MODULARITY AND COMPONENT SHARING AS A PRODUCT DESIGN AND MANUFACTURING STRATEGY

by

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Submitted to the Sloan School of Management
in partial fulfillment of the requirements for the Degree of

MASTER OF SCIENCE IN MANAGEMENT

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June, 1991

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ABSTRACT

The recent trend toward global competition and the need to produce a large variety of products in order to compete effectively has changed the focus of manufacturing into looking for new methodologies in which to increase ones efficiency. Many companies have focused on improving the design of their products to achieve this goal.

One particular design strategy that has been widely used but never studied in depth is the use of modularity and commonality. The purpose of this thesis is to make an initial study of some of the critical issues a company will face in attempting to make effective use of this design strategy.

The thesis first presents some of the many advantages and disadvantages involved in using modularity and commonality. In addition to the many obvious manufacturing and assembly benefits achieved, the use of this design strategy can also impact the overall competitiveness of a firm by providing them with a more flexible product line which can easily change in response to market demands and technological advances.

In an effort to quantify some of these issues, this thesis then presents the results of three case studies on the use of modularity and commonality for a company with particular interest in this design strategy. The goal here is to gain a better understanding of the strategic implications of using such a design strategy and to develop a methodology for determining the cost advantages involved.

This thesis is meant to mark the beginning of a comprehensive study in the decision making factors involved in using modularity and commonality as a design strategy. The hope for the future is that designers and engineers will begin to use this knowledge to make more effective design decisions.

Thesis Supervisor: Professor Karl T. Ulrich
Title: Assistant Professor of Management
ACKNOWLEDGEMENTS

I would like to thank Professor Karl Ulrich for his guidance, support and unavering interest in this thesis. His ideas and enthusiasm for this project were instrumental in providing me with a broad range of experiences and opportunities.

I would also like to acknowledge Dr. Daniel E. Whitney, my Draper supervisor and Richard E. Gustavson for their support and insight into the manufacturing arena.

Special acknowledgement and thank you to Henry Stoll without whom this thesis would have never taken place or been completed.

I would also like to thank Carl Ashley, Jack Carlson, Robert Medved, Larry Ward, Robert Armstrong and Fred Reker for their help in making this project a success and extend a special thanks to David Merritt who always found time in his busy day to help.

I would like to extend a special thanks to the LFM program and the new LFM office which has been a second home to me during the thesis crunch. Special thanks also to Parkson Chao for the great tennis games and insight into the difference in definition between modularity and commonality and to Steven David who never let me get too involved in my thesis to forget about Macroeconomics.

Special thanks also goes to Karen Lee, of course, who has been like a sister to me and has kept me excited about both her upcoming wedding and mine.

Last and most importantly, I would like to thank my parents, brother and sister for their steadfast belief in me and my fiance Joe Presing for his guidance and emotional support throughout the stressful last month at Sloan.

This research is supported by the National Science Foundation under Grant DMC-8715800 made to the Charles Stark Draper Laboratory, Inc. It represents the opinions of the author only, and is offered for the stimulation and exchange of ideas. It does not represent the findings or policies of the National Science Foundation.
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1. Introduction

1.1 Recent Trends

The recent increase in global competition and resulting decline in productivity growth have forced U.S. manufacturers to find new modes of operation in which to compete more effectively. The onset of firms (mostly Japanese) that can simultaneously compete on large product variety and high quality while continuing to maintain a low cost advantage present a formidable challenge that cannot be met with current or established modes of manufacturing and managerial operations. Indeed the entrance of these firms has not only changed the focus of manufacturing to methodologies such as design for manufacture or concurrent design, but has also caused a fundamental restructuring of the market environment in which the U.S. has to compete.

Among this restructuring has been the increase in the variety of products available in the marketplace. In response to global competition and rapid changes in technology, firms have begun to widen their product line to meet more market segments, gain market share and beat out the competition. Sony, for example has kept ahead of its competition by introducing 5 or 6 new variations of the walkman every year, reaping the benefits through their dominant 40% market share.\textsuperscript{1} Toyota has used the same strategy and made large

\textsuperscript{1}Uzumeri, M.V., \textit{The Challenge of Change and Variety in Manufacturing}, School of Management, Rensselaer Polytechnic Institute, Troy, NY, May 1990
inroads into the car market by flooding the market with a large variety of cars, claiming the spot as the number one car manufacturer in Japan.²

The need to keep a continuous flow of new products in the pipeline has also led to a new emphasis on shortening the time to market and decreasing the product development life cycle. By being the first to market, firms can gain market share and better recoup the costs of production by having their product out in the marketplace longer. Incremental changes to the product design are the focus instead of entire redesigns, allowing companies to reuse previous work, eliminating the time it takes to reinvent the wheel.

Partly as a result of this increase in variety, the market environment itself has become increasingly fragmented. Marketers are finding themselves faced with a consumer whose needs are more specific, whose loyalty to a particular brand or company is beginning to waver and whose product tastes are more for current looks and styling. In order to retain or gain customers, new importance must be placed on better service, meeting customer lead times and producing new up to date products that satisfy a variety of needs.

With changing market expectations, increased product variety and quicker rates of innovation, U.S manufacturers are finding it increasingly difficult to predict whether or not a product will do well in the marketplace. In addition, as the playing ground becomes more complex, the cost to manage and manufacture this complexity has skyrocketed. U.S. firms have had to face increased overhead costs in supervision, quality control, tool maintenance etc. and increased

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²Kunkel, P. "Beat the Competition", Business Week, March 25, 1991
manufacturing costs in having a greater numbers of parts, greater material handling and higher inventory costs etc. The result has simply made it difficult for firms to price their products competitively causing them to lose out to competitors who can.

Integrating design into the entire product life cycle can be one answer to the problem. By using effective design, companies can better meet customer requirements, maximize responsiveness in the marketplace and keep a lid on costs. Integration of design into the manufacturing process can lead to greater manufacturability and higher quality products as traditional DFA studies show. The design of a product can also enable better servicing and repair and can lead to a competitive advantage in the marketplace as well.

One particular design strategy that allows companies to achieve a large product variety while simultaneously minimizing lifecycle costs is the use of modularity and component sharing in design. Advantages can be gained by using a large number of shared components across the product line minimizing costs through economies of scale while concurrently achieving product variety by differentiating products through only a handful of components.

In using this design technique, the cost of incorporating a more expensive subassembly into the product line can be reduced through the use of economies of scale while less expensive subassemblies can be differentiated to achieve variety. Increased customer satisfaction and service can also be achieved by careful selection of common components versus differentiating components to balance lead times and/or uneven process times reducing time from customer order to shipment. To the extent that one can predict the future, this particular design strategy can shorten the transition from current products to future
products to achieve a long term competitive advantage. Sony's lead position in the Walkman market is primarily due to their ability to turn out a large variety of products while simultaneously making use of the latest technology.³

In using this particular design strategy the underlying assumption is that there is a tradeoff involved between a certain level of standardization needed to achieve the economies of scale associated in producing and inventoring the product and the need to provide each customer with a product tailored to their needs. In addition, the use of common components will ultimately result in the giving away of extra material and additional features to customers who want less. This can lead to high material costs or a substantial loss of sales if a large portion of a firm's customers are unsatisfied by the current set of product options available.

The focus of this thesis is to study this particular design strategy in more detail. In particular some of the strategic and economic reasons associated with using this particular design strategy will be analyzed. Through a case study, focus will then be placed on gaining a better understanding of some of the implications of using such a design strategy and on developing a methodology for analyzing the cost advantages involved.

1.2 Thesis Overview

Chapter Two will begin by listing some of the advantages and disadvantages of modularity and component sharing in design. In particular, the focus will be on trying to gain a better understanding of the quantitative and qualitative

³Sanderson, S. W., Time and Cost Models for Managing Change and Variety in a Fast Product Cycle Environment, Computer Integrated Manufacturing Program at Rensselaer Polytechnic Institute & Center for Innovative Management at Lehigh University, 1990
implications of using modules and common components and to identify particular types of environments in which this design strategy might best be used

In an effort to quantify some of the issues involved, Chapters 3 and 4 will cover a case study done with Acme Electric, a company with a particular interest in this research. Chapter 3 will first focus on the industry in which Acme Electric must compete and determine the companies strategic direction and goals for future competitiveness. The second half of the chapter will then analyze ways in which designing using modularity and component sharing may help them to reach these goals.

