

# Pro-DFM: A Multi Factor Model for Integrating Design for Manufacturability in the New Product Development (NPD) Process

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Product development has become a relatively expensive and high-risk process, that is characterized by increasingly shorter life-cycles and higher degrees of competitiveness. To maximize the efficiency and success of their product development initiatives many companies have adopted and implemented a NPD process. These NPD processes range from the semi-structured to the structured, and typically involve a series of stages and gates. The primary goal of NPD is to deliver a product with high functional utility, and attractive features resulting in market success for the product. In addition, there are several general process objectives (see table 1).

Achieving the table 1 objectives requires that we follow a concurrent engineering approach to NPD. Unlike a sequential NPD process, a concurrent approach emphasizes cross functional integration and early evaluation of downstream issues. One such issue is product cost reduction (last bullet in table 1), through lower manufacturing costs. This implies that a Design for Manufacturability (DFM) analysis must be integrated in the NPD process. Further the DFM metrics must be linked to one more gates.

## DFM Introduction

DFM may be described as a method for evaluating product designs so as to identify likely manufacturing cost drivers, and then leading to solutions for the mitigation of these

cost drivers. The use of DFM techniques early in the design cycle results in shorter design delays, easy production transitions, and higher quality [1].

Table 1. General Objectives of the NPD Process

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| <ul style="list-style-type: none"><li>• Structuring the process through a stage-gate system so as to ensure that problems are detected early</li><li>• Focus all involved on customers needs, expectations, and excitements</li><li>• To consistently deliver new products on time, to cost and performance specifications.</li><li>• View the process itself as a potential source of competitive advantage</li><li>• Integrate all related activities not just engineering</li><li>• To facilitate the identification and solution of any product cost reduction opportunities</li></ul> |
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Several methods for DFM analysis have been proposed. The most well known of these is Design for Assembly [2], developed in the 1980s by Profs. Boothroyd and Dewhurst. An extensive review of the different DFM methods and their associated software tools is reported in [3]. The review observes that the methods vary significantly by approach, scope, and level of sophistication. At one end of the spectrum are

software tools for providing estimates of the approximate manufacturing cost. While, at the other end are sophisticated tools that perform detailed design analyses and offer redesign suggestions.

We find that of the different DFM methods only two have gained acceptance in the product design community: (i) Bootroyd-Dewhurst DFA/DFM, and (ii) SEER-DFM. Both these methods focus primarily on the geometrical features of the parts in the design. Using parametric models, and a library of knowledge bases, these methods estimate the part production and assembly costs. These costs are then used as an indicator of the manufacturability of the proposed design. Key Factors in their DFM analysis are: Assembly time estimate, Part reduction, and Design efficiency calculation

**Pro-DFM is an Efficient Solution for NPD-DFM Integration**

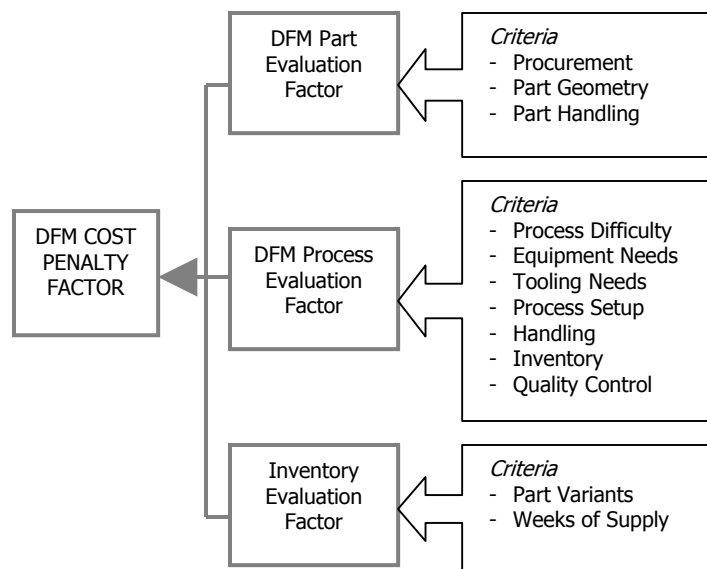
There continues to be a need for an easy to use and portable DFM solution, which can be integrated into the NPD process. An effective NPD DFM analysis requires that the following three sequential events occur in an efficient manner:

1. Capture and deploy all new design and production related data to the NPD team
2. Evaluate, quantify and document the manufacturability of the proposed design
3. Integrate the manufacturability evaluation into cost estimating.

