DFMA and Its Role in the Integrated Product Development Process

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ABSTRACT

Product optimization requires balancing cost, marketability, and time to market. Much of this balance is set during the concept phase of product development since the vast majority of the final product cost is fixed by the completion of this phase. Today's designers and engineers have access to a wide range of tools that can be used throughout the product development process. These tools include competitive research, benchmarking, cost estimation techniques, Quality Function Deployment (QFD), Design for Manufacturing and Assembly (DFMA), and Computer Aided Design tools to name a few. Often, some of these tools are not implemented early enough in the design process, resulting in lost opportunities to optimize the design. This paper will concentrate on the use of benchmarking, visualization, DFMA and cost estimating applied from the concept phase of product development through the end delivery cycle. The first half of the paper will address the four tools in detail. The second half of the paper will illustrate the importance of implementing these techniques collectively from the beginning of the product development cycle through a case study of a recent development of an actual commercial product. The case study represents actual work done on the development of a recently released commercial product. Some specific sensitive information has been modified to protect the client.

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INTRODUCTION

In the late 1970's, America began to see a decline in its dominance as the world leader in the design and manufacture of new products. Goods from Japan in the 60's that had been considered junk were now more in demand. From automobiles to watches to cameras to televisions, the US was losing the product development battle in the market place.

Subsequently, extensive research was undertaken to understand Japan's dominance. From this emerged articles and books describing the tools and techniques that were being used in product development. In the book The Machine That Changed the World[1], US and Japanese automobile manufacturers are compared in order to illustrate the fundamental differences in product development philosophies. The authors found that world class companies need to employ techniques such as strategic development, product development funnels and cross-functional integrated teams to remain ahead of the competition.[2]

Perhaps the most effective paradigm that occurred has been the shift from the 'over-the-wall' philosophy (where the development process is serial) to today's philosophy of concurrent design. This compression of schedules and resultant concurrent efforts have even further elevated the importance of the concept phase. At this stage, only a small amount of design funds have been spent but this beginning design has already locked in nearly seventy to ninety-five percent of its total life cycle cost [3].

Strategic development, product development funnels and cross-functional integrated teams are 'strategic' or 'corporate-level' techniques and have been well researched and documented. This paper will focus on the 'hands-on' level of product development by examining the use of four specific techniques from which all development programs would benefit, namely product benchmarking, product visualization, cost estimating and Design for Manufacturing and Assembly (DFMA). Many companies already employ some or all of these techniques but often do not implement all of them at the concept stage of product design and development nor continue their use throughout the entire project. Product life cycle costs can be minimized if these techniques are implemented very early in the program, i.e. the concept phase. All members of the product development team, including the customer (including marketing), design and engineering and manufacturing can benefit from the use of these techniques as described in figure 1.

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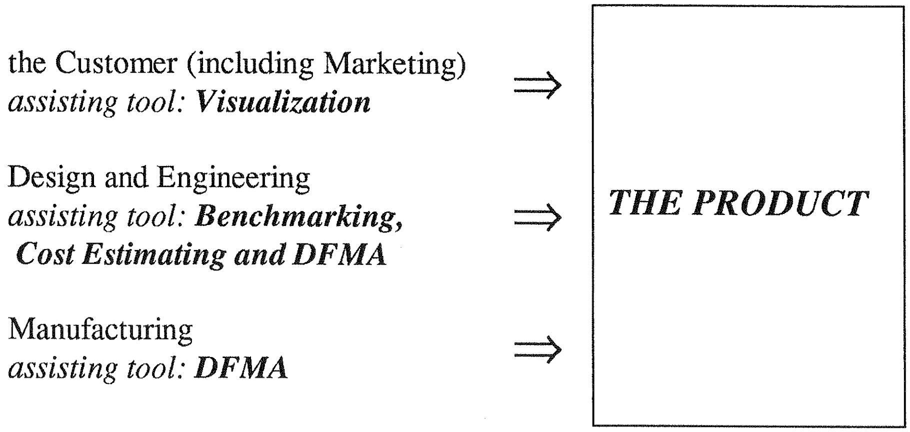
[1] James P. Womack, Daniel T. Jones and Daniel Roos, The Machine That Changed the World: The Story of Lean Production (New York: Harper Perennial, 1990).

[2] Steven C. Wheelwright Kim B. Clark, Revolutionizing Product Development: Quantum Leaps in Speed, Efficiency and Quality, (New York: The Free Press, 1991).

[3] R.J. Symon and K.J. Dangerfield, "The Application of Design to Cost at Rolls- Royce", Rolls-Royce Limited, Aero Division, Bristol UK



The product development team with their most helpful tools
figure 1

BENCHMARKING

"Know your enemy and know yourself; in a hundred battles you will never be in peril."[4] This was sound advice in 500 BC that still rings true today. In 1979, Xerox wanted to understand, "how in the world could the Japanese manufacture [a copier] in Japan, ship it over to the United States, land it, sell it to a distributor who sells it to a dealer who marks up the cost to the final customer, and the price the final customer pays is [still] about what it would cost [Xerox] to build the machine in the first place."[5] Benchmarking enabled Xerox to answer these questions and to design, build, manufacture and market a competitive copier.

One can not design in a vacuum; the 'goodness' of a product is almost always (except in the case of a novel design) measured with respect to an existing design. It is logical, therefore, to have a design process that takes competitors' products into account. Competitors' hardware is a rich source of design information providing concept and design solutions, current market trends, cost and quality drivers, and missing or unwanted functionality.

Benchmarking, as defined by Webster's dictionary, is "a standard or point of reference in measuring or judging quality, value, etc." Within the context of companies and their products, Xerox defined benchmarking as "the continuous process of measuring products, services, and practice, against the toughest competitors or those recognized as industry leaders."[6] However, this is not to say that benchmarking is copying the competition; benchmarking provides knowledge that aids the design process.

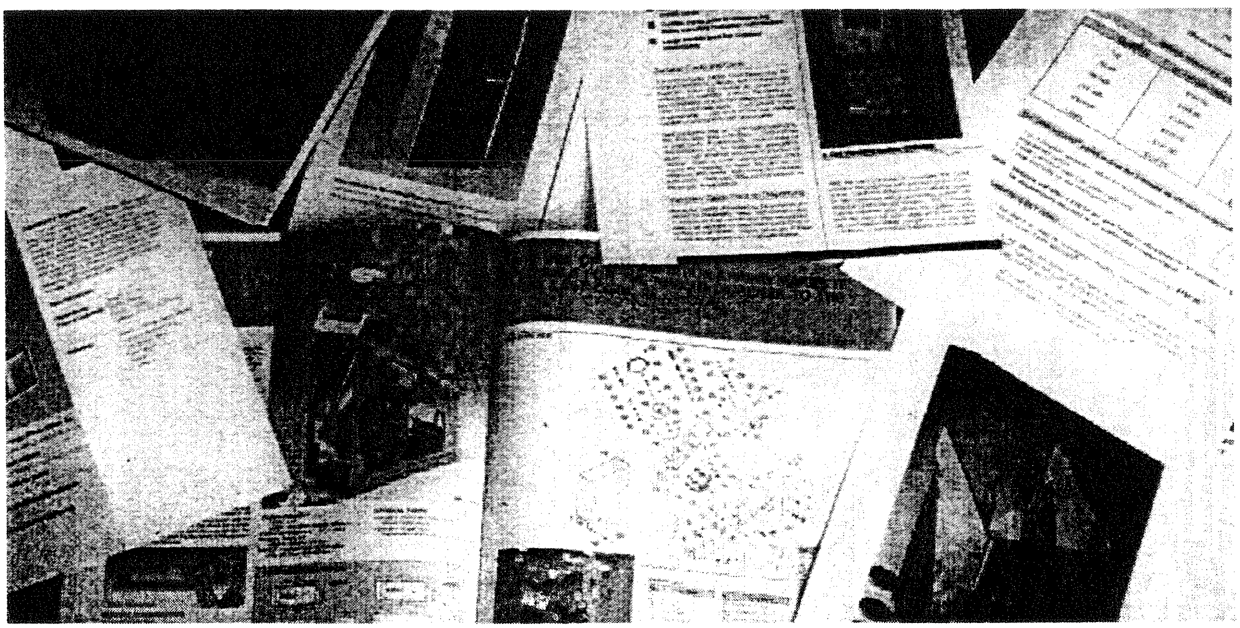
Meeker and Thornton presented a methodology to systematically evaluate existing designs using a process called "product benchmarking" and discussed how to incorporate the benchmark