Chapter 4 continues with the study by covering three specific cases of using modularity in more detail.

Case 1
Case 1 is designed to study the decision making factors involved in understanding how to reduce variety and which varieties should be kept. The tradeoff here is the cost of giving away additional features (material) to customers that would be happy with less and lost revenue due to insufficient product options versus the overhead and labor costs saved in the simplification of the product line. The emphasis that customers place on certain product features is also important to consider in this analysis as this ultimately determines the product options a firm should provide.

Case 2
Case 2 focuses on trying to determine the cost associated in adding an alternative or variant to a module. For instance, if \( A = \{a_1, a_2, \ldots, a_n\} \) where \( A \) is a module and \( a_1, \ldots, a_n \) are the number of varieties of module \( A \), the attempt will be to study the impact of adding \( a_{n+1} \) to \( A \) so that \( A = \{a_1, a_2, \ldots, a_n, a_{n+1}\} \). An additional issue
that will be touched upon is the idea of selective variety, that is providing variety to certain parts of the product line but not others.

**Case 3**

Case 3 will focus on the partial redesign of Acme Electric's product using modular techniques to study the costs, strategic implications and change in customer utility affected. The goal here is to determine those areas of Acme Electric's product line where modularity and component sharing can make the most impact on Acme's competitiveness in the marketplace.

In Chapter 5 a general methodology will be developed for using modularity and component sharing in product design and manufacturing. General principles, rules and methods will be developed to try and incorporate some of the decisions design and manufacturing engineers must face in deciding how to best use modules to reduce manufacturing costs and increase product effectiveness.
2. Modularity and Commonality

Given the recent increase in global competition, it is rare to find a company which produces only one variant of a product. Many firms have switched to multi-product environments in order to stay in business. The study of modularity and component sharing in manufacturing and product design stems from the need for these companies to minimize the increase in cost of introducing variety into their product line.

The purpose of this chapter will be to list some of the advantages and disadvantages of using modularity and commonality as a design strategy and identify several environments in which this design strategy may best be used.

2.1 Definitions

2.1.1 Commonality vs Modularity

Commonality can be defined as the use of a common component by several separate products.

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Different Products

Mercury Sable  Ford Taurus  Ford Mustang

3.0 L V-6 Engine

Common Component
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Modularity can be defined as the use of interchangeable variants of a module in one product.

Product

Ford Taurus

3.0 L V-6 Engine  3.5 L V-6 Engine

Different Variants of Engine Module

There are many costs associated with the introduction of variety. A large majority of these are increases in overhead costs such as higher inventory, material handling and supervision that result from the need to manage the additional complexity of the manufacturing process. Additional costs incurred are investments in machinery that will help to manufacture the variety more efficiently. For example a laser cutting machine can help to make different types of box covers more efficiently. Other investments might be those used to help customers distinguish between the large variety of products. The production of labels and decals is one prime example as is the use of paint lines for differentiating by color.

In using modularity and commonality, companies can achieve two goals simultaneously. First, they can add variety to their product line by using various combinations of interchangeable modules. Second, they can reduce the cost to manufacturing this variety due to the economies of scale achieved through inventorying and producing a large quantity of the same module.
Most modules are thought of as a physical entity. However, it is important to note that a module need not be a physical entity. For instance software programs can be considered a module and the interchanging of different software programs can produce variety. Motorola has achieved this by programming their pagers with the different functional requirements requested by their customers. The growth of system integrators who interpret end-user requirements and customize computer hardware and software to meet a certain need is an additional example of the increase in variety due to the use of software.

2.1.2 Totally Modular vs Partially Modular

An interesting distinction to make is the difference between a total modular design and a partial modular design. Figure 2.1 shows an example of what is meant by totally modular. Note that each module is interchangeable with every other module. In a partially modular design, only parts of the product are modular. A good example of this is in the automobile industry where parts of the car such as the engine or door handle might be interchangeable while other modules such as the car body are not.

Very few firms today use a totally modular design approach. This might be due to cost or to the implicit need for standard interfaces between interchangeable modules. For instance, the interface between the car and its engine is well defined and allows for easy exchange of different types of engines. For the car body, the interface between the front half of a Honda Accord and the back half of a Honda Prelude, for example, is less defined at this point in time and as such the car body is not modular. Due to the many cost advantages of using modularity and commonality in product design, however, most firms use at least some degree of this design strategy in their products.
2.2 Strategic Environment

As with any product strategy, certain strategic environments and industry characteristics will benefit more from the use of modularity and commonality in design than others.

2.2.1 Competitive Factors

Price
Firms that compete using modularity and commonality as a design strategy tend to compete in the high to medium price range, not the low end. This is most likely due to the fact that modularity provides a certain level of flexibility both to the customer in being able to "choose their own product" and the manufacturer in being able to reuse designs. The comparison of the designs of a low end Sony walkman and a more expensive Sony walkman exemplify this concept. The low end walkman is designed as a highly integrated product with almost no distinct
modules. The circuit board functions as both a circuit board and as the holder for all the mechanical mechanisms. The more expensive walkman is modular and has modules such as the tape holder that can be interchanged or used in other walkman designs.\(^4\) The introduction of the Kodak disposable camera is another example of a low end product that is highly integrated and not designed using modules.

2.2.2 Competitive Environments

Companies who target a large number of market segments and have a large variety in their product line will benefit the most from using modularity and commonality.

Global manufacturing firms can also benefit from this strategy because of their need to use variety to meet different design constraints. For example, Europe's electrical system is different from the United States'. The ability to produce electrical distribution equipment that can operate in both environments will enable these firms to expand globally as well as locally.

Modularity and component sharing can also benefit firms competing in mature industries. In no growth environments, competition is usually based more on price and customer service with profit driven by gaining market share. The efficiency with which companies using modularity manufacture their products and their ability to target more than one market segment allows them to do well in this sort of environment.

\(^4\) Two Sony Walkmans were taken apart and studied to obtain this information.
Firms competing in highly unstable or changing environments can also benefit from this particular design strategy. By producing more than one variant of a module, these firms are somewhat shielded from standardization of products in the marketplace that do not coincide with what the firm is currently providing. For instance, a standardization on the 3.25 inch diskette in the computer industry will hurt those firms that only use or produce the 5.25 inch diskette much more than those that play in both markets. Similarly an increase in the cost of a certain material such as copper may place some companies that depend solely on copper into dire straits while only slightly impacting a company that offers say both copper and aluminum.

2.2.3 Manufacturing Systems

In order for any design strategy to be successful, a complementary manufacturing strategy is needed that enables the efficient processing of these new designs. As Kunkel says in Business Week:

"Limited success can be achieved through product redesign by careful selection of materials and drawing board development, but the ultimate goal for total flexibility - in terms of product type and of volume mix, cannot be achieved unless a planned approach to the development of a manufacturing system is adopted."\(^5\)

Two manufacturing strategies that complement the use of modularity and commonality are: the use of methodologies such as JIT, FMS and Kanbans and Factory Control Systems or CIM techniques.

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A variety intensive firm will cause different challenges for their manufacturing department than a firm that plays a niche strategy. Firms that produce a large variety must deal with increased complexity resulting in an increase in setups and the need for smaller batch sizes. The use of manufacturing methodologies such as JIT, Kanbans and FMS allow a company to more efficiently manufacture smaller batch sizes.

