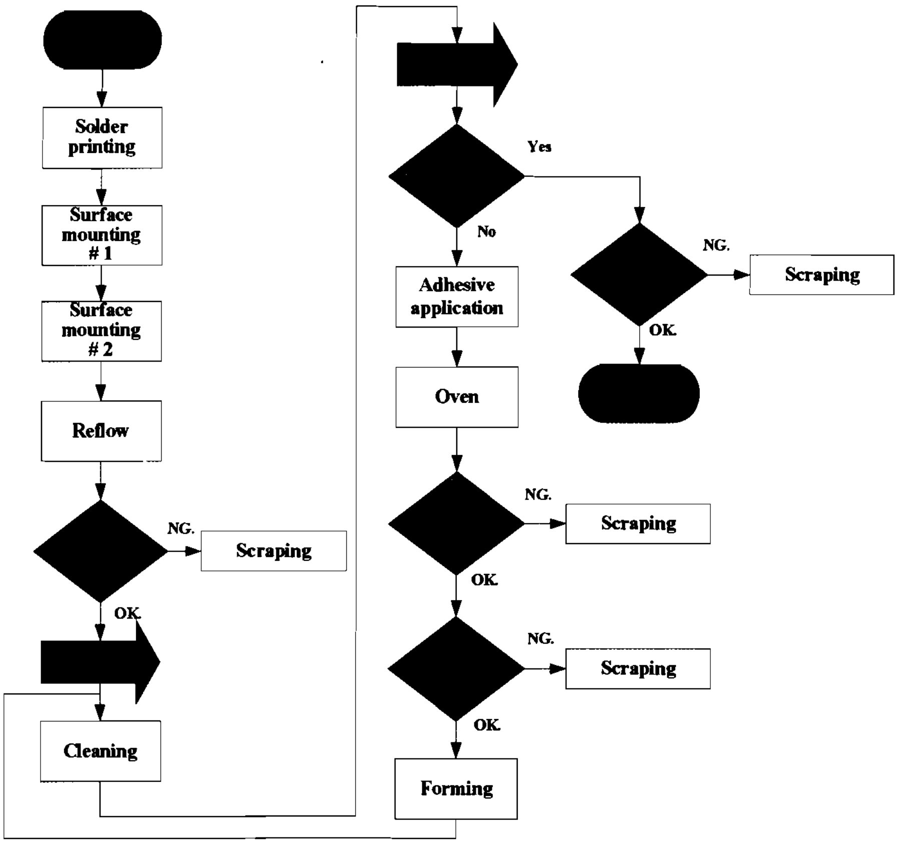

Figure 2. Process flow diagram of FPCA fabrication.