[4] S. Tzu, translated by T. Clery, The Art of War, Shambhala, 1988.
[5] G. Jacobson and J. Hillkirk, Xerox: The American Samurai, (New York: Collier Books, 1986).
[6] R.C. Camp, Benchmarking: The Search for Industries Best Practices that Lead to Superior Performance, (Milwaukee: Quality Press, 1989).

information into the current specification, concept, embodiment and detail design phases.[7] Unfortunately, many companies still suffer from the 'not invented here' (or NIH) syndrome and refuse to use this rich source of information. Some design groups believe that if a design is not done in house it is not worth considering. However, the NIH syndrome conflicts with common sense; as Thomas Edison once replied to praise about being a genius, "Actually, I'm a good sponge, I absorb ideas and put them to use. Most of my ideas first belonged to people who didn't bother to use them." [8]

Benchmarking can provide information about product markets as well as products. By searching various electronic databases, including those with Internet-access, and standard industrial references one can learn about a product's market. Searches can result in a list of companies that make products that roughly fit any descriptive word or phrase. These companies can subsequently be called and solicited for catalogs and technical as well as price information. Although several databases are available, one of the most helpful is Dialog.[9]

In addition to database searches, perhaps the most effective method of learning about the products themselves is to collect the competition's product brochures (see figure 2). Many times, this is the only way of determining whether the product or company is a valid competitor. Brochures may also provide some useful information, ranging from marketing data to part count.



Competitors' catalogues can be particularly useful for benchmarking
figure 2

[7] David Meeker and Anna Thorton, "Benchmarking Within the Product Development Process", 1995 ASME Design Conference.

[8] G. Jacobson and J. Hillkirk, Xerox: The American Samurai, (New York: Collier Books, 1986), pp. 233-234.

[9] Dialog is the world's largest on-line information research service with over 450 on-line databases. Dialog contains information from millions of documents including liturature from the scientific, technical, medical, and government fields, and many more, including full-text access to many newspapers world-wide.

VISUALIZATION

The latest buzz word 'concurrent engineering' is nothing more than the realization that serial design results in serial mistakes. By considering as much input as possible from the entire team as early as possible, drastic reductions in overall development time as well as reductions in the number of redesigns can be realized. The 'team' typically consists of marketing, management, engineering, manufacturing (including suppliers), distribution -- and don't forget the most important member: the customer. The trouble is that the team members consist of people from a vast range of backgrounds, technical understanding and ability to comprehend not-yet-fully developed products. A major hurdle for today's companies is to ensure that each member understands the product throughout the product development process to the best of his/her ability so that the key decisions that drive 60-80% of the overall costs are made based upon the best information available at conception.

The universal language that allows for most team members to fully understand even an early concept under consideration is the one of visualization, that is, the art of presenting an idea visually for evaluation for both technical and perception reasons. A key component of product visualization is speed -- if the team has to wait, they won't! They will make their own assumptions and decisions which is what we are trying to avoid. The notion of rapid visualization techniques is thus introduced.

Two fundamental options exist for addressing early product visualization: still images (both computer generated as well as hand sketches) and physical models. A third option, virtual reality, which allows for a truly 'real-world' experience is just beginning to become more of a force in today's design world but will be only briefly discussed.

COMPUTER GENERATED STILL IMAGES

The 2D CAD systems of the past have given way to today's solid modelers that represents both a more thorough design tool for the engineer as well as a 'free' visualization tool for the rest of the team. These tools have allowed for both technical and non-technical team members to better understand the design intent earlier in the design process, resulting in earlier feedback to the design engineer. Only the 'big boys' could afford to commit to these 3D CAD systems just a few years ago. Today, 'low-cost' 3D solid (or surface) modelers are available in the $3,000 - $6,000 range (including Pentium-based hardware) from AutoCAD, CADKEY and others. Higher end systems allow for more general geometries plus add-ons such as sheet metal unfolding, finite element modeling (FEM), etc. These systems can run in the $30,000 - $60,000 range (including workstation-based hardware) and include suppliers such as ProEngineer, SDRC, Computervision, Unigraphics and others.

Only a few of these 3D systems are able to deliver photographic or semi-photographic output. Most of the time, the more typical less detailed output is sufficient to portray the idea. Often, however, early customer feedback via consumer testing is required and using these less detailed images can skew the data. High-end visualization or rendering software, such as Alias, used to generate the images for the movies 'Waterworld' and 'Toy Story', can truly mimic reality in moving or still images. Lower priced systems, such as those available from Autodesk, can also bring reality to a design.[10]

Still, images can only excite one of the five senses that a person uses to 'experience' a product. Physical models address this issue.

SKETCHES AND MODELS

Computer generated images are extremely effective once a database exists from with which to work. Early in the concept phase, however, fundamental design directions are amorphous enough to be impossible to quickly represent in a computer model. Industrial designers are masters of visually describing a product long before it becomes reality. By first using rough sketches to illustrate the core of the variety of ideas, then more detailed sketches that include additional detail, then even more detailed renderings, a fundamental architecture or concept can be considered by people with a wide range of backgrounds. These images can be made quickly and require only a vague notion of the internal architecture - enough to ensure its viability as a concept. For cost sensitive products, these sketches may also have sufficient detail for cost estimation using the parametric method as described later. Often, it is the commitment to the generation of a number of 'off-the-wall' concepts very early on in the program that often results in a truly innovative product. These 'off-the-wall' notions are usually the result of brainstorming, where the 'rules' are temporarily left outside the room to allow for drastically different ideas resulting from completely free, open and creative minds. Only after the brainstormed ideas are generated are the rules gradually allowed to be reapplied so that the idea may be synthesized into a feasible solution.

These sketches usually can result in the narrowing down of the total number of concepts to a few whereupon more detailed sketches and rough models can be generated. These models allow for the earliest 3D representations of the concept which can result in feedback from potential customers to production fabrication suppliers.

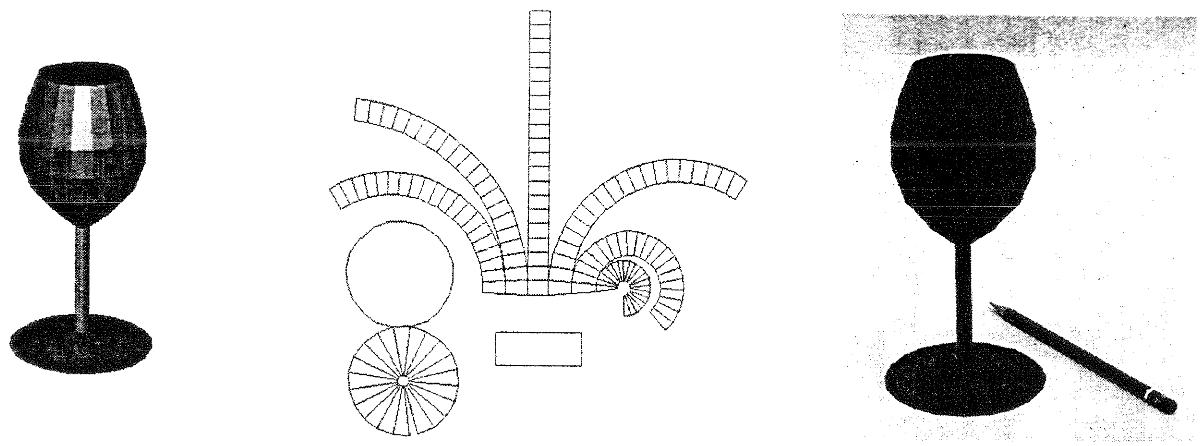
As an aside, fabrication of rough models can also serve as a great aid to the selection of a system architecture for more complicated products. Often, a system can be too complicated to be comprehensible for description on paper. With sufficient technical support, motor drive trains, inspection cameras, cooling systems and the like can be modeled so that the most technically sophisticated machines and products can be made more readily understandable.