Shortening the time to market is another trend that manufacturing firms have had to face. The use of modularity and commonality allows companies to make parts ahead of time and assembly the product when ordered, decreasing the time to market. Efficient scheduling of these products to decrease overall assembly time can contribute to the decrease in customer lead time. Companies such as Motorola, Hewlett Packard and GE have begun to develop Factory Control Systems that help to automatically integrate the process of accepting customer orders, determine the modules needed and then optimize the scheduling of this products to enable more efficient assembly. Figure 2.2 shows the customer order to shipment flow. The combination of using modular design and an integrated Factory Control System has, among other benefits, allowed GE’s lighting panel business unit to reduce their delivery cycle from two weeks to 3 days and effectively steal market share away from competitors.6

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2.3 Advantages and Disadvantages of this Design Strategy

Assumptions

In trying to study the benefits and costs of using modularity and component sharing in product and manufacturing design, we felt the need to distinguish between multi-site v.s. single-site environments
Focus on a single-site environment is important because it allows us to focus more on design decisions that may be generalized to more than just a particular industry or firm. In a multi-site environment, many more levels of complexity are added to the decision making process. For instance the geographic location of plants may affect the ability to achieve economies of scale through common components because of the inability to make this component in only one plant. By restricting our focus to single-site environments we can gain more of an insight into the fundamental issues of modularity and commonality.

Designing using modularity and component sharing impacts every aspect of the product development life cycle from the initial stages of the design process to the way in which the product is strategically positioned in the marketplace. As a result, we felt the need to categorize the potential advantages and disadvantages of this design strategy into three areas: design, manufacture and product strategy. It is important to note, however, that many of the issues discussed do not cleanly fall into one of these three categories. The grouping of potential advantages and disadvantages was used simply for clarification.

2.3.1 Design

Advantages

a) Simplification of the Design Problem

Most products on today's market are too complex to be designed as a whole. Breaking up the product into modules sets clear boundaries and standard interfaces that effectively makes a design teams job more manageable and more efficient.
b) Designing in Parallel

Decomposing the product allows several design teams to work in parallel, ultimately shortening the design time and allowing groups to share or reuse parts of previous designs such as power boards, analog boards etc.

c) Allows Designers to Focus

Breaking a design into separate components allows designers to focus in on one particular part of the design process, reduce the complexity of the problem and lead to more effective design decisions.

d) Company Design Expertise

Individual firms or areas within firms may have special expertise in certain design techniques due to specialization and experience in a particular area. The breaking down of the design into modules enables firms to take advantage of that particular design expertise.

Disadvantages

a) Blind to New Design Techniques

Breaking down the design process into separate design components, however, can ultimately cause designers to be too tunnel focused. As a result designers sometimes become blind to new design techniques that can make an entire product design or even separate design components easier to manufacture or that better meet customer needs.

b) May Sacrifice Performance Optimization

Optimizing the performance of individual components does not necessarily mean that the culmination of those designs will in itself be optimal. As a result designing in sections may produce a less than
optimal whole, and work needs to be done to bring modules together optimally.

c) Less Integration in Design

Designing in sections may also cause the whole design to be less integrated. Problems may occur when attempting to connect these designs together especially if clear inputs and outputs of particular design sections were not clearly specified ahead of time.

d) Lack of Functional Sharing

Functional decomposition is a widely used method in deciding what to make a module. In doing so, however, designers may overlook more effective designs that group two or more functions together. A prime example of this is Sony's bottom of the line walkman which was designed with the circuit board being used as the frame to attach the mechanical mechanisms to as well as to hold all of the circuitry.

e) Potential for Redundancy

Splitting the design process into separate components can also lead to design redundancy. With different design teams working on separate parts of the whole process, there could be a distinct lack of communication between the two teams and as such possible redundancy.

2.3.2 Corporate Strategy

Advantages

a) Better Able to Meet Customer Demand

The use of modules and common components allows firms to achieve variety while minimizing life cycle costs. By being able to target many
market segments instead of a few, firms by definition are better able to meet customer's demands.

b) Greater Product Mix

A greater product mix can be achieved when designing in modules because of all the different combinations of modules that can be put together. By adding one variety to a particular module one essentially doubles the amount of offerings available to the customer.

c) Addition to Product Line is Simplified

By breaking a product into modules, one can reuse modules or designs instead of starting from scratch. This simplifies additions to the product line by reducing product and process design time.

d) Shorter Time to Market

By decomposing a product into modules firms can design and manufacture components in parallel thus shortening the time to market. Segmenting production in make-to-order vs make-to-stock modules can also shorten the time to market by making long lead time components to stock and making short lead time components to order.

e) Reuse of Modules over Several Product Generations

As product generations change, not all parts of the product change as well. Firms can reuse modules that don't change or vary slightly from product generation to product generation. This saves the firm both time and money.
f) Ability to Handle Special Requests

The use of common components over several different products can enable a firm to handle special requests more easily if the special request is a mutation of one of the different products already generated.

g) Easy to Upgrade and Repair

By segmenting a product into modules, repair is made easier and less costly because only certain modules need to be replaced not whole products. For the same reason upgrades are also made simpler.

Disadvantages

Single-site production

a) Possible higher unit Variable Costs

The need to achieve economies of scale through the use of common components causes firms to be selective in the varieties they offer. Since firms cannot provide all varieties, unit variable costs will be higher as firms must give away more expensive units to satisfy customers who would otherwise accept a less expensive alternative.

Multi-site production

b) Constrained by Geographic Location of Plants

With firms that have many plants it may be difficult to achieve economies of scale through common components if this component cannot be made at a single plant site.
c) Increased Dependence on Suppliers

   To take advantage of expertise in design, process technology etc. some firms may decomposed their product to take advantage of out-sourcing. This, however, places an increased dependence on ones suppliers to meet specifications and time deadlines.

2.3.3 Manufacturing

Advantages

a) Ease of Assembly

   Certain methods of product decomposition allow for easier assembly. For instance, breaking down a product into a certain number of modules and then breaking each module itself down, simplifies final assembly simply because their are fewer tasks to be performed.

b) Economies of Scale

   Using common components throughout different products allows companies to produce that component more efficiently and decrease the manufacturing costs per unit.

c) Potentially lower setup and lower costs/unit

   The use of common components allows companies to reduce setup times and take advantage of large-scale machinery that will ultimately lead to a reduction in the manufacturing cost per unit.

d) Increased Quality through Facilitation of Rework and Testing

   Testing and rework is facilitated because each individual module can be tested as a separate entity and repairs can be made while it is still cost
effective to do so. This increases the quality of the product due to quicker
diagnosis of things when they go wrong. Maintenance is also made easier
as only certain sections of a product need be replaced.

e) Isolate problem-prone areas in manufacturing line
If part of the manufacturing process is new and untested or simply causes
more problems then it would be advantageous to separate this particular
part of the process out to minimize its impact on the rest of the system.

f) Isolate special facilities
Likewise special facilities such as the clean room which require different
processing may be segregated out from the rest of the process to increase
overall efficiency.

g) Strategic Partnerships
Breaking the process down into modules allows firms to take advantage of
strategic partnerships with other companies that have certain
 technological expertise such as disk drives bought by laptop computer
makers.

h) Reduction in Number of Parts
Reducing the product down into modules may ultimately lead to a
reduction of parts and thus benefits can be achieved through traditional
DFM rules.

i) Lower Scrap Costs
Since more products can interchange common parts with each other,
cannibalization is easier. Thus scrap costs are lower because there is less
vulnerability of the process to machine failures or rejects.
Disadvantages

a) More intermediate parts in bill of materials
   Designing in modules can sometimes lead to an increase in the number of parts due to redundancy. More parts requires a more complex tracking system.

b) Dependence on Quality of Module: Potential for Increased Alignment Complexity
   The overall quality of the product depends to a large extent on how closely a module meets its design specifications. Potential exists for problems to occur when trying to assemble the separate modules together. For example, one of the major problems car manufacturers have had to face is fitting the doors, trunks and hoods to the car body.

2.4 Conclusion

There are many qualitative and quantitative advantages to using modularity and commonality as a product design and manufacturing strategy. The major benefit is that the use of this design strategy impacts all areas of the product development cycle from design to manufacture to better serving the customer in the marketplace.

