# METHODS OF INTEGRATING DESIGN AND COST INFORMATION TO ACHIEVE ENHANCED MANUFACTURING COST/PERFORMANCE TRADE-OFFS

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## ABSTRACT

In this paper we address problems which arise when large organizations attempt a tight integration of design and cost while developing complex products. Topics include the sources of cost and design data, the arrangement of the databases, and the interfaces required. We also discuss the management methods required to develop and implement Design/Cost Database Commonality.

## INTRODUCTION

The least expensive way to create a low-cost product is to design low cost into the product initially. This requires knowledge of the product fabrication method and the fabrication costs, in the design stage. Capturing the appropriate cost knowledge in the. design phase is simple for products with only a few parts and a few fabrication steps. However, a modern aircraft with five million unique parts presents an entirely different problem. Recent results by Hoult & Meador [1] show that having *Cost Awareness in Design* can lead to major savings.

The result of capturing the appropriate cost knowledge in the design phase leads to the integration of design and cost. This integration deals with the intersection(s) of cost accounting, engineering design, and manufacturing. *Well, you ask, what do you mean by the intersection of such different areas? It's like comparing apples, oranges and grapes! If that's the problem, we need some very special ways to think about it.* Moreover, if we are talking about such complex things as modern aircraft (and automobiles, and TV sets, and

dishwashers...) the design and development teams involve lots of people, so there must be some very special technical management issues that also arise.

This paper describes the tools, methods, and management processes needed to integrate this design and cost information. The process by which organizations have achieved this goal involves considerable culture change that takes time to accomplish. It also requires new tools that are not yet fully developed. It requires a special vision to recognize how these tools can powerfully augment Integrated Product and Process Development Teams (IPPDT).

This research is based, in part, on results and insights from the Lean Aircraft Initiative at MIT, and from the Lean Enterprise Model (LEM), one of the outputs of that research [2]. In our next section we discuss elements of integrating design and cost in an IPPD & IPPDT. A description of the tools being developed, and the technology issues that arise in their development will also be discussed.

As in many issues that require cultural change, management must be involved in a broad way. But in integrating design and cost, management must also be involved locally. **The Management of Design Cost Integration** deals with the complex trade-offs between local and global management issues that arise in integrating design and cost.

## THE ELEMENTS OF INTEGRATED DESIGN AND COST IN IPPD & IPPDT.

There are four main elements of integration of design and cost, shown schematically in Figure 1.

## Elements of Integrated Design and Cost
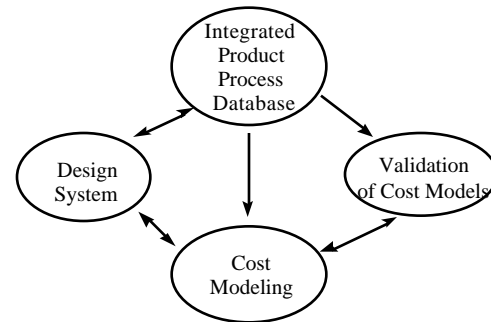


**Figure 1**

First, the integrated database includes product information (designs, parts, and so on), fabrication and assembly processes, and accounting costs. This database is linked to the Design System (CAD), Cost Modeling, and Validation. The methodology of how to create and link such integrated elements is not yet well understood. It is impractical to collect a large complex database in a single unit. Rather, it may involve the creation of a virtual database, using object oriented technology. This involves the assignment of an "object" to the part being designed, the fabrication process, and the costs that arise from the production of the part. It is the "object agent" that makes the link.

The Design System includes the CAD modeling system, and often includes a CAM (computer-aided manufacturing) module inside the CAD system. There are a few commercial tools that link the design system and the cost model. These links involve some novel, and at present, poorly understood problems.

The cost modeling may include traditional, empirical correlation's of costs with design features. Another choice is to use a more rigorous, and faster approach using *Complexity Theory* as proposed by Hoult & Meador [3]. Some cost modeling software, such as that offered by Cognition, includes a shell for a knowledge-based expert system that can warn of poor design decisions. Cognition also offers a tool that links its software to Pro/Engineer, a feature-based CAD system. We discuss later in this document the issues of how CAD systems need to be linked to cost models.

Accuracy of the cost model is one of several issues. Capturing essentially all the detail of a design in the Cost Model is also important. In addition, the ability to predict the relative costs of two closely related designs is very helpful. Typical accuracy for a preliminary cost estimate might be +-30%, but if the relative cost trends are captured, the designer has useful guidance for cost reduction.

The validation of Cost Models extracts data from the database and compares the data with predications of the cost model. There are a number of issues here. The capture of all direct costs is very important. Also the capture of indirect costs is important but is difficult and not always needed.

Clearly, Figure 1 shows a complex and sophisticated information system. The technical management of such a novel system warrants special attention. Some of these management issues will be discussed in a later section. Here, it is worth mentioning that setting up a system such as described in Figure 1 is, even in the most knowledgeable organizations, a task of several years.

