Design-for-Cost – An Approach for Distributed Manufacturing Cost Estimation

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Abstract. Researches have shown that design changes cost more in later stages of product development. Therefore, companies adopt Design-for-X methods to optimize product designs from many aspects in the early design stage. Despite such efforts, they often encounter several design changes during the commission of the production; and one of the main reasons is a failure to meet their target cost. Accurately estimating cost in the early design stage is difficult due to insufficient information. In particular, as production becomes more distributed cost estimation is also more difficult because information is more distributed. This paper introduces a cost estimation method to address this problem. It describes a distributed manufacturing situation and a cost breakdown framework. A use case is provided to illustrate how the framework allows for supply-chain cost negotiation and design adjustments in the early design stage.

Keywords: Cost Estimation, New Product Introduction, Cost Breakdown Approach, Design-for-Cost, Supply Chain Management.

1 Introduction

Researches have shown that design changes cost more in later stages of product development [1]. Therefore, companies adopt Design-for-X methods to optimize the product design from many aspects such as quality, time to delivery and cost in the early design stage. Companies have strong interest in the ability to accurately estimate manufacturing cost earlier in the design stage, because executives pay a lot of attention to profit.

In the New Product Introduction (NPI) process, companies typically set target market, volume, price, and manufacturing cost along with the design and functions of a product at the first stage [2]. They are very interested in maintaining the profit margin; therefore, target manufacturing costs are validated at every NPI stage. Despite this general practice, unexpected cost usually shows up at the commission of production because the current cost estimation approach is insufficient for today's distributed manufacturing environment.

Traditionally, manufacturers[1] have most of the information necessary for cost estimation. It is not the case for distributed manufacturing. Manufacturers need to interact

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[1] In this paper, *manufacturers* refer to the organizations that design and/or produce products or components that need subassemblies from *supplier* organizations. The two roles are played

with suppliers, estimate component costs, and consider delivery and packaging costs from the early design stage. Cost estimation approach for distributed manufacturing needs to enable manufacturers to negotiate with suppliers and come up with supply chain strategies to reduce cost. For example, in addition to the typical design adjustments to reduce material and manufacturing process costs, manufacturers may find suppliers who can use the same material and purchase the material on behalf of all the suppliers to receive larger bulk-buying discount. Without proper cost break down in the estimation, manufacturers will have difficulty negotiating with suppliers as they do not know which cost elements can be reduced.

This paper proposes a framework for manufacturing cost estimation in the early design stage for the case of distributed manufacturing. The framework reduces risks in encountering unexpected cost at the commission of production that could result in a costly design change. The rest of paper is organized as follows. First, a literature review on manufacturing cost estimation is given. Then, our cost estimation framework is outlined. Finally, a case study showing cost estimation of a supplied component is illustrated followed by a conclusion and future work.

2 Literature Review

In this chapter, a summary of existing manufacturing cost estimation methods and cost elements is provided.

2.1 Cost Estimation Methods

Manufacturing cost estimation methods can generally be divided into two groups: qualitative methods and quantitative methods [3].

Qualitative methods are based on a comparative analysis between a new product and similar products manufactured previously. On the other hand, quantitative methods are based on a detailed cost analysis of product design, its features, and corresponding manufacturing processes instead of simply relying on the past data or tribal knowledge of an estimator. The qualitative methods do not provide a cost break down that can be used to understand cost elements to the benefit of design change and cost negotiation.

There are several types of quantitative method including Operation-based approach [4], Feature-based approach [5] and Break-down approach [6]. Operation-based approach mainly estimates cost in terms of types of operations and considers material cost, factory expenses and manufacturing processing cost as part of the costs associated with time of performing operations. This approach focuses on accurate estimation of the manufacturing processing cost but provides less detailed consideration on other cost elements.

by organizations in a distributed manufacturing chain. For example, GM (a manufacturer) designs and produces cars which requires instrument panel assembly from Delphi (a supplier). Delphi on the other hand can be a manufacturer ordering electrical harness from a supplier.

The feature-based cost estimation approach identifies cost-related features of the design and respectively estimates their costs. However, existing approaches in this category only considered conventional machining process.

The break-down approach breaks down manufacturing cost into cost elements. An estimation is applied to each cost elements. The estimated manufacturing cost is a sum of all cost elements incurred during the production cycle. Cost elements include material cost, manufacturing process cost, maintenance cost, and repair cost. Additionally, [6] added insurance cost, [7] added overhead costs, and [8] calculated the manufacturing process cost based on the hourly usage of machinery.