Pro-DFM is a worksheet based tool that facilitates the accomplishment of these three events. The key innovation in Pro-DFM is its ability to provide accurate production cost estimates with little analytical effort. This is accomplished by the use of a parametric cost model which focuses on the primary drivers of cost. The following features distinguish Pro-DFM from traditional approaches:

**Based on User Evaluations** - We find that manufacturability evaluation tend to be very company specific, since plants, workers, and profit margins are very different. This limits the use of knowledge libraries, since they are not able to differentiate between company specifics. Pro-DFM provides a format and scale for the manufacturability evaluation, but it is the NPD team that selects the relevant response. This approach automatically adapts Pro-DFM for each company.

Figure 1. The DFM Cost Penalty Derivation



**A Multi-Factor Model** – The Pro-DFM model analyses three different factors: parts, assembly processes, and inventory. Each of these is independently analyzed and based on multiple criteria as shown in figure 1. We find this approach to be amenable to a most NPD processes, and conducive to integration.

**Scaled Query Evaluation** – Traditional DFM analysis tends to focus on part geometrics and the mechanics of the assembly process. This requires both detailed design data and significant user data. Arguably, these are the most common roadblocks to DFM use. In Pro-DFM the evaluation criteria are presented in the form of simple queries, with an anchored scale response. This facilitates quick

and easy responses with little loss of accuracy. Further, null responses are possible, letting the analysis build-up as more data becomes available. The scaled queries also are easy to interpret by the NPD team, leading to more effective DFM driven design improvements.

**Integrated with NPD Costing** – The results of a DFM analysis are best presented, in conjunction with product cost estimates. This enables the NPD team to evaluate the pros and cons of the results, and identify any design changes. Using a cost roll-up model (figure 2) Pro-DFM seamlessly links the DFM results to the estimated production cost.

Figure 2. The Cost Roll-up Model

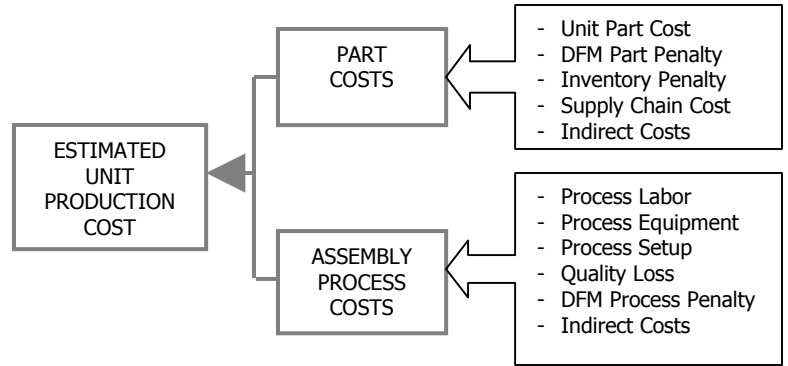


Table 2. Example DFM Sub-Criterion

<p><i>Criteria:</i> Part Handling  <i>Sub-Criteria:</i> Part Feed Automation</p> <p><i>Response Scale:</i> Part feeding into assembly machines will be          (0-2) Automatic on existing equipment          (2-5) Automatic needs new equipment          (4-8) Manual assisted feeding          (5-10) 100% Manual feeding</p>
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### Deriving the DFM Cost Penalty

In Pro-DFM we evaluate and analyze each part and assembly process step for manufacturability. These evaluations are used to derive the three factors shown in figure 1. The factor evaluation is divided into criteria, with each criteria being further divided into sub-criteria. From experience we have limited the number of sub-criteria to 9 for parts and 19 for assembly processes.