To integrate design and cost, the process of developing products must include costs in an orderly way. Costs are best controlled the earlier they are brought into the design phase. Figure 2 shows a GANTT chart of the product development process.
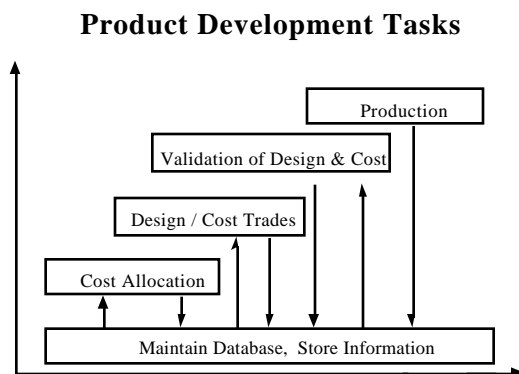
### Product Development Tasks



**Figure 2**

The product is being developed by several IPPD teams, which are formed when the clock in Figure 2 starts running. The tasks shown in Figure 2 focus on the links between design and cost and the important role the database plays in the process.

The first task in provider development concern is cost allocation. Let's assume that all the appropriate information for the particular product being developed is in the database and accessible to the IPPD teams. The cost allocation infers a flow down of the target costs to finer and finer levels of detail until all elements of cost, down to the last nut and bolt, has a target cost. It will be appreciated that this is no small task for a modern aerospace product, such as a Boeing 777 airliner.

The Design/Cost Trades Task is typically time-constrained. This arises because in the development of complex products the IPPD team makes a design decision and immediately begins to realize its consequences. If the cost impact of the design decision are not known immediately, costly rework arises when the consequences of the design decision must be cost-corrected. Thus, it happens that one of the metrics for *Database Commonality* is the time to roll-up cost estimates for the product. In the U.S. aerospace industry, typical roll-up times were months [1], but the best in class rolled up costs daily. In the appliance industry, one leading firm has cost roll-up times measured in minutes instead of hours. In a *Wall Street Journal* article in 1995, a Chrysler representative was quoted as saying that cost roll up time of 24 hours was too slow. Figure 2 shows the feedback to the database of the cost trade-off activity. This feedback loop characterizes one feature of the Lean Enterprise Model: the principle of "smooth flow of information" [4].

When the initial production runs are made, costs are validated so that the cost models shown in Figure 1 remain up to date. The database should contain actual costs and a comparison of the initial cost estimates with the actual costs so that any systematic bias in the cost modeling can be discovered and corrected.

Finally, when the product goes into production the actual costs are recorded in the database and the cost elements of Figure 1 updated for the next product.

With a broad outline of the element of integration and cost, and an idea of how the product development process can integrate design and cost, we now turn to some of the outstanding issues in actually getting it done.

The first issue is **feature mapping** (i.e. the link between design features and manufacturing features). The cost modeler must extract from the design those features made by a specific manufacturing process in order to define a cost for those features. Even with a feature-based CAD system, such as Pro/E, a given feature in the CAD model can be manufactured in a number of different ways. That is, the mapping from design features to manufacturing features is one to many. Each choice for a mapping ideally leads to a different cost estimate. This problem of **feature mapping** is just beginning to be addressed.

However, for a class of products this problem is tractable. The class is characterized by products built from nearly standard components fabricated with a limited number of technologically mature and very well characterized manufacturing processes. In this class are most appliances, and a significant fraction of all automotive components. For these products, the method for dealing with the feature mapping problem has two steps: First limit the domain of the cost model to a limited and well characterized class of parts and a small number of manufacturing processes by which these parts can be made. Second, develop a small number of decision rules or a decision support system to define the mapping.

The second issue is **cost capture**, a simple concept but extraordinarily difficult to implement in some cases. How do you determine what a given part actually costs? Most manufacturing cost accounting systems run on standard costs and variances. The difficulty with such accounting data is that when it is posted to the cost ledger, it is aggregated, and lacks the detail of exactly how much each little feature of the product costs. But the goal of integration of design and cost is precisely to capture and model such detail, so that costs can be reduced continually, by a series of small steps.

There is a second, more complex problem with **cost capture**: the indirect cost issue. In aerospace products, touch labor is less than 10% of the cost of the product. With the large design effort, the non recurring (that is, indirect) costs are a large fraction of the cost of the product. Capturing the indirect costs requires an activity based accounting cost system (ABC), and some way to deal with the **feature mapping** issues as they are reflected in the ABC allocations.

Commercial firms with low overheads have successfully ignored this problem so far.

## THE MANAGEMENT OF DESIGN COST INTEGRATION

The coherent management of design cost integration poses some unique problems. They arise in part from the practical problems of limiting the domain of application of design tools, cost models, and other elements of the database. With domain limitation each IPPD team has the tools and data needed for its tasks, but need not spend effort searching vast amounts of unhelpful data.