In an effort to quantify some of the advantages and disadvantages listed in this chapter, the next section will cover both a strategic analysis and an in-detail look at some of the critical issues in modularity for a company who is interested in this research.
A strategic look at the industry in which this company competes will allow one to gain more insight into the qualitative side of using modularity and commonality. In addition, analysis at this level will provide one with the tools to determine how modularity can best be used to increase the competitive positioning this company has in the industry. Further detailed analysis of the critical issues complement this study by providing a better understanding of the issues involved in trying to reach this goal.
3. Acme Electric: A Case Study in Using Modularity & Commonality

Acme Electric is a manufacturer of a large variety of electrical distribution equipment. The focus for this case study will be the on the electrical distribution panel segment of Acme Electric's product line.

This purpose of this case study will be to perform an analysis of how the use of modularity and commonality in design can impact the overall strategic positioning of Acme Electric within the electrical distribution industry. The intent will be to study the strategic and economic implications of using this design strategy and discover additional issues that may be applied generally across other types of products.

The first half of this chapter will cover a short analysis of the electrical distribution industry and look closely at three factors that are needed to compete effectively in this market. The second half of the chapter will then focus on Acme Electric, discuss how their product strategy fits within this given framework for competitive success and analyze how designing using modularity and commonality will help them to achieve these goals. Chapter 4 will then continue with an economic analysis of three of the key uses of modularity discussed in this chapter.

3.1 The Industry

The electrical distribution industry can be characterized as a mature one with recent growth of only about 1.2%. Demand in the industry consists of a large number of different types of customers with very different needs. An electrical
distribution panel is also considered a durable good (one that does not need frequent replacement) and as such, repeat sales are dependent more on new building construction projects initiated by a pleased customer rather than simply the fulfilling of a replacement sale market. The result of these characteristics, a mature industry, a large variety of customers and no readily available repeat sale market have directed the focus of manufacturers in this industry to try and produce a large variety of products in order to compete more effectively. Given the need for large variety, the evaluation of designing using modular techniques can potentially be a critical issue for this industry.

3.1.1 Industry Competition

Competition in this industry is predominantly being fought along price, customer service, flexibility and reliability. Customers are seeking a product that fits all of their needs at a good price and with reliable service. Competition for customers is intense for several reasons:

1) *Lack of switching costs.* Given a particular customer, it costs very little for one to choose to buy Acme Electric's panels versus a competitor's panels. The primary cost is the time required to learn the specification of a new panel line. With almost identical products and no switching costs, the customer will go to whoever fits his/her need with the highest quality, reliability and good price.

2) *Slow Industry:* The electrical distribution industry is growing slowly with no real markets in which to grow into. As a result, expansion in this industry will be primarily achieved through stealing market share away from competitors or through globalization.
3.1.2 Key Factors for Success

The key to determining the impact that designing using modular techniques can have on a company, is to first determine the forces that drive the affected industry. Reliability, safety, low cost, flexibility and service all play an important role in the electrical distribution panel industry. For the purpose of this thesis, we will assume that reliability and safety are a given and will focus on how the use of modularity can help a company to lower costs increase flexibility and improve customer service.

Low Cost

Given that the market is mature, expansion in this industry will be accomplished only at another's expense. In this type of environment, price becomes increasingly important and the ability to adjust price either in response to competitor's moves or to cut price a competitor will lead to a strong competitive advantage for that firm.

Flexibility

Given a mature industry, competitive superiority will come to firms that have the flexibility to reach more than one market group. Customizability is also important in an industry like this one where specially specified electrical distribution panels are more the norm than not. Two factors add to the need to be flexible.

1) Large Variety Customers. As mentioned before, there are a large variety of customers that make up the overall demand for electrical distribution panels. Each of these customers has a very different need. Figure 3.1 shows a typical
order flow for electrical distribution panels for a new building project, the
diverse set of customers that influence the purchase decision and the
requirements each set of customers is interested in receiving.

![Diagram showing the New Building Construction Order Flow]

- Reliability
- Performance
- Price

- Reliability
- Performance
- Price
- Easy to Specify
- Convenient Sizes

- Reliability
- Availability
- Price

- Convenient Pkg
- Service
- Delivery
- Price

- Easy to Install
- Standardized Installation Tool Requirements
- Physically Manageable

- Availability of Parts
- Easy to Install
- Easy to Access
- Reasonably Priced

Legend
- Customer
- Not a Customer

Figure 3.1
Diverse Set of Electrical Distribution Panel Customers and Their Requirements

Companies that can satisfy a large number of these different customer
requirements will gain a competitive edge over their competition.

2) Large Variety of Electrical Distribution Panels. Electrical distribution
panels vary depending on number of circuits, installation space, size of
switches etc. As such there is a large variety of electrical distribution panel specifications that can be demanded. Success will come to that firm that can produce a large number of different types of electrical distribution panels.

**Service**

As with any maturing industry, new creative ways need to be used as a way of increasing a company's competitiveness. One way in which to achieve this is through improving customer service. Good customer service entails having a reliable product, one that is easily maintained, easy to deliver, easy to order and easy to understand, etc. The idea behind service is to take the stress out of the purchase of an electrical distribution panel.

**3.2 Acme Electric**

Acme Electric plays a dominant role within the electrical distribution industry. They have a strong presence in the U.S. and have begun to direct resources toward becoming a global player as well. Much of their current interest in modularity and commonality is due to the recent increase in competitiveness within their industry.

**3.2.1 Acme Electric's Electrical Distribution Panel**

Acme Electric's electrical distribution panel is divided into four sections, the enclosure, the cover, the internal bus structure and the switches.
Enclosures are used to hold the entire electrical distribution panel. Due to the different circuit configurations, wire space needed and installation space constraints, enclosure sizes vary by width, length and depth. In addition to this, Acme Electric provides varying functionality in their enclosures including rainproof, dustproof and explosion proof.

Covers perform a variety of functions. The first is to isolate the internal bus structure from the customer for safety reasons. The second is to provide a covering for the enclosure. The third is to provide the user access to the switches. Covers come in several different types.

The internal bus structure provides the basic functionality of the electrical distribution panel. The basic elements of the internal bus structure consist of bus bars which function as the main electrical conductor and carry the electrical supply throughout the electrical distribution panel and the main lug which forms the connection between the main electric supply and the electrical distribution panel. Acme Electric uses 2 different bus bar materials, copper and aluminum.

The switches form the connection between the individual circuits and the electrical supply carried by the bus bars. Switches vary in size (1-pole, 2-pole to 3-pole), depending on the amount of electricity they need to control. In addition there exists a main breaker which functions as a large switch and controls whether or not electric current will flow along the bus bars of the electrical distribution panel.

This case study will focus solely on the enclosure, cover and internal bus structure and will exclude the switches for two reasons. Simplification and because switches are likely to remain a stand-alone module at Acme Electric for the foreseeable future.
3.2.2 The Main Product Line

Acme Electric has an extremely complex main product line. As mentioned above, they have a large variety of different size enclosures, many different types of covers per enclosure, 2 bus bar materials, numerous different enclosure types etc.

In addition to this complexity, Acme Electric targets three different market segments depending on a customer’s voltage and amperage requirements. A volt is the unit of measure that is used to measure the pressure or force needed to move an electrical current. An ampere is a unit of measure used to measure the quantity of electrical current that flows through a wire. Customers choose the electrical distribution panel they need depending on the amount of volts they need, low volt or high volt and the amount of amperes they need, low to high. Acme Electric has segmented their market into the low voltage, low amperage segment, the low voltage, high amperage segment and the high voltage all amperage segment. Figure 3.2 shows in detail the main product line and large variety of electrical distribution panel configurations that Acme Electric currently offers their customers.

In addition to choosing the voltage and amperage requirement for their electrical distribution panel, customers also choose the number of circuits they desire from a set of five options and choose whether or not they want a main lug or a main breaker in their electrical distribution panel. The latter choice then determines the minimum enclosure size that a customer will need for their electrical distribution panel.
Figure 3.2
Main Product Family Tree

Electrical Distribution Panel

Low Voltage

Amp 1

C1

Amp 2

C2

Amp 3

C3

Amp 4

C4

High Voltage

Amp 1

C1

Amp 2

C2

Amp 3

C3

Amp 4

C4

Voltage
(2 types)

Amperage
(4 types)

Circuits
(5 types)

Main Lug
Enclosure Type 1
(13 types)

Main Breaker
Enclosure Type 2
(6 additional types)

Enclosure Width
(2 types)

Enclosure Depth
(2 types)
3.2.3 Other Acme Electric Products

In addition to this main product line, Acme Electric manufactures many other special types of electrical distribution panels that meet different customer needs. These panels are considered part of Acme Electric's product offering and can be ordered through their catalog but were not incorporated into the product tree in Figure 3.2. In addition Acme Electric also manufactures custom ordered panels that cannot be found in the catalog and are usually very specific one time customer requests.