For more accurate cost estimation, we adopt a cost break-down approach. However, our research focuses on estimating cost for distributed manufacturing. For that, we have to look into what data is available for the manufacturer; and it is necessary to extend the scope of cost elements such as packaging and delivery cost. The scope of this paper and associated cost elements is described in 2.2.

2.2 Cost Elements

According to [9], selling price consisted of material, labor, indirect, selling and administrative expense and profit as shown in **Fig. 1**.

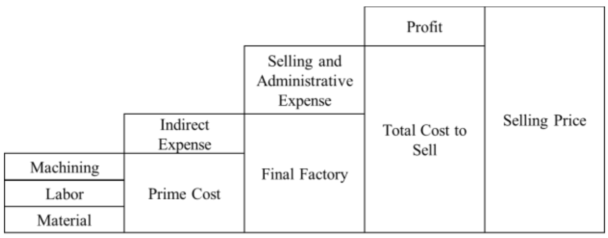

Fig. 1. Elements of Cost

Most researches focus on *Final Factory Cost*, however, it is necessary to widen the scope to *Selling Price* to include packaging and delivery cost in the *Total Cost to Sell* in order to estimate cost of a distributed manufacturer. To enable detailed cost analysis, cost elements for machining, tool, and defects should be added to *Prime Cost*. In conclusion, cost elements for distributed manufacturing are shown in **Fig. 2**.

Material	Tool	Machining	Labor	Defect	Packaging	Delivery	Selling & Administrative	Profit
Selling Price = Distributed Manufacturing Cost								

Fig. 2. Cost Elements for Distributed Manufacturing

3 Cost Estimation Framework

In this chapter, we introduce a cost estimation framework for a supplied component. We suppose that design of the component starts after target market, volume, and price are set as they are needed for the cost estimation.

Several researches provided logic (cost elements and formula) for estimating costs. However, they can be difficult to apply in the early design stage of distributed manufacturing because data are not available. Therefore, it is necessary to incrementally increase the accuracy of cost estimation as shown in **Fig. 3** - starting from using logic requiring least information and add more details and data as they become available. The approaches to update logic and improve the accuracy include further breaking cost elements, decompose parameters in formula, and collecting more data and update the database. Ways to collect data include investigating trends in the market, prototyping the component internally, contacting the supplier, contacting the equipment makers, and contacting raw material suppliers.

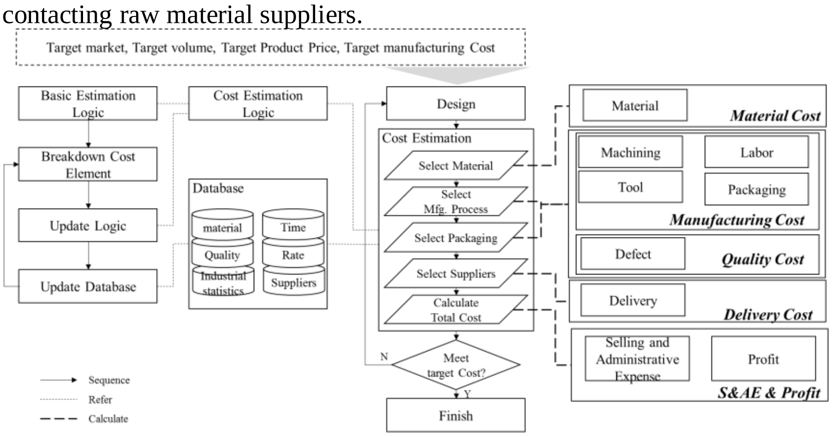

Fig. 3. Cost Estimation Framework for Distributed Manufacturing

As shown in **Fig. 2**, Selling Price of supplier (or supplied component) needs to be estimated. Therefore, the cost of the designed part is estimated considering the material, the manufacturing process, the packaging method, and the anticipated supplier, and then compare with the target cost. Right hand side of **Fig. 3** shows which cost elements (in **Fig. 2**) are related to cost estimation steps.

In the early stages of development, since every aspect of the design is not decided, such as the raw material, manufacturing method, assumptions have to be made on the parameters of cost elements. Therefore, only as the design of the product becomes more concrete, the cost can be estimated more accurately.