Many times, these rough models are sufficient to select the one or two best concepts for a product. At this point, along with a moderate amount of detailed design engineering, the outer shell of the product can be defined to a point where there is a high degree of confidence that it will not change by an appreciable amount. Now, a more detailed foam or wood model can be fabricated and finished to look very similar to the final until. This model can serve as a vehicle for customer feedback, early advertising and production supplier input.

One example of a new generation of rapid product realization tools can be found at MIT. Benjamin Linder has created a computer based method for constructing three-dimensional

[10] Barbara Schmitz, "Designing With Direction", *Machine Design*, 66(14), pp. 14s-21s, July 25, 1994.

surfaces from sheet material.[11] The primary motivation behind his work was to provide mechanical designers, architects, mathematicians and teachers easy access to physical models of their three dimensional shapes. Having a 3D representation of the design object in question enables the design team members to more effectively carry out the tasks of visualization, evaluation and communication. Linder's method is not intended to supersede any of the rapid prototyping methods in existence but to offer another tool for the designer to use. The advantages of this method include its low cost, its relatively low skill requirement, its ability to model arbitrary shapes and sizes (larger than a minimum level of detail) and its ability to accommodate a wide range of sheet materials (such as paper, plexiglas, and sheetmetal). To better understand Linder's method, consider the model of a wine glass (see figure 3). By cutting out these shapes and folding and pasting at the lines, the wine glass can be created in 3D form. This example is paper, but the same glass could be reproduced with foam core or sheet plastic.



3D CAD model, computer generated flat pattern and final photo of wine glass
(copyrighted; used with permission by Benjamin Linder)
figure 3

The visualization techniques that have been described up to this point have been exclusively for the purpose of improving understanding of the design, such as technical and 'user experience' issues. These 'models' can also be made to bridge the gap between concept and prototype. By including partial or entire subassemblies that may be made partially or entirely functional, more technical features, such as functionality, accessibility and robustness, may be tested. These models can be made using the wide range of rapid prototyping techniques that are available today, such as stereolithography (SLA) or computer numerically controlled (CNC) machining direct from a CAD database. The difficult part here is determining when a component or sub-assembly is 'ready' for modeling. Typically, engineers do not want to build anything until the design is mostly complete, however, valuable data is often found by building the design in process.

<u>VIRTUAL REALITY</u>

Product developers are also beginning to use virtual reality (VR) in the early stages of the product development process. McDonnell Douglas has used VR in the design of an F-18 engine housing

[11] Benjamin M. Linder, "A Computer-Based Method for Constructing Three-Dimensional Surfaces From Sheet Material", Masters Thesis, May 1993. Mr. Linder can be reached at blinder@mit.edu.

and Matsushita Electric Works Ltd. has been using VR since 1991 to help in the layout of their kitchen appliances [12]. VR is the ultimate in bringing the customer into the design process. Unfortunately, its cost today is still prohibitive for most companies.

DESIGN FOR MANUFACTURING AND ASSEMBLY

Design for Manufacturing and Assembly (DFMA) has its roots in work that was started at the University of Massachusetts funded by the then-National Science Foundation (NSF) in 1977. DFMA has evolved over time to become a philosophy of optimizing the total product from the standpoint of assembly, part design and total life cycle cost. DFMA is a well-established technique for accomplishing significant improvements of products through the application of a set of generic guidelines:

- Minimize part count
- Encourage modular design
- Design for top-down assembly
- Minimize separate fasteners
- Specify standard parts
- Facilitate parts handling
- Minimize reorientation at assembly
- Minimize cables
- Minimize final adjustments after assembly
- Use self fastening parts
- Use self-locating parts
- Accommodate process/part variation

By implementing DFMA in the concept phase, significant cost reductions can be realized since again, 60-80% of the products cost will be fixed in this phase. These rules simplify the product through the reduction in the number of parts. The vast majority of products can easily be further simplified. A recent paper surveyed 43 published DFMA case studies and showed the number of parts in products can be reduced 51%, on average.[13] The impact of the part count reduction is found throughout the entire product development process. Afterall, the best part is no part at all -- non-existent parts do not require designing, procuring, manufacturing, inspecting, assembly, testing, or servicing![14]

DFMA provides a theoretical minimum part count for a product by answering several simple questions about any part considered in the design:

1. Does the part move?
2. Does it need to be made from a different material?

[12] Victor D. Chase, "In Virtual Reality, Customers Help Product Design", *Appliance Manufacturer*, 43(5) p. 14, May 1995.

[13] Geoffrey Boothroyd, "Product Design For Manufacture and Assembly", 1994 Design for Manufacturing and Assembly Conference, Newport, R.I.

[14] Otis Port, "Best Engineered Part is No Part at All", *Business Week*, May 8,1989, p 150.

3. Does it have to be separate for assembly, service, or disassembly reasons?

If the answer to each of these questions is 'no', then the part can, and should, probably be eliminated.

A complete DFMA analysis on a product yields other important information as well, such as assembly times, part counts, structured bill of materials (BOM), build sequence, and list of manufacturing operations. DFMA allows for an "apples vs. apples" comparison of the various products. Thus, it is an ideal tool for comparing competing designs during the concept phase. Also, by analyzing the results, a best-in-class product specification can be created. The DFMA analysis is then maintained from the first concept of the new product through completion, enabling trade-offs to be made between different materials, processes and design concepts before project dollars are committed.

COST ESTIMATING

In a landmark paper[15], Toshiro Hiromoto wrote about the notion of cost targeting, which he referred to as the 'hidden edge' as to why the Japanese were out-performing their US counterparts at the time. Cost targeting was strikingly different from standard practice in the US and Europe. Says Steven Hronec, head of Arthur Andersen & Co.'s manufacturing practice: "US companies design a product by throwing it over the wall from one department to another -- from engineering, to marketing, and so on. At the end of the design phase, after something like 85% of the product's costs have been built in, the specifications are given to the accountants, who tell you what the product will cost. They will tell you based on labor rates, material prices, and prevailing manufacturing standards." Slighted is the vision of what a product should cost, which would motivate and assist the engineers designing it. US accountants, Hronec says, "mainly just add up the pieces."[16]

Not only has the role of Japanese cost management practices been overlooked but, they are indeed a critical part of Japan's success story. Many readers might be tempted to say, "So what? Look at Japan now--the success was short-lived. But, it would be a dangerous mistake to ignore the important lessons about strategic cost management that we can learn from Japanese firms, simply because their economy is currently undergoing major readjustments."[17]

In essence, the Japanese system of target costing is illustrated in figure 4 and can be described as follows. Target costing is the discipline that ensures that new products are profitable when they are launched. There are two major steps in target costing. The first is to determine a product's target price and target margin so that its target cost can be determined. The second is to decompose that target cost down to the component and raw material level so that the purchase prices of those items can be determined. A product's target cost is determined by subtracting its

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[15] Toshiro Hiromoto, Hitotsubashi University, "Another Hidden Edge - Japanese Management Accounting", *Harvard Business Review*, July-August 1988, p.22.

[16] "Japan's Smart Secret Weapon; It's a Unique Cost-Management System", *Fortune*, 124 (4) August 12, 1991, p. 72.