3.2.4 Acme Electric's Current Product Strategy

Acme Electric's main strategy is to compete by playing in a large number of market segments. Part of the company's value added is in their willingness to manufacture what ever the customer wants regardless of cost and to sell a whole electrical system package and not just individual panels. Given the large variety of customers and large variety of electrical distribution panel configurations needed in an electrical system package, this means that Acme Electric must have the flexibility to offer a wide product mix and meet a wide variety of customer needs.

As the market matures and competition for market share becomes more intense, Acme Electric has begun to look for further ways in which to produce their variety more efficiently.

3.2.5 Using Modularity at Acme Electric: Key Factors for Success

The use of modularity and commonality in the design of a electrical distribution panel can continue to increase Acme Electric's overall productivity and efficiency
in manufacturing a large product line. In the previous section on the industry, low cost, flexibility and customer service were cited as three of the factors needed to increase ones competitive positioning within this industry. The follow section attempts to describe some ways in which the use of modularity can help Acme Electric to better meet these three factors for success.

**Low Cost and Flexibility**

The main impact that designing using modularity and commonality can have, is to help a company such as Acme Electric reduce the cost of producing such a large product mix but continue to provide customers with the functionality they desire. One way to accomplish this is to use modular techniques to *simplify the main product line*. An example of a simplified version of Acme Electric’s main product line shown in Figure 3.2 might look like Figure 3.3.

In this diagram, the majority of the functionality that was provided with the original product mix is still met but is met with fewer products. Note that although the number of different ampere options has been reduced down to three types, the functionality of the electrical distribution panel has not been reduced since the three amperage types can provide the same capability. The number of enclosures has also been reduced but again, the functionality of a enclosure, to hold the electrical distribution panel, has not changed. In fact, this product offering actually adds a third voltage panel application that was not offered in the original product line.
Two critical factors arise in the implementation of this new product tree. The
first is that there needs to be an accurate assessment of what customers really
want and what features they are willing to give up for other benefits. For
instance, in order to reduce the number of different enclosure sizes, Acme
Electric should have a pretty good idea of how this change will impact their
customers. Accurate answers to questions concerning what customers really
want will allow companies to make the best use of modularity and commonality
in product design.

The second factor is that the simplification of the product line raises some new
safety issues. With the new product options, a customer who has a low
amperage panel might have the capability of flowing a higher level of electrical
current their electrical distribution panel without knowing it. Acme Electric
must be somehow insure that their customers are either aware of this additional
capability or prevent them from being hurt by it.

Modularity and commonality can also be used at Acme Electric to help group
some of their main product line panel designs together. By using modularity,
Acme Electric can design modules that are common across different designs and
possibly take advantage of economies of scale. Differentiation can then be
achieved through the use of other modules. This change can produce numerous
cost savings for Acme Electric. It will reduce the number of manufacturing and
assembly operations, reduce setups, simplify material handling, reduce material
cost and allow Acme Electric to take advantage of automated assembly.

The use of modularity can also help to reduce the cost to manufacture Acme
Electric’s other types of electrical distribution panels. An example of this might
be with the manufacture of a “split bus” panel. A “split bus” electrical
distribution panel is essentially a modification of two internal bus structures attached to one another top to bottom. Currently the process to manufacture this product is different from that of the regular electrical distribution panels due to different assembly steps and sizing needed. By designing the regular and "split bus" electrical distribution panels using a modular approach, Acme Electric can reduce their manufacturing costs by producing modules that can be shared by both types of panels.

Cost can also be reduced by *packaging features together*. For instance, Japanese automobile makers group product features together so that if a customer wants tinted windows, a customer also gets power locks. If certain features of an electrical distribution panel are naturally grouped by customers, then modularity can be used to package these feature together by simply designing modules that have both of these features. An example of this might be to offer certain enclosure sizes in explosion proof construction only, or having certain electrical distribution panel options only come with a certain type of cover.

**Customer Service**

Another one of Acme Electric's focus is on decreasing their cycle time and meeting customer needs better. The use of modularity and commonality can enable Acme Electric to meet these needs. According to Hal Mather's article on "Logistics in Manufacturing" a customer has a certain lead time in which they are willing to wait to receive their purchase. A successful firm will be one that is able to deliver the product within this time frame. One way to achieve this is through the mushroom product idea. (see Figure 3.4) Components with long lead times should be chosen to be common across the family of products and made ahead of time. Variability is achieved at the last moment through
assembly of the common components or through the addition of components whose lead times are shorter than that of the customer's lead time. This technique allows a company to decrease their cycle time and provide better customer service.

![Diagram](Image)

Figure 3.4
The Mushroom Product

For Acme Electric, the decision might be made to design an electrical distribution panel using some combination of a module that consists of say X circuits. Each electrical distribution panel would then be made up of some multiple of the X circuit modules. By making these X circuit modules ahead of time, Acme Electric can provide better customer service because they only have to assemble and ship the product on receipt of customer order and do not have to wait for parts of the product to be made.

Modular design can also provide a customer the flexibility to change their electrical distribution panel features at any time. One example of this might be
the addition of additional circuits in their electrical distribution panel or the removal of some during the remodeling of a house or building.

Many times, customers in the field are interested in changing the configuration of the electrical distribution panel they ordered due to changes that were made in the field or after the electrical distribution panel was ordered. Other times, customers make mistakes when specifying the features of the electrical distribution panel they want. By using modular design, electricians can change the features of the electrical distribution panel in the field and do not have to wait to reorder an electrical distribution panel with the corrected specifications.

3.3 Concerns in Using Modularity and Commonality

As mentioned before, safety and an accurate assessment of the relative importance of certain product features to customers are two concerns that arise when one attempts to use modularity in design. In redesigning electrical distribution panels, there are also certain constraints under which one must function. Local National and Electrical codes are one as are UL standards. Other constraints are less obvious. For instance, the installation of electrical distribution panels has traditionally been done by first installing the enclosure and then installing the internal bus structure and cover at some future date. As a result, the design of electrical distribution panels must be accomplished keeping the enclosure and internal bus structure separate pieces. Any effective redesign must take both of these types of constraints into account.

An implicit assumption in the use of modularity and commonality is that there are some costs to be saved in the reduction of variety. If it costs a company relatively the same amount to manufacture a large variety of components versus
a smaller number than it might not be beneficial to reduce variety since customers almost always like more variety than less. Effective use of modularity and commonality should be used on parts of the design where cost is high due to complexity.

3.4 Conclusion

Many suggestions and recommendations were discussed in this chapter as to ways in which Acme Electric can use modularity to increase their competitive positioning in the marketplace. Some of these suggestions impact Acme Electric’s ability to use price as a strategic weapon by lowering their cost to manufacture their products while other recommendations allow Acme Electric to improve on their customer service.

To quantify some of the ideas in this section, the next chapter delves into more detail and covers a cost analysis of three sample cases of using modularity and commonality techniques. The goal here will be to try to understand the cost tradeoffs involved in making the decision to use this design strategy and to see the potential economic impact such a strategy can have.
4. Economic Implications of using Modularity and Commonality

The purpose of this chapter is to quantify some of the ideas presented in the previous chapter. Three separate cases were chosen that exemplify some of the issues and decisions Acme Electric will face in adopting a modular design strategy. These are:

- Case 1: Enclosure & Cover Reduction Rationalization
- Case 2: Cost of Offering both Copper and Aluminum Bus Bars
- Case 3: Modular Design vs Non Modular Design

Note that all of the cost data in this Chapter has been disguised for the sake of confidentiality.