4 Cost Estimation Method and Cost Breakdown

In this chapter, we introduce basic formula for each cost element and discuss their essential aspects. The formula may need to be adjusted for different supplied components and situations. Each of the cost elements is estimated per a part.

4.1 Material Cost

Most of the researches estimate material cost with unit cost and amount and a basic estimation logic of material cost C_{mat} is given by

$$Material\ Cost\ C_{mat} = m_t \times U_{mat} \quad (1)$$

where m_t is the total amount of the raw material and U_{mat} is the unit cost for raw material However, the amount of material should be broken down into the net material, m_n, and loss material, m_l, to present an opportunity to reduce the loss material. The design engineer may improve the design or the manufacturer may work with supplier to improve the process to reduce the loss material. Loss materials are, for example, for preheating in injection molding process and for chips or scraps in NC machining. Thus, the material cost C_{mat} which characterizes material loss is given by:

$$Material\ Cost\ C_{mat} = (\ m_n + m_l\ ) \times U_{mat} \quad (2)$$

4.2 Machining, Labor and Tool Costs

Generally, the basic estimation formula for machining is expressed as the product of machine rate and machining time [6].

$$Machining\ Cost\ C_{mcn} = r_m \times t_m \quad (3)$$

where r_m is the machine rate and t_m is the machining time. Machine rate is usually calculated by dividing the cost to operate a machine or machines for the needed processing duration by the duration itself. Details of machine rate estimation is beyond the scope of this paper, but it can be calculated approximately with depreciation, electricity and maintenance cost. Machining time can be subdivided into setup time (t_s) operation time(t_o) and nonoperation (idle time and down time) time (t_{no}) [10].

$$Machining\ Cost\ C_{mcn} = r_m \times (t_s + t_o + t_{no}) \quad (4)$$

Labor cost which is similar with machining cost is given by

$$Labor\ Cost\ C_l = r_l \times t_l \quad (5)$$

where r_l is the labor rate and t_l is the labor operation time. A labor rate is the cost of labor that is used to deriving the costs of various activities or products directly related to manufacturing. Calculating accurate labor cost can be difficult for distributed manufacturing because every supplier has different wage and compensation. Average labor rate of the industry can be used and is a good reference point for negotiation. The average labor operation time can be obtained by dividing the total number of products made during the day by the work time per day. However, it is also possible to apply the technique of analyzing the operation time such as Modular Arrangement of Predetermined Time Standards (MODAPTS) [11].

Tool cost is the cost of devices such as a mold or a jig, which is calculated by dividing the price of the device by the target production quantity.

$$\textit{Tool Cost } C_{tool} = \frac{Tools\ Prices}{Target\ production\ volume} \tag{6}$$

4.3 Defect Cost

As every manufacturing process has failures, defect cost needs to be considered. Defect rate is difficult to predict before start of manufacturing and it can vary between suppliers. Therefore, the defect rate is typically set to the same as or lower than an average of historical defect rates. In order to predict the defect cost, defect cost C_{dft} is given by

$$\textit{Defect Cost } C_{dft} = (C_{mat} + C_{mcn} + C_l\ ) \times r_d \tag{7}$$

where r_d is the defect rate.

4.4 Packaging Cost

Packaging cost includes all the materials and processes needed for delivering the supplied component to the manufacturer.

$$\textit{Packaging Cost } C_{pkg} = p_b \div n_p + r_l \times t_p \tag{8}$$

where p_b is the cost for package box, n_p is the number of parts for a box and t_p is the packing time.

4.5 Delivery Cost

Delivery cost is the cost of delivering the packaged product from the supplier to the manufacturer. The method of estimating cost may vary depending on the transportation, but the formula below includes essential parameters for cost reduction analysis.

$$\textit{Delivery Cost } C_{dlv} = r_d \times d \div n_t \div n_p \tag{9}$$

where r_d is the delivery rate, d is the distance from supplier to buyer and n_t is the number of boxes in a transport.