[17] Robin Cooper, "Japanese Cost Management Practices", *CMA Magazine*, 68(8), October 1994, pp.20-25.

target profit margin from its target selling price. That is: target cost equals target price less target margin.

U.S.

Market Research
⇓
Product characteristics
⇓
Design
⇓
Engineering
⇓
Supplier Pricing
⇓
COST
(If cost is too high, return to design phase)
⇓
MANUFACTURING
⇓
Periodic Cost Reduction

JAPAN

Market Research
⇓
Product characteristics
⇓
Planned selling price less desired profit
⇓
TARGET COST
⇓ ⇓ ⇓
Design | Engr'g | Supplier Pricing
(Target costs for each component force marketers, designers and engineers from all departments and suppliers to struggle and negotiate tradeoffs)
⇓
MANUFACTURING
⇓
Continuous Cost Reduction

The target cost is the key, and it is based on the price that is most likely to appeal to buyers minus the desired profit. "Cost engineers" make sure the product meets that target.

Western companies more often design the product, calculate the cost and then try to figure out whether it will sell.

Target Costing: How the Japanese keep costs low [18]
figure 4

The target price of a new product is determined primarily from market analysis. The target margin is set based upon corporate profit expectations, historical results, competitive analysis, and, occasionally, computer simulations. This target cost is calculated during the concept phase of product development.

The people responsible for projecting and measuring product costs are not accountants with no feel for the product, as in the US, but typically engineers -- cost engineers, as they are known at many companies. These specialists have often rotated through several departments, including purchasing, design, and sometimes even sales, before taking on a cost-planning job. The payoff is a broad perspective that gives them the ability to spot ways to reduce costs early in the concept

[18] "Japan's Smart Secret Weapon; It's a Unique Cost-Management System", *Fortune*, 124 (4) August 12, 1991, p. 72.

phase. Although the goal is for each product to meet its target cost, sometimes lower margin products may be developed.

What matters for many Japanese companies is not the apparent profit an individual product can earn but the profitability of portfolios of related products. Margins depend on where a product is in its life cycle or the role it plays for a line of products. Says Kevin Jones, a longtime McKinsey consultant in Tokyo: "What you often find at Japanese companies is the attitude, 'We're in this business to win. If we believe it makes competitive sense to carry Product X, we will carry it. We will try our damnedest to make it profitable, but whether or not a product is profitable is not the nub of whether we'll be able to win in the overall business.' "

For example, two years ago Sony's product-development gurus thought they saw a way to expand the market for personal stereo component systems. Sony believed that an even smaller version of the so-called Pixy would play well among a slightly older audience of consumers. Akira Kubota, general manager for audio products, says the forecast for the new product was not exactly inspiring. But "we decided to take a chance, because we knew we could cover the product with higher-margin products in the same group." To Sony's surprise, the smaller version was an immediate hit -- with the younger crowd that had been buying the larger version all along. The new product became the industry standard and helped Sony enlarge its share of this market by 50%. Had Sony based its decision on the product's expected "stand-alone" profitability, as many US companies currently do, it would never have been launched.[19]

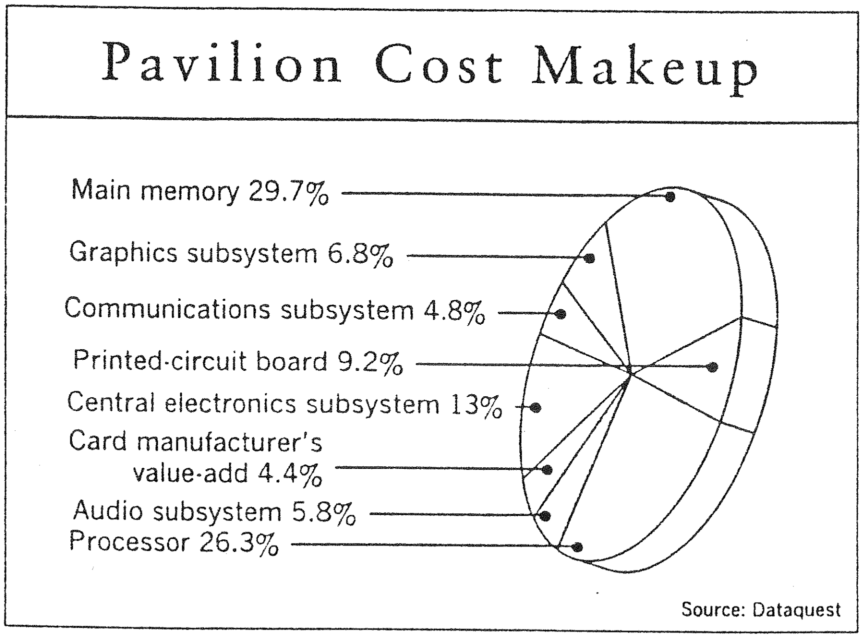
DFMA analysis tools such as Boothroyd and Dewhurst's DFM modules augmented with internally generated data and data from industry sources such as the Bureau of Labor Statistics or manufacturers trade associations can result in reasonably accurate estimates for fabricated parts costs.

There are three levels of cost estimating which can be the basis of a cost estimation effort:

> **Level 1 -- Parametric Method.** An estimate is created from the first impression of a knowledgeable engineer of what a part, assembly or system would cost based on prior experience.
>
> **Level 2 -- Analogy Method.** An estimate is based on prior experience with similar products, budgetary estimates, supplier quotes, or expert opinion and experience.
>
> **Level 3 -- Engineering Method.** An estimate is calculated for every part, using material cost estimation data bases, and time/motion studies. A high degree of accuracy is achieved by comparisons to industry standards and vendor quotes.

The costs resulting from this cost estimation effort can be easily tabulated and used for comparison by major sub-assemblies. As an example, figure 5 shows the cost breakdown of HP's Pentium-based PC known as the Pavilion, resulting from a teardown of the product by Dataquest.

[19] Japan's Smart Secret Weapon; It's a Unique Cost-Management System, Fortune, v124 n4 Aug 12, 1991 p72



Cost estimation of HP's Pavilion PC[20]
figure 5

This information is very useful in helping to set the target goals for the next generation product as well as a source for learning about new design strategies and techniques.

[20] Allen Leibovitch, "Pavilion puts HP into the home", *OEM Magazine*, March [illegible], p. 84.

CASE STUDY

The product under development was an automated coin changer. The company was already in one of the segments of this somewhat segmented market but wished to develop a next-generation machine.

BENCHMARKING

A search of various electronic databases and standard industrial references was used to learn about the automated coin changer market. This search resulted in a list of companies that made products that roughly fit the descriptive words used of coin changers, coin chutes and coin slides. These companies were called and catalogs and technical as well as price information were solicited. In addition, a brief patent search was conducted to check for any possible patent issues. Although several databases were used, the most helpful was Dialog. Further checking yielded secondary information about some of the companies that were being researched.

An example of product information that was found as a result of the search follows.

> HIGH-SPEED CURRENCY DISPENSER FROM BRANDT REDUCES TRANSACTION TIMES
> News Release April 14, 1989 p. 1
> A high speed, two denomination currency dispenser from Brandt Inc. dramatically reduces operator change-making time and results in lower labor cost per sales dollar in fast food and retail operations. The compact Model 8902 currency dispenser, designed for front counter, drive-through and express lane applications, eliminates change counting responsibility, reduces cash drawer shortages, improves cleanliness and improves security. A patented counting and document inspection system ensures accurate dispensing and handles new and worn bills without operator adjustments. The Model 8902 features a locked top cover for better security control and an exclusive document inspection system that detects doubles and chain notes.

An example of one of the pertinent patents that were found as a result of the search follows (only the related abstract is included for brevity).