4.1 Case 1: Enclosure & Cover Reduction Rationalization

4.1.1 Goal

The use of modularity and commonality in product design allows a company to reduce the cost of manufacturing a large variety of products. The use of this strategy, however, depends on the fact that a certain number of common components must be used across the product line to enable the company to achieve cost reduction through economies of scale. The tradeoff here, is the disutility of not providing each customer with a module fitting their exact requirements and the economies of scale achieved in producing and inventorying a large number of the same part. The goal of Case 1 will be to study this tradeoff in more detail and determine some of the factors that influence the
decision of when a company should use common components and when they should not.

The focus for this study will be to look at the number of different enclosure options that Acme Electric currently offers their customers and look for ways in which this number can be reduced. Currently, Acme Electric produces approximately 30 different enclosure sizes, one for every different electrical distribution panel specification. As the number of different enclosure sizes rises so does the cost to manufacture this variety. In the attempt to reduce cost, the question arises as to whether or not 30 different enclosure sizes are really needed to satisfy customers and whether a smaller set of enclosures will suffice. The potential cost savings in reducing the number of enclosures is increased when one considers the fact that Acme Electric manufactures up to four different types of covers for every enclosure type. By reducing the number of types of enclosures by one, Acme Electric can reduce the number of covers that must be produced by as much as four.

4.1.2 Approach

The cost of an enclosure and cover is determined by three factors, material, labor and overhead. Figure 4.1 shows an example of the comparison being made. In this figure the decision is to determine whether or not it would be feasible to make the reduction from four different enclosure types to two different enclosure types. The increase in cost between the two options is the material dollars being given away to customers who would settle for a smaller size enclosure. For example, those customers that originally received enclosure C, now get enclosure D which contains more material and thus has a higher material cost.
The decrease in cost is the overhead and direct labor dollars saved from having fewer enclosure types to manufacture. Some of the overhead expenditures that might be reduced are material movement, supervision, mfg engineering, records and maintenance, etc. Other overhead expenditures do not change with the reduction in the number of enclosures. These are buildings & grounds, depreciation, property tax, etc. The importance that a particular customer places on having or not having a particular size enclosure will also have an effect on determining whether a reduction in the number of enclosures is a good solution as an unhappy customer will result in lost revenue. A summary of the cost tradeoff involved can be seen in Table 4.1 below.
Table 4.1  
Cost Tradeoff for Enclosure & Cover Reduction Rationalization

<table>
<thead>
<tr>
<th>Increase</th>
<th>Decrease</th>
<th>Unchanged/Uncertain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material Dollars</td>
<td>Labor Dollars</td>
<td>Customer Utility</td>
</tr>
<tr>
<td></td>
<td>OH Dollars</td>
<td>OH Dollars</td>
</tr>
<tr>
<td></td>
<td>Maintenance - Material</td>
<td>Buildings &amp; Grounds</td>
</tr>
<tr>
<td></td>
<td>Maintenance - Records</td>
<td>Depreciation</td>
</tr>
<tr>
<td></td>
<td>Storeroom Transaction</td>
<td>Major Maintenance</td>
</tr>
<tr>
<td></td>
<td>Direct Overtime</td>
<td>Property Taxes</td>
</tr>
<tr>
<td></td>
<td>Mfg Engineering</td>
<td>Etc.</td>
</tr>
<tr>
<td></td>
<td>Purchasing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Supervision</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Etc.</td>
<td></td>
</tr>
</tbody>
</table>

Note that for enclosures and covers the customer utility for a change in the number of different enclosure options is uncertain. This can be attributed to the fact that although customers, in general, prefer a larger enclosure it is unclear if customers will settle for fewer options.

4.1.3 General Equation

The general expression that captures the cost tradeoff between two different enclosure options is as follows: (in per year dollars)

\[ \Delta OH_{\text{covers & encl}} + (\Delta L_{\text{covers & encl}}) \cdot V + (\Delta M_{\text{covers & encl}}) \cdot V + \Delta U_{\text{covers & encl}} >= 0 \]

where:
\[ \Delta = \text{Difference between two different enclosure options offered.} \]
\[ V = \text{Production Volume of both options} \]
\[ \Delta U = \text{Change in Customer Utility between two options} \]
\[ \Delta M = \text{Change in Material Dollars between two options} \]
\[ \Delta OH = \text{Change in Overhead Dollars between two options} \]
\[ \Delta L = \text{Change in Direct Labor Dollars between two options} \]
An option will be feasible if the savings in overhead and direct labor dollars outweigh the increase in material cost incurred for that same product option.

4.1.4 Analysis

By applying this equation to different enclosure options, a comparison can be made that will help Acme Electric determine the optimum number of different enclosure options that should be offered. For simplification purposes, the focus for this analysis will be restricted to only one of the width options available and to the five different enclosure options shown in Table 4.2. These five enclosure options were chosen at random and were used simply to provide a good range of options for the analysis.

<table>
<thead>
<tr>
<th># Different Enclosure Types</th>
<th>% Reduction in number of options</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>No change</td>
</tr>
<tr>
<td>12</td>
<td>35% Reduction</td>
</tr>
<tr>
<td>8</td>
<td>55% Reduction</td>
</tr>
<tr>
<td>4</td>
<td>77% Reduction</td>
</tr>
<tr>
<td>1</td>
<td>Maximum Reduction</td>
</tr>
</tbody>
</table>

\( \Delta \) Labor Dollars

For the purposes of this analysis, we will assume that the direct labor (per year) in producing covers and enclosures does not change as one varies the different number of enclosure types offered.
\( \Delta \) Material Dollars

The change in material dollars can be calculated by taking the difference between the material cost of the enclosures that the customers received originally versus the current material cost of the new options. The new material cost for each replacement enclosure can be determined by first multiplying the sum of the production volumes of the missing enclosures by the material cost/unit of the enclosure that will replace them and by then subtracting from this the original material cost of this subset of enclosures. The sum of the change in material cost for each of these replacement enclosures equals the total change in material dollars incurred. Figure 4.2 shows an example of a simple material calculation where Enclosure B will replace Enclosure A & Enclosure B and Enclosure D will replace Enclosure C & Enclosure D.

\[ \Delta \text{Total Material Dollars} = \]
\[ [(V_a+V_b)*M_b - ((V_a*M_a)+(V_b*M_b))] + [(V_c+V_d)*M_d - ((V_c*M_c)+(V_d*M_d))] \]

The methods for deciding which enclosure options to keep is explained in Section 1.6 of this Chapter, titled "Issues: Decision of Which Enclosure Options to Choose".
Overhead Dollars

The change in overhead dollars depends on Acme Electric’s current costing system. Figure 4.3 shows the setup for Acme Electric’s current allocation of overhead dollars. By using appropriate cost drivers, such as the number of part numbers, Acme Electric allocates their general overhead cost pools to activity centers according to the percentage of cost driver that is attributed to that activity center. Figure 4.4 shows an example of the method of allocation of the cost pool Purchases across the different activity centers. In studying the change in overhead dollars for enclosures and covers, focus will be placed on reducing the overhead dollars allocated to the Enclosure Activity Center and the Cover Activity Center.

The change in overhead dollars can be determined by studying how sensitive the cost drivers are to changes in the number of enclosure types offered. For instance, the number of part numbers within an activity center is often used as a cost driver. In reducing the number of enclosure types from 20 to 10, this cost driver will most likely be reduced by 50%. The assumption that is made is that the cost allocated to the activity center by this cost driver will also drop by 50%.

It is important to note that in the short run, this method of determining the change in overhead dollars will not result in any change in overhead dollars as the plant has already incurred this cost. In the long run, however, these changes in the cost driver should give an approximation as to how much the overhead dollars will shrink over the long run given that the plant only has to produce 50% of the variety they had to previously.
Figure 4.3

Acme Electric Plant Overhead *

$9,706K

<table>
<thead>
<tr>
<th>Production Related/Production Support</th>
<th>Scheduling</th>
<th>...</th>
<th>Quality Inspections</th>
<th>Depreciation</th>
<th>Shipping Supplies</th>
<th>...</th>
<th>Utilities</th>
</tr>
</thead>
</table>

Cost Drivers
# of Part #
DL Hours
# Tools
Etc.