4.6 Selling and Administrative Cost and Profit

These cost elements can be estimated as percentage over other cost elements. Selling and administrative (S&A) cost also includes research and development. These ratios vary by industries and suppliers and may be obtained from industry statistics such as in [12-13]. The S&A ratio can be higher for a supplier with an R&D center, such as a PCB manufacturer. In addition, the profit ratio can be negotiable, and it may increase for favorable partners such as those delivering consistent quality components and on-time delivery. The basic formulas for the two cost elements are:

$$\text{Selling and Administrative Cost } C_{sac} = (C_{mat} + C_{mcn} + C_l + C_{pkg} + C_{dlv}) \times r_{sac} \tag{10}$$

$$\text{Profit } C_{prf} = (C_{mat} + C_{mcn} + C_l + C_{pkg} + C_{dlv} + C_{sac}) \times r_{prf} \tag{11}$$

where r_{sac} is the selling and administrative ratio and r_{prf} is the profit ratio.

5 Use case

The use case is a scenario in which a refrigerator manufacturer needs an injection-molding parts from a supplier. After the supplier receives the drawings, molds are manufactured. And after the injection-molding part production and quality inspections are completed, they are put in protective tapes and delivered in boxes. Below, we discuss cost estimations and cost reductions experienced in this use case.

The component used 120g of abs resin; therefore, according to (1) is:

$$Material\ Cost\ C_{mat} = m_t\ (120g) \times U_{mat}\ (\$2.7/kg) = \$0.324$$

However, it was determined that if two parts were produced at the same time in a single mold, machining, labor, and tool costs were reduced despite an increase in material cost. The increase in material cost came from additional resin needed for the sprue and runner (12g) in the mold. Hence, material cost using (2) is:

$$Material\ Cost\ C_{mat} = m_t\ (120g + 12\ /2) \times U_{mat}\ (\$2.7/kg) = \$0.340$$

The price of the mold to produce the product is about $30,000 and can be used 200,000 times. However, since we produce two parts in one mold,

$$Tool\ Cost\ C_{tool} = \frac{\$300,000}{200,000} \div 2 = \$0.75$$

Machine rate for injection is calculated to be $24 per hour and the machining time is 40 seconds for two pieces.

$$Machining\ Cost\ C_{mcn} = r_m(\$24/hour) \times t_{mcn}\ (40s\ /\ 2) = \$0.13$$

The operator extracts the injected parts from the machine and performs visual inspection. The labor rate is $30 per hour and has the same tact time as machining time. Therefore, applying (3),

$$Labor\ Cost\ C_l = r_l(\$30/hour) \times t_l\ (40s\ /\ 2) = \$0.17$$

Since historically the average failure rate of the supplier in the use case was 2%,

$$Defect\ Cost\ C_{dft} = (C_{mat}(\$0.340) + C_{mcn}(\$0.33) + C_l(\$0.37)) \times r_d(2\%) = \$0.01$$

After the manufacturing is completed, tape is attached, and a total of 100 parts are inserted into a $2 container, which takes about 20 seconds per part. Therefore,

$$Packaging\ Cost\ C_{pkg} = p_b(2) \div n_p(100) + r_l(\$30/hour) \times t_p(20s) = \$0.187$$

A truck delivers parts with 400 boxes for 20km,

$$Delivery\ Cost\ C_{dlv} = r_d\ (\$20/km) \times d(20) \div n_t(400 \times 100) = \$0.01$$

Since the average S&A rate is 7% and profit rate is 8%, they cost $0.11 and $0.14.

And finally, the total cost is a summation of all the cost elements: $1.85 per part.

Discussion: If the estimated cost cannot meet the target cost, it is necessary to consider changing to cheaper raw materials, increasing the number of parts in the mold, or changing the packaging method to reduce the cost.

The estimated costs cannot be guaranteed to be available from the supplier but can be negotiated with supplier based on the estimation. For example, it may be possible to negotiate the defect rate, S&A rate, etc.; or to come up with a supply chain strategy such as bulk buying raw materials at a lower price on behalf of multiple suppliers, arrange logistics services, etc.

6 Conclusion

In this paper, we introduced a method and a use case to estimate cost for distribute manufacturing components. In order to estimate cost of distribute manufacturing, *selling price* should be considered instead of *final factory cost*. We also introduced cost elements of the selling price for a more accurate cost estimation. Through this, a framework is proposed that incrementally enhance the detail of cost estimation during the design process. A use case illustrated cost estimation of a component and discussed how parameters identified in cost elements may be used for adjusting design and negotiating with suppliers.

Future works include integrating the quantitative cost estimation approaches described in this paper with qualitative approaches. In this way machining time and working time can be better predicted based on data kept in a database of cost estimation. Therefore, defining data schema for such database is an important research topic.

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