> COLLECTOR ASSEMBLY FOR COIN HANDLING MACHINE
> PATENT NO.: 5,443,419
> ISSUED: August 22, 1995 (19950822)
> ASSIGNEE(s): Brandt, Inc, (A U.S. Company or Corporation), Watertown, WI
> (Wisconsin), US (United States of America)
> [Assignee Code(s): 24849]
> ABSTRACT
> A coin handling machine such as a coin sorter has a plurality of collectors in the form of drawers or chutes arranged in a circular array and each adapted to receive coins of a particular denomination through its open top. A switch and switch actuator plate are mounted in the center of the array. A spring-loaded pivot lever extends radially from the plate to each collector location. The plate is normally held in a neutral position but will be moved to actuate the switch when any one of the levers is released. The levers are normally held against release by the presence of a collector at each station. Actuation of the switch will disable the operation of the machine. The machine may be mounted on a platform of a stand to which bagging spouts are removably attached beneath the chutes. The spouts are incapable of removal when the machine is in place on the platform.

Gathering information from a database search often requires common sense and screening since keywords will yield results that fit the search parameters but are not relevant as shown in the case of the citation below. The keywords used in the search were *'change making machines'*.

> Title: It's back

Authors: Rutledge, John
Journal: Forbes [FBR] ISSN: 0015-6914
Vol: 154 Iss: 12 Date: Nov 21, 1994 p: 50

Abstract: Reflecting the biases of macroeconomics, government economic reports are largely designed as yardsticks of current economic activity. When outside forces make some types of assets owned by US investors more attractive than others, investors' reactions can unleash tidal waves of **change, making** or destroying fortunes. As inflation rises or falls it can cause seismic changes in the relative profitability of asset groups. Within 2 years, either inflation will spread into the labor market, portending lower profits and higher interest rates, or inflation will be subdued, in which case commodity prices and profits will be lower. In either case, profits will suffer.

Below is a list of companies that make coin and or currency processing machines, resulting from a Dialog database search:

Asahi Seiko	Danyl	Nitsuko American
Brandt	HR Electronics	Protel
Bellatrix Systems	Magner	Standard Change Maker
Brandt	Mars Electronics Int'l	Technitrol
Coin Controls	Monarch	Telequip
Creative Technology	NCR	Validata Computer And Research

<u>Resultant Overview of the Coin Changer Market Place</u>

[21]

It is estimated that Americans spent $28 billion in vending machines in 1994.[22] All this money, whether it be pin ball machines, food machines, US Postal machines, change machines, or toll booths, was processed by some sort of currency machine. The industry consists of several segments described by function: accepting (such as vending machines), sorting, counting and dispensing of currency, including coins, tokens and bills. The retail market is similar to the banking market in that many different coin types are dispensed, while the vending market typically only requires dispensing of one or two types of coins. The market appears to consist of a lot of small niche suppliers within each of the segments.

The case study that follows is a product in the coin changer market, which includes machines that can be found in banks, fastfood restaurants and supermarkets. In these environments, cash registers are coupled with a machine that returns change to the customer automatically, resulting in higher accuracy, reduced transaction time, higher security and frees up the teller for other tasks.

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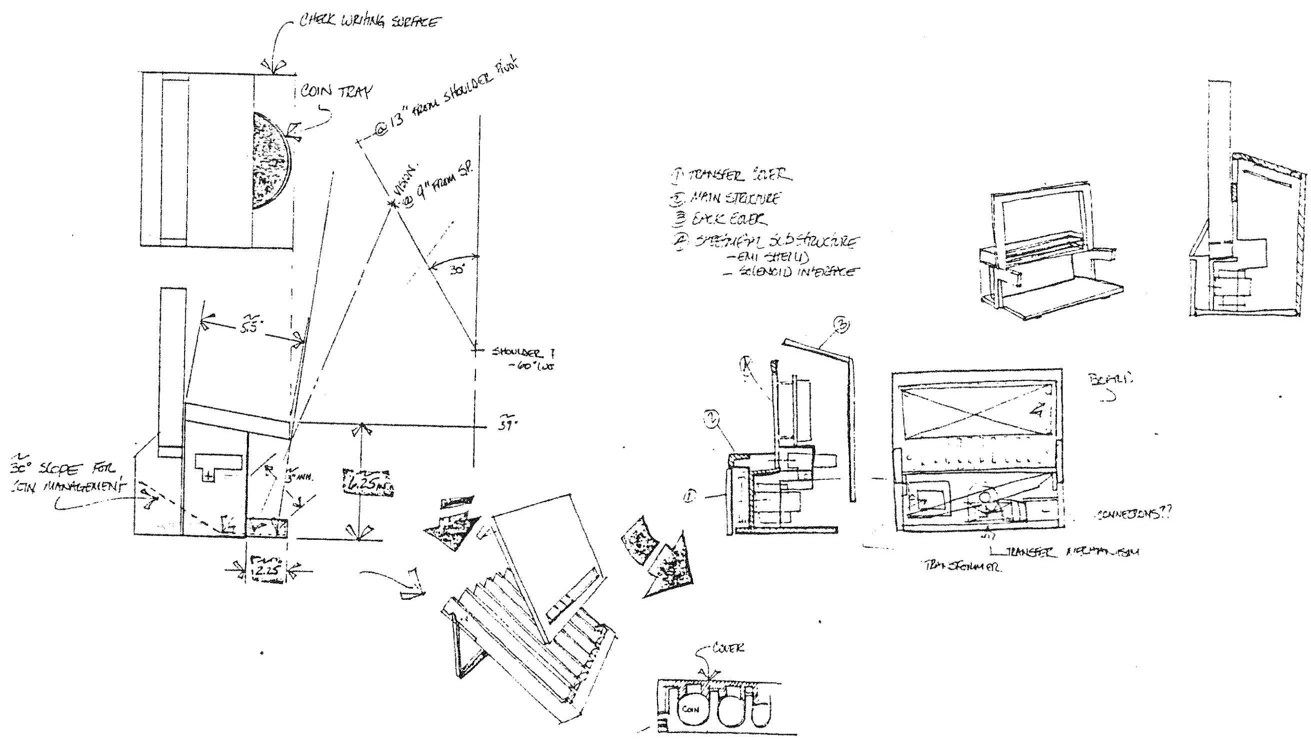
[21] Scott Adams, <u>Dilbert</u>, Boston Globe, April 9, 1996
[22] <u>Change Converter is Rolling in Busi[illegible] Companys Role is Easing Headache of Cashing in Coins</u> Indianapolis Star (IN) Febru[illegible] 1995 p. B7

The major players in this market include NCR, Brandt and Telequip. The strategy for the design of the next-generation coin changer included three key criteria: 1) cost reduction, 2) upgrade of aesthetics and ease of use and 3) addition of features.