<table>
<thead>
<tr>
<th>Enclosures $317K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depreciation $51K</td>
</tr>
<tr>
<td>Prod Related $28K</td>
</tr>
<tr>
<td>Scheduling $26K</td>
</tr>
<tr>
<td>etc.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Covers $1,523K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depreciation $156K</td>
</tr>
<tr>
<td>Prod Related $56K</td>
</tr>
<tr>
<td>Scheduling $18K</td>
</tr>
<tr>
<td>etc.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Internal Structure $1,145K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depreciation $112K</td>
</tr>
<tr>
<td>Production Related $19K</td>
</tr>
<tr>
<td>Scheduling $38K</td>
</tr>
<tr>
<td>etc.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Etc</td>
</tr>
</tbody>
</table>

Activity Centers

* Note: This data has been disguised.
Figure 4.4

ACTIVITY BASED COST ASSIGNMENT

FIRST STAGE DRIVERS
DRIVEN BY NUMBER OF
PART NUMBERS

<table>
<thead>
<tr>
<th>Part Numbers</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>122</td>
<td>26.4%</td>
</tr>
<tr>
<td>53</td>
<td>11.4%</td>
</tr>
<tr>
<td>53</td>
<td>11.2%</td>
</tr>
<tr>
<td>10</td>
<td>2.1%</td>
</tr>
<tr>
<td>67</td>
<td>14.5%</td>
</tr>
<tr>
<td>25</td>
<td>5.4%</td>
</tr>
<tr>
<td>23</td>
<td>4.9%</td>
</tr>
<tr>
<td>2</td>
<td>0.4%</td>
</tr>
<tr>
<td>4</td>
<td>0.8%</td>
</tr>
<tr>
<td>73</td>
<td>15.8%</td>
</tr>
<tr>
<td>30</td>
<td>6.5%</td>
</tr>
</tbody>
</table>

ACTIVITY CENTER

PRODUCT A

PRODUCT B

PRODUCT C

PRODUCT D

PRODUCT E

PRODUCT F

ENCLOSURE A

ENCLOSURE B

ENCLOSURE C

INTERNAL STRUCTURE

INTERPLANT PARTS

COST POOL

$2,767

$1,198

$1,177

$226

$1,521

$571

$517

$47

$89

$1,658

$686

Total Part Numbers: 461

Total: $10,458

Note: This data has been disguised.
4.1.5 Results

The results of this analysis follow the intuition that as the number of different enclosure options drops so does the cost to produce this variety.

**Δ Material Dollars**

Table 4.3 shows the change in material cost incurred for the different enclosure options and the corresponding percentage reduction in overhead dollars needed to cover this increase in cost. In looking at this table, some immediate insights can be drawn.

Table 4.3
Change in Material Dollars for Various Enclosure Options

<table>
<thead>
<tr>
<th># Different Enclosures</th>
<th>Enclosures</th>
<th>Δ Material</th>
<th>% Δ OH</th>
<th>Covers</th>
<th>Δ Material</th>
<th>% Δ OH</th>
<th>Total</th>
<th>Δ Material</th>
<th>% Δ OH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Needed</td>
<td></td>
<td></td>
<td>Needed</td>
<td></td>
<td></td>
<td>Needed</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>$0</td>
<td>0%</td>
<td></td>
<td>$0</td>
<td>0%</td>
<td></td>
<td>$0</td>
<td>0%</td>
</tr>
<tr>
<td>12</td>
<td>$7,163</td>
<td>2.26%</td>
<td></td>
<td>$1,696</td>
<td>.11%</td>
<td></td>
<td>$8,859</td>
<td>.48%</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>$28,313</td>
<td>8.93%</td>
<td></td>
<td>$11,742</td>
<td>.77%</td>
<td></td>
<td>$40,055</td>
<td>2.18%</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>$252,396</td>
<td>79.62%</td>
<td></td>
<td>$314,349</td>
<td>20.64%</td>
<td></td>
<td>$566,745</td>
<td>30.80%</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>$1,033,858</td>
<td>326%</td>
<td></td>
<td>$845,912</td>
<td>55%</td>
<td></td>
<td>$1,879,770</td>
<td>102%</td>
<td></td>
</tr>
</tbody>
</table>

Disguised Data

These are:

- Reduction to 1 enclosure requires 102% savings in overhead dollars which is probably infeasible.

- 8 Enclosures requires 2.18% savings in overhead dollars which is feasible. Although less than 8 enclosures may also be feasible, the customer utility for the number of enclosure options beyond this point might begin to diminish.
• The material cost for enclosures is much higher than the material cost for covers

Δ OH Dollars

Figure 4.5 and 4.6 show the top 70% of the cost pools allocated to enclosures and covers, the associated cost driver and the potential percentage decrease in overhead cost for the chosen enclosure options. These percentage decrease in cost drivers were obtained through discussion with the manufacturing engineers at Acme Electric, and through estimates based on current knowledge of plant operations.

As can be seen by comparing the two figures:

• Most of the overhead savings can be attributed to covers. This makes intuitive sense as the process of manufacturing covers is more complex than the process to manufacture enclosures. In addition, the reduction in one enclosure results in a reduction of almost four cover types.

• The maximum amount of OH savings is $303K or 16% of the overhead dollars allocated to both enclosures and covers. Table 4.4 shows the overhead savings for various enclosure options.

Table 4.4
Overhead Savings for Different Enclosure Types

<table>
<thead>
<tr>
<th># Different Enclosure Types</th>
<th>OH Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>$125K</td>
</tr>
<tr>
<td>8</td>
<td>$169K</td>
</tr>
<tr>
<td>4</td>
<td>$257K</td>
</tr>
<tr>
<td>1</td>
<td>$303K</td>
</tr>
</tbody>
</table>

Disguised Data
• There are diminishing marginal returns, i.e. as one continues to decrease the number of enclosures down to one, one saves less and less in overhead.
Figure 4.5 Enclosure Activity Center ($317K) *

**Tradeoff: 20 Different Enclosure Types to 12,8,4 & 1 Different Enclosure Types**

<table>
<thead>
<tr>
<th>Cost Pool</th>
<th>Total</th>
<th>Key Driver</th>
<th>%Δ Driver</th>
<th>Δ OH</th>
<th>%Δ Driver</th>
<th>Δ OH</th>
<th>%Δ Driver</th>
<th>Δ OH</th>
<th>%Δ Driver</th>
<th>Δ OH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maint. Material</td>
<td>$12,706</td>
<td>Square Ft Used</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
</tr>
<tr>
<td>Depreciation</td>
<td>$35,950</td>
<td>Depreciation</td>
<td>15%</td>
<td>$5,392</td>
<td>25%</td>
<td>$8,987</td>
<td>30%</td>
<td>$10,785</td>
<td>40%</td>
<td>$14,380</td>
</tr>
<tr>
<td>Equipment Repair</td>
<td>$17,485</td>
<td>Tracked</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
</tr>
<tr>
<td>Insurance</td>
<td>$10,926</td>
<td>Tracked</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
</tr>
<tr>
<td>Maint. Project Work</td>
<td>$8,150</td>
<td>Tracked</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
</tr>
<tr>
<td>Maint of Facilities</td>
<td>$8,716</td>
<td>Square Ft Used</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
</tr>
<tr>
<td>Marketing</td>
<td>$6,781</td>
<td># Part #</td>
<td>35%</td>
<td>$2,373</td>
<td>50%</td>
<td>$3,390</td>
<td>80%</td>
<td>$5,425</td>
<td>90%</td>
<td>$6,103</td>
</tr>
<tr>
<td>Mfg Engineering</td>
<td>$23,337</td>
<td># Hours</td>
<td>15%</td>
<td>$3,500</td>
<td>30%</td>
<td>$7,001</td>
<td>60%</td>
<td>$14,002</td>
<td>60%</td>
<td>$14,002</td>
</tr>
<tr>
<td>Productive Supplies</td>
<td>$19,827</td>
<td>Tracked</td>
<td>5%</td>
<td>$991</td>
<td>10%</td>
<td>$1,983</td>
<td>20%</td>
<td>$3,965</td>
<td>20%</td>
<td>$3,965</td>
</tr>
<tr>
<td>Property Taxes</td>
<td>$9,767</td>
<td>Tracked</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
</tr>
<tr>
<td>Purchasing</td>
<td>$8,520</td>
<td># Purchased Parts</td>
<td>25%</td>
<td>$2,130</td>
<td>40%</td>
<td>$3,408</td>
<td>60%</td>
<td>$5,112</td>
<td>60%</td>
<td>$5,112</td>
</tr>
<tr>
<td>Scheduling</td>
<td>$18,358</td>
<td># Part #</td>
<td>35%</td>
<td>$6,425</td>
<td>50%</td>
<td>$9,179</td>
<td>80%</td>
<td>$14,687</td>
<td>90%</td>
<td>$16,522</td>
</tr>
<tr>
<td>Supervision</td>
<td>$5,232</td>
<td># Hourly Workers</td>
<td>20%</td>
<td>$1,046</td>
<td>30%</td>
<td>$1,570</td>
<td>40%</td>
<td>$2,093</td>
<td>60%</td>
<td>$3,139</td>
</tr>
<tr>
<td>Toolroom</td>
<td>$7,805</td>
<td># Tools</td>
<td>15%</td>
<td>$1,171</td>
<td>25%</td>
<td>$1,951</td>
<td>50%</td>
<td>$3,903</td>
<td>80%</td>
<td>$6,244</td>
</tr>
<tr>
<td>Utilities</td>
<td>$18,316</td>
<td>Square Ft Used</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
</tr>
<tr>
<td>Other</td>
<td>$105,582</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Overhead</td>
<td>$317,457</td>
<td>OH Savings</td>
<td>$23,036</td>
<td></td>
<td>$37,469</td>
<td></td>
<td>$59,971</td>
<td></td>
<td>$69,467</td>
<td></td>
</tr>
</tbody>
</table>