Each sub-criterion is formatted as a standard query, with an anchored response score scale (range is 0-10 for no penalty to maximum penalty). The NPD team uses its judgment to select the evaluation score that best represents the specific situation.

Let  $i=1, \dots, N$  be the parts in the assembly, and  $j=1, \dots, M$  the processing steps. Further, let  $k=1, \dots, 9$  and  $p=1, \dots, 19$  be the part and process sub-criteria. Then we introduce the following notation and functions:

- $W_k$   $V_p$  importance weight of a sub-criteria
- $X_{ik}$   $Y_{jp}$  DFM evaluation scores
- $B_i$  Number of part variants (color, etc.)
- $S_i$  Projected weeks of supply per order

*DFM Part Eval Factor ( $DP_i$ )* – Projects the likely additional costs in the processing of this part:

$$DP_i = \sum_k \{W_k X_{ik}\} / 90$$

*DFM Assembly Process Eval Factor ( $DA_j$ )* – Projects the likely additional costs in the execution of this assembly step:

$$DA_j = \sum_p \{V_p Y_{jp}\} / 190$$

By default Pro-DFM sets  $W_k$  and  $V_p$  as 1.0. If the NPD team consensus is that a sub-criterion is less critical to the DFM evaluation, then they may assign it any value in the 0 to 1 range. Note that a 0 value will imply that the sub-criterion has no impact on the DFM analysis. The DFM Eval Factors will take values in the 0 to 1 range and represent the cost penalty assigned to the part or process. For example if a part is expected to cost \$1.50 to purchase and  $DP_i = 0.50$ , then Pro-DFM projects that a more accurate cost estimate is \$ 1.50 (1+0.50) = \$2.25.

*Inventory Eval Factor ( $DV_i$ )* – Projects the likely additional costs for maintaining the needed parts inventory:

$$DV_i = 0.4 * \{(B_i - 1) / 10\} + 0.6 * \{S_i / 52\}$$

In the extreme case where there are more than 10 part variants and over a years supply needs to be inventoried,  $DV_i=1$ , and the part cost is doubled.

### **The Estimated Unit Production (EUP) Cost**

The EUP Cost is what Pro-DFM estimates it will cost to make the new product. This estimate is the most accurate cost derivation and considers all DFM Eval factors plus other factors as shown in figure 2. The calculation of the EUP is as follows:

$$\text{EUP COST} = \{ \text{Direct Part Cost (i)} (DP_i + DV_i + \text{Indirect Rate}) + \text{Inbound Supply Chain} \} + \{ \text{Direct Assembly Cost (i)} (DA_j + \text{Indirect Rate}) + \text{Outbound Supply Chain} \}$$

### **The Pro-DFM Improvement Loop**

In traditional DFM it is often difficult to isolate what changes can be made to improve the manufacturability. One reason for this is that the logic is locked in the knowledge base. Further, the evaluation is not linear, hence

making neighborhood changes may not necessarily result in improvements. From the Pro-DFM manufacturability evaluation “design exceptions” can be identified. The NPD Team can then initiates design and process changes to improve manufacturability and reduce cost.

The worksheet format of Pro-DFM solves this problem completely. The causality of high EUP costs and high DFM Eval factors are immediately evident to the user. Design changes and issues can therefore be quickly isolated and discussed with manufacturing.

### **References**

- [1] J. G. Bralla, *Handbook of Product Design for Manufacturing*, McGraw-Hill Professional; New York, 2<sup>nd</sup> edition (1998)
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- [3] S. Gupta, D. Das, W.C. Regli, and D.S. Nau, "Automated manufacturability analysis: A survey," *Research in Engineering Design*, Vol. 9, No. 3, pp. 168—190, (1997)

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