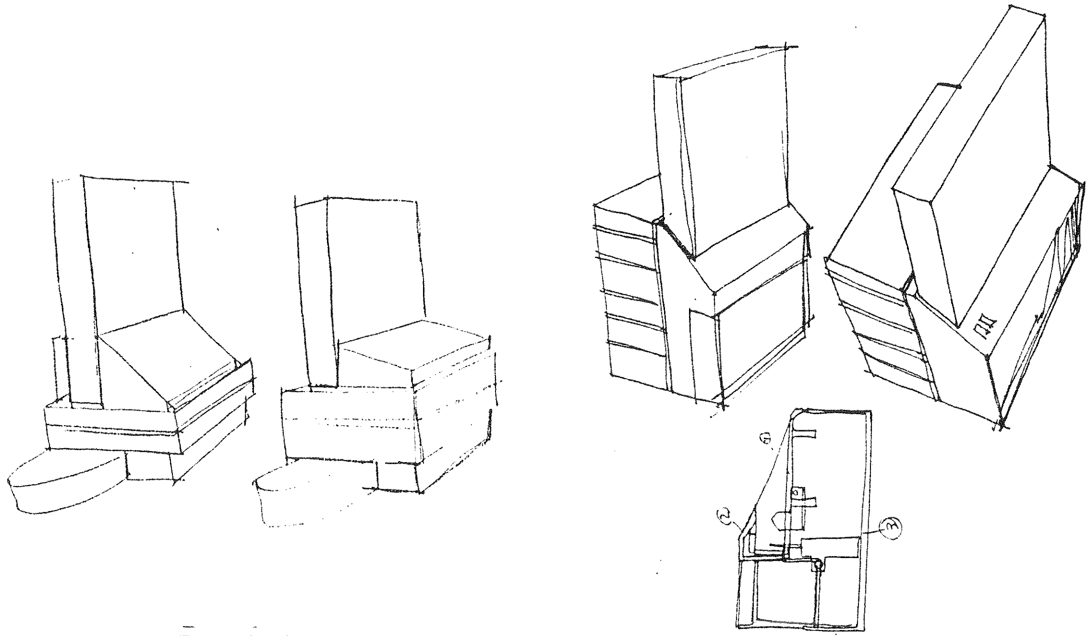
VISUALIZATION

The concept phase of the program began with research of how and where the product was to be used. Concurrent to this effort was the research and brainstorming of how to design the specific subassemblies at a lower cost with respect to the current product. The benchmarking analysis resulted in the realization that the major opportunities for cost optimization lay in the coin canister and ejector system. System architecture sketches and preliminary layouts were generated to portray the concepts in a form that was understandable by the entire team. Figure 6 illustrates the level of rough sketching that was done to portray key concepts.



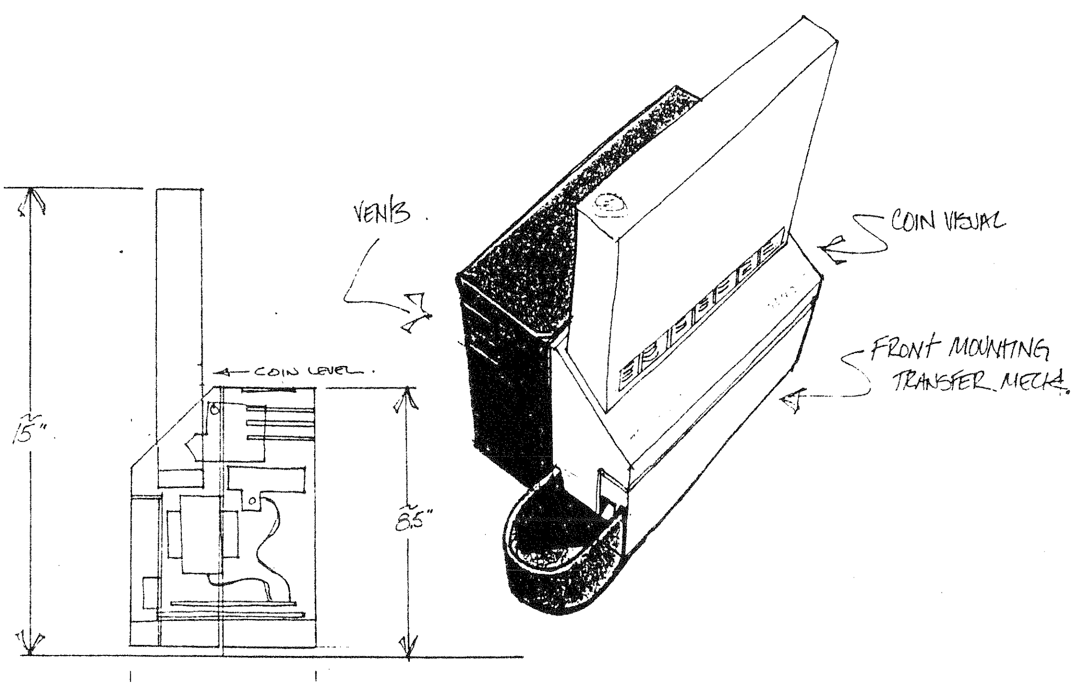
Rough sketches illustrating very early-on coin changer concepts
figure 6

These sketches were adequate to make key strategic decisions, thereby reducing the number of possible concepts requiring additional refinement. The few remaining concepts were then refined in sketch form with additional detail that addressed the next level of concerns by the team. It is at this level where the 'look' and 'feel' of the evolving product can first be portrayed in the form of rough sketches with different 'styles' (see figure 7).



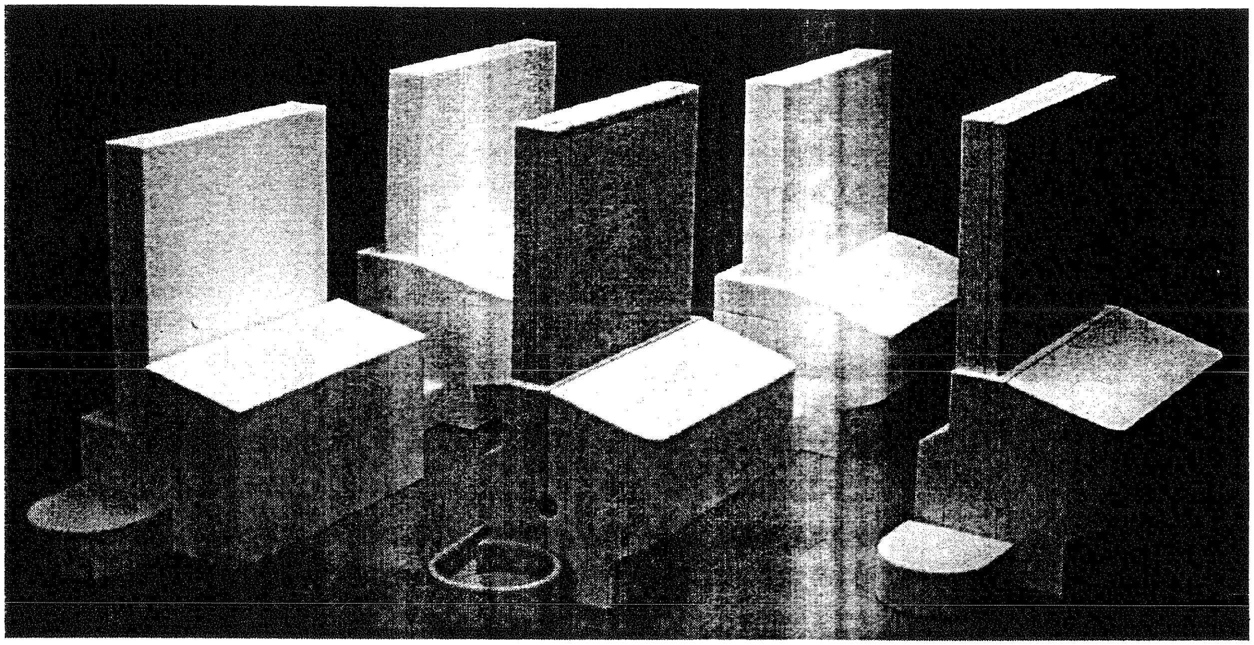
Rough sketches of coin changer concept with next level of detail
figure 7

The remaining concepts were further reduced by the team into just a few fundamental directions with differing styles where still more detail would be required to decide on the ultimate concept. The engineering issues were addressed using sketches as well as structural and cost analyses, while the aesthetic designs were addressed by the generation of renderings of the remaining concepts, one of which is shown in figure 8. These renderings were the first colored images that portrayed the design intent and were generated in rough as well as fine detail.



Rendering of coin changer concept
figure 8

At this point in time, the design was pretty much fixed. Only the details had to be refined to pronounce the concept phase 'complete'. Rough 3D models were fabricated which allowed for the feedback from non-technical personnel, such as potential customers of the concepts (see white models in figure 9). From this feedback, the design was even further refined and a more detailed appearance model (including color and graphics) was fabricated as can be seen in the foreground of figure 9. This model served as a 'buy-off' of the design whereupon detailed internal engineering (via CAD) was could begin.