Balancing this need for **local** delegation and management is the **global** need for database creation and management. Figure 3 shows these ideas.

More specifically, surveys, interviews and experience have shown that selecting and implementing a CAD tool is a **global** decision. Likewise, the shell for the cost model is a global decision as well. Training clearly falls in the same category.

| Global | Local |
|---|---|
| Cost Model Tools | Model Tailoring |
| Training | Process Validation |
| Data Base Maintainence | |
| Linkages | Model Validation |

**Figure 3**

Let us defer for a moment the **global** issues of database creation and maintenance, and the methods for linking the elements of the database together.

The **local** issues arise from the need to limit the domain of application of the tools and database when they are applied to a specific design project, and the fact that validation is always specific to particular parts and processes, and hence **local**.

The **local** issues require different methods of delegation than do the **global** issues. Virtually all the organizations that we have interviewed that have been successful in integrating design and cost have implicitly or explicitly recognized this distinction.

The database management issues require special discussion. The elements of the database required to integrate design and cost are shown in Figure 4.

## Database Components
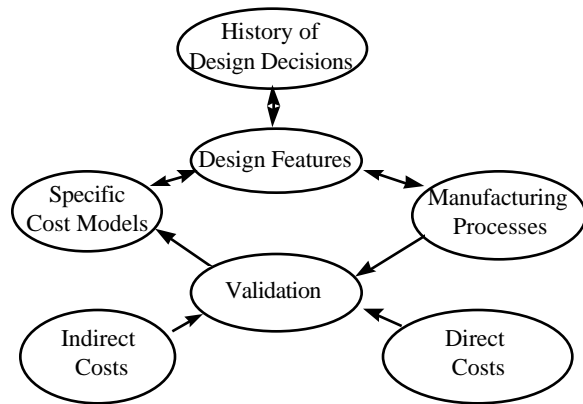
**Figure 4**

At the top of Figure 4 is a little recognized element: the history of design decisions. In the past, this history was, and currently is, carried around in the heads of the designers. In the aerospace industry, with fewer and fewer ongoing development programs, it is likely that the designers with experience are laid off, or working on some other project. We should mention that military weapons systems can have very long lifetimes: for example, the F-16 has been built for 25 years, through some 50 modifications. Contrast this with the shorter cycle in automobiles. Our case study research (see T. Stout [5]) has shown that having a coherent design history can lead to major savings in product life cycle costs.

Currently the design features database is being captured in one overall CAD system, which contains all the mechanical parts of the product. For example, Chrysler and Boeing used CATIA for the Neon and 777 respectively.

From the management perspective, the remaining bubbles in Figure 4 are more challenging. To control the risks in product development, in most commercial industries, the manufacturing processes used in building new products are quite mature. In these cases, the database of manufacturing processes is fairly easy to construct, with its appropriate cost factors.

In advanced military equipment, the manufacturing processes may be quite new, and in those cases, there are major difficulties in quantifying the manufacturing processes, and building their database elements.

The lower bubbles in Figure 4 can be the most difficult, as they involve issues of **feature mapping** and **cost capture** across the different areas of application. The path goes from design history to specific design features to manufacturing processes which fabricates the design features to the cost associated with fabrication.

The methodology to properly construct and link this database is undergoing rapid evolution at present. *Database Commonality* is achieved by building these linkages.

## THE KEYS TO SUCCESSFUL DESIGN COST INTEGRATION

There are world wide trends to shorten the time it takes to develop new products. In the world auto industry, reduction in product development time is becoming a competitive weapon. Times to develop new autos have fallen from 60 months to under 24 months in recent years. Because the design effort is roughly proportional to the time spent, there is a corresponding large cost saving. The faster products are developed, the more important the information architecture which allows the fast and appropriate use of information.

Of these architectures, none is more important than integrating design and cost. Put simply, cheaper products are faster to design and build, and easier to sell, all other things being equal.

But "other things being equal" implies the need for rapid, detailed and accurate design cost trades.

There are four keys to successful integration of design and cost. The first is the management commitment to the **global** and **local** issues described above. In doing this, there must be a recognition that integrating design and cost requires a major **culture change** in many firms. Culture change does not happen quickly, and requires careful planning.

The establishment of *Database Commonality* and the necessary Cost modeling tools, and their links to the elements of the database requires careful planning, so that the issues of **feature mapping** and **cost capture** are consistent with the changing culture.

For the organizations which reach towards the goal of design cost integration, the rewards are great: lower cost products developed faster with less investment.

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2. The Lean Aircraft Initiative is a joint effort between industry, government, and universities. It consists of 29 companies and divisions of companies, spanning the whole of the US aerospace industry, the US Air Force, Army and Navy, and a number of universities, including MIT, Penn State, and Georgia Tech.

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