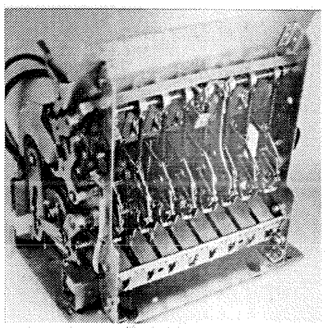


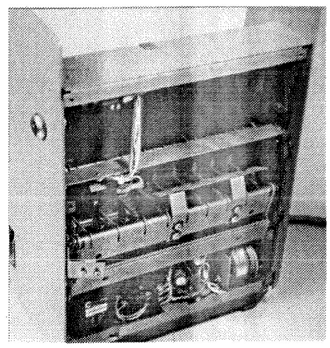
Rough models (left, right and background) with final appearance model (middle) of coin changer concept
figure 9

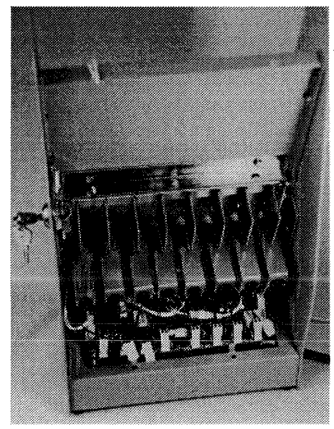
DFMA

Early on in the concept phase, a DFMA analysis was performed on several coin changers to better understand their part count, BOM structure, and their minimum part count potential.

Three analyses are shown of some of the competitive designs as well as the current model under evaluation. Figure 10 shows a comparison of the overall units (exclusive of covers).



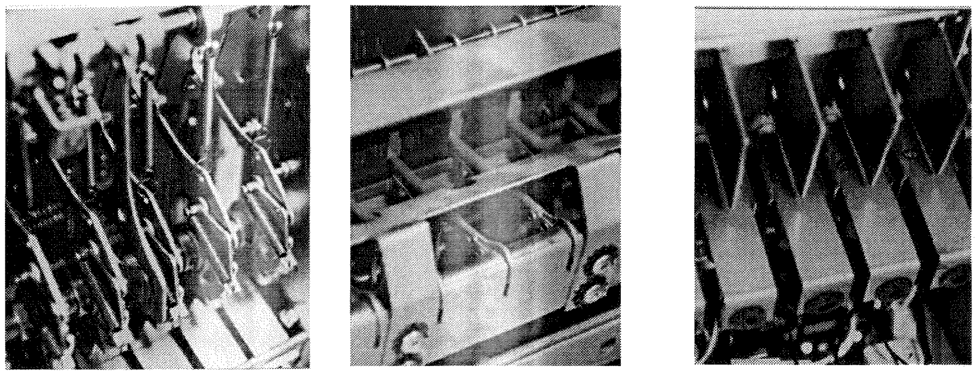




criteria	product A	product B	product C
Number of parts (excluding fasteners)	160	180	80
Number of separate fasteners	60	70	60
Number of discrete electrical interconnects	30	72	20

Parts count comparison of competitive coin handlers
figure 10

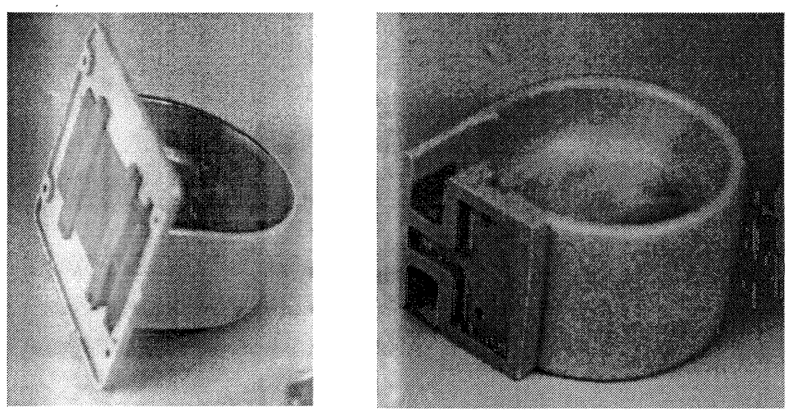
Figure 11 shows the relative complexity of the 'coin-ejecting' feature, which is the element that ejects the coins from the corresponding column of coins into the coin cup. This element is duplicated for each column of coins in each machine.



	Product A	Product B	Product C
Number of parts per coin column to eject coins	18	20	4

Parts count comparison of coin ejector elements
figure 11

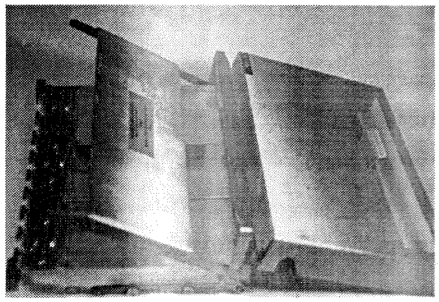
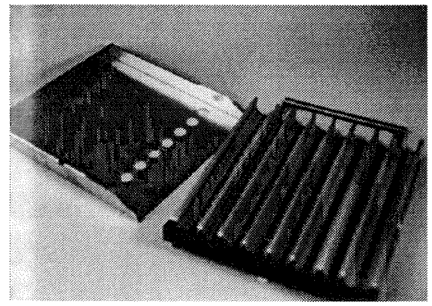
Figure 12 shows a comparison of two coin cups, into which the coins are ejected for the customer to pick up.



criteria	product A	product C
Number of parts (excluding fasteners)	2	1
Number of separate fasteners	8	2

Parts count comparison of coin cups
figure 12

Figure 13 compares two coin canisters.

criteria	product B	product C
Number of parts (excluding fasteners)	53	15
Number of separate fasteners	20	11

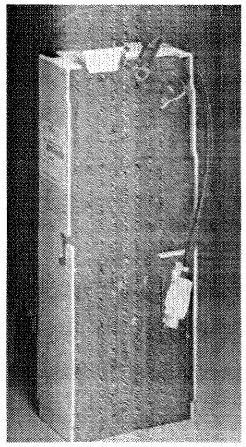
Parts count comparison of coin canisters
figure 13

This analysis generated a number of detailed metrics to attempt to improve. In addition, the general observation was made that there were *a lot* of parts in products A and B (which are competitive products). Clearly, product C was the product to which any further effort should be compared.

COST ESTIMATING

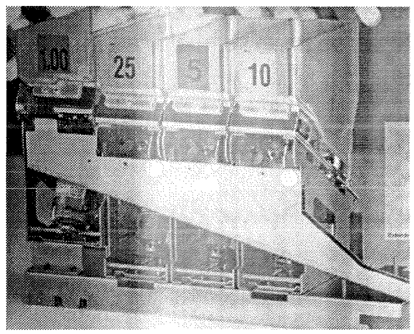
For the coin changer project, selling prices were obtained on many of the units available on the market (see figure 14). While prices do not directly lead to manufacturing costs, the information is useful nonetheless for comparison purposes.

Mars TRC-6510



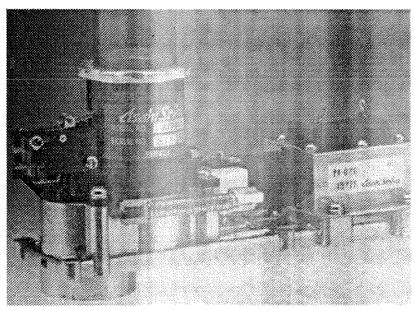
qty 1	$256
qty 100	n/a
qty 1,000	n/a
qty 2,000	n/a

Asahi Seiko HM-4



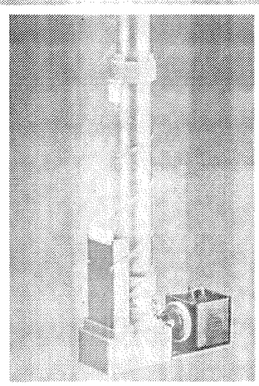
qty 1	$950
qty 100	$784
qty 1,000	$670
qty 2,000	$589

Asahi Seiko AES-112



qty 1	$34
qty 100	$28
qty 1,000	$24
qty 2,000	$21

Coin Controls
Compact Payout



qty 1	$96
qty 100	$80
qty 1,000	$45
qty 2,000	$45

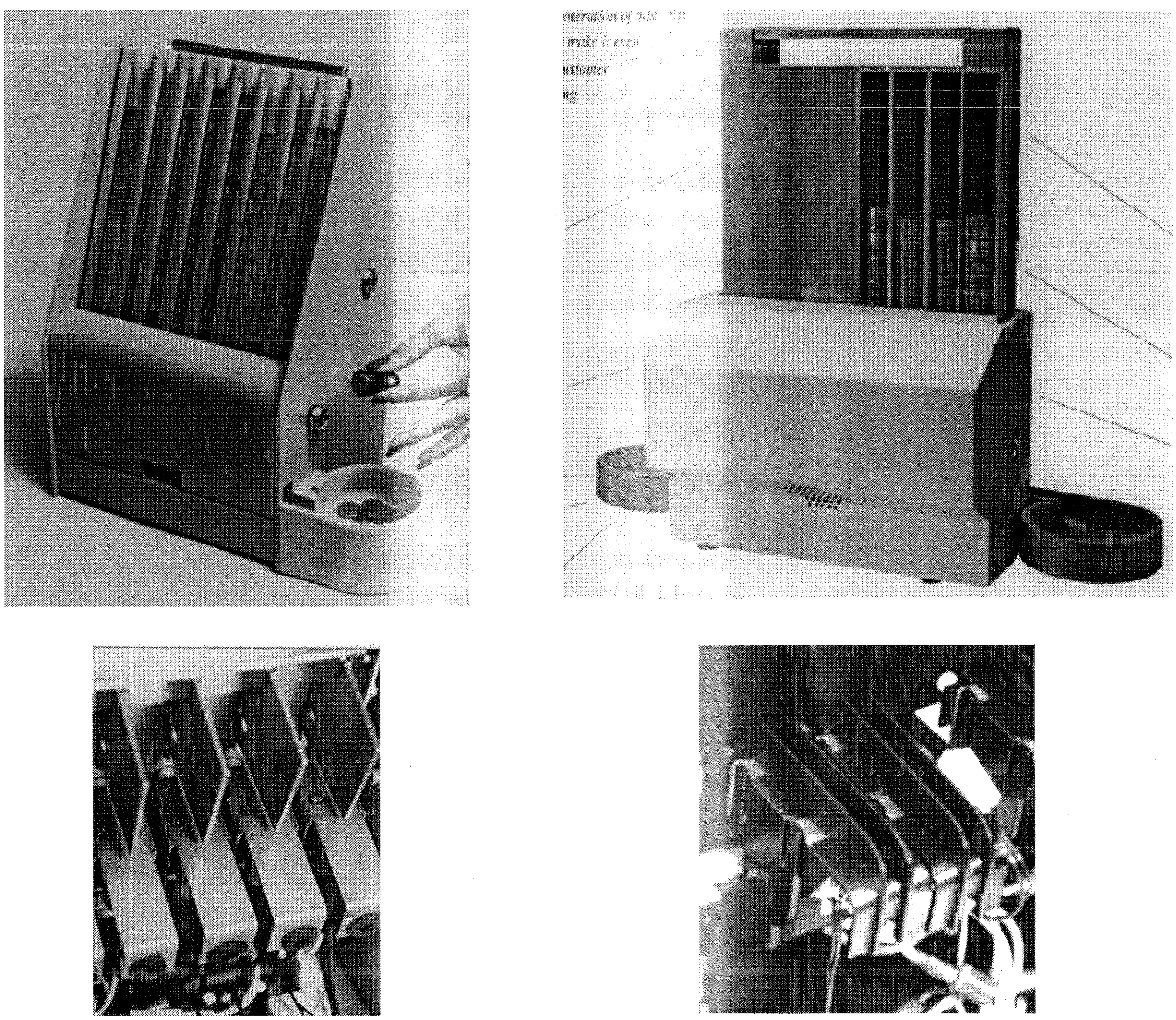
Competitive costing data
figure 14

CONCLUSION

The typical product development program could benefit greatly from the *early* inclusion of product benchmarking, visualization, cost estimating and DFMA. By addressing issues like the design's part count or cost early, the data can be included in the fundamental decision process, which can include concept comparison charts for selection such as Pugh charts. The data can also become the cornerstone of the formal product specification. In addition, these tools help in setting metrics for success that are all too often neglected in today's programs.

The results of this work on the case study program is illustrated in figures 15-17 including several metrics which we have been permitted to publish.

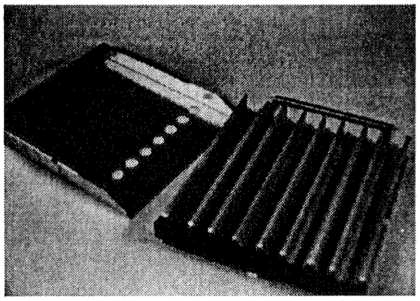
Baseline Product | New Product

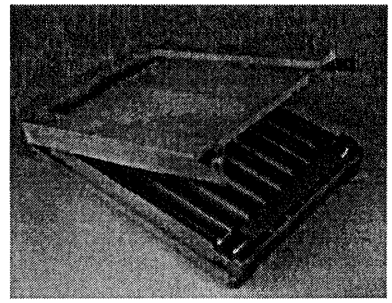


coin ejector elements

Program summary: key subsystems
figure 15

Baseline Product | New Product

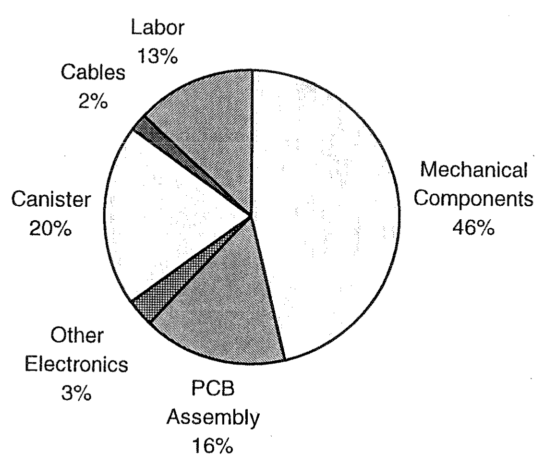




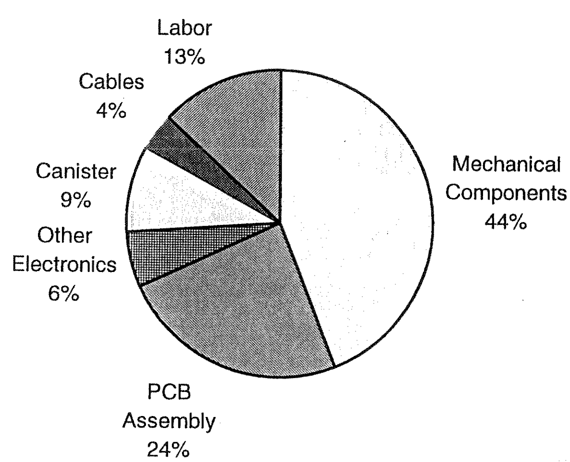
coin cannister

Program summary: key subsystems, cont.
figure 16

Baseline Product



New Product



Breakdown of total costs

Overall reductions:

Reduction in part count:	25%
Reduction in assembly time:	33%
Reduction in number of fasteners:	40%

Program summary: key comparisons
figure 17