* Note: The Cost Data, Cost Drivers and OH Cost Pools in this Exhibit have been disguised.
### Figure 4.6 Cover Activity Center ($1,523K)*

**Tradeoff: 20 Different Enclosure Types to 12,8,4 & 1 Different Enclosure Types**

<table>
<thead>
<tr>
<th>Cost Pool</th>
<th>Total</th>
<th>Key Driver</th>
<th>%Δ Driver</th>
<th>Δ OH</th>
<th>%Δ Driver</th>
<th>Δ OH</th>
<th>%Δ Driver</th>
<th>Δ OH</th>
<th>%Δ Driver</th>
<th>Δ OH</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>12 Boxes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depreciation</td>
<td>$109,880</td>
<td>Depreciation</td>
<td>15%</td>
<td>$16,482</td>
<td>25%</td>
<td>$27,470</td>
<td>30%</td>
<td>$32,964</td>
<td>40%</td>
<td>$43,952</td>
</tr>
<tr>
<td>Design ECO's</td>
<td>$16,257</td>
<td># ECO's</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
</tr>
<tr>
<td>Design</td>
<td>$9,311</td>
<td># Part #</td>
<td>35%</td>
<td>$3,259</td>
<td>50%</td>
<td>$4,656</td>
<td>80%</td>
<td>$7,449</td>
<td>90%</td>
<td>$8,380</td>
</tr>
<tr>
<td>Direct Overtime</td>
<td>$9,084</td>
<td># Hrs Overtime</td>
<td>35%</td>
<td>$3,179</td>
<td>50%</td>
<td>$4,542</td>
<td>60%</td>
<td>$5,450</td>
<td>60%</td>
<td>$5,450</td>
</tr>
<tr>
<td>Equip Repair</td>
<td>$66,781</td>
<td>Tracked</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
</tr>
<tr>
<td>Maint Facilities</td>
<td>$85,145</td>
<td>Square Ft Used</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
</tr>
<tr>
<td>Maint Material</td>
<td>$76,201</td>
<td>Tracked</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
</tr>
<tr>
<td>Marketing</td>
<td>$35,158</td>
<td># Part #</td>
<td>35%</td>
<td>$12,305</td>
<td>50%</td>
<td>$17,579</td>
<td>80%</td>
<td>$28,126</td>
<td>90%</td>
<td>$31,642</td>
</tr>
<tr>
<td>Mfg Engineering</td>
<td>$72,490</td>
<td># Hours</td>
<td>20%</td>
<td>$14,498</td>
<td>30%</td>
<td>$21,747</td>
<td>60%</td>
<td>$43,494</td>
<td>60%</td>
<td>$43,494</td>
</tr>
<tr>
<td>Outside Services</td>
<td>$7,115</td>
<td>Square Ft Used</td>
<td>0%</td>
<td>$0</td>
<td>15%</td>
<td>$1,067</td>
<td>20%</td>
<td>$1,423</td>
<td>20%</td>
<td>$1,423</td>
</tr>
<tr>
<td>Maintenance</td>
<td>$82,953</td>
<td>Tracked</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
</tr>
<tr>
<td>Supplies</td>
<td>$37,369</td>
<td>Tracked</td>
<td>5%</td>
<td>$1,868</td>
<td>10%</td>
<td>$3,737</td>
<td>20%</td>
<td>$7,474</td>
<td>20%</td>
<td>$7,474</td>
</tr>
<tr>
<td>Property Taxes</td>
<td>$25,946</td>
<td>Property Tax $</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
<td>0%</td>
<td>$0</td>
</tr>
<tr>
<td>Scheduling</td>
<td>$12,690</td>
<td># Part #</td>
<td>50%</td>
<td>$6,345</td>
<td>50%</td>
<td>$6,345</td>
<td>80%</td>
<td>$10,152</td>
<td>90%</td>
<td>$11,421</td>
</tr>
<tr>
<td>Storerm Trans</td>
<td>$38,585</td>
<td># Storerm Trans.</td>
<td>40%</td>
<td>$15,434</td>
<td>40%</td>
<td>$15,434</td>
<td>45%</td>
<td>$17,363</td>
<td>50%</td>
<td>$19,293</td>
</tr>
<tr>
<td>Supervision</td>
<td>$54,391</td>
<td># Hrly Workers</td>
<td>30%</td>
<td>$16,317</td>
<td>30%</td>
<td>$16,317</td>
<td>40%</td>
<td>$21,757</td>
<td>60%</td>
<td>$32,635</td>
</tr>
<tr>
<td>Toolroom</td>
<td>$25,260</td>
<td># Tools</td>
<td>25%</td>
<td>$6,315</td>
<td>25%</td>
<td>$6,315</td>
<td>50%</td>
<td>$12,630</td>
<td>80%</td>
<td>$20,208</td>
</tr>
<tr>
<td>Utilities</td>
<td>$42,137</td>
<td>Square Ft Used</td>
<td>15%</td>
<td>$6,321</td>
<td>15%</td>
<td>$6,321</td>
<td>20%</td>
<td>$8,427</td>
<td>20%</td>
<td>$8,427</td>
</tr>
<tr>
<td><strong>1 Box</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Overhead $</td>
<td>$1,523,000</td>
<td>OH Savings</td>
<td>$102,324</td>
<td></td>
<td>$131,529</td>
<td></td>
<td>$196,709</td>
<td></td>
<td>$233,798</td>
<td></td>
</tr>
</tbody>
</table>

*Note: The Cost Data, Cost Drivers and OH Cost Pools in this Exhibit have been disguised.*
Tradeoff

As can be seen by Figure 4.7, the minimum number of enclosure types that Acme Electric can produce without increasing their costs is approximately 8. Producing enclosures between 1 and 8 will result in an increase in cost. Any option between 8 and 12 will result in cost savings of approximately $116K to $129K. This suggests that there is a wide range of options that can be chosen with approximately the same amount of savings.

**OH$ and Material$ Tradeoff**

![Graph showing OH$ and Material$ Tradeoff with a range of different enclosure options and their corresponding savings and dissavings.]

**Figure 4.7**

A summary of the cost saved for certain enclosure options can be found in Table 4.5.
Table 4.5
Potential Cost Savings

<table>
<thead>
<tr>
<th># Different Enclosure Types</th>
<th>Cost Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>$117K</td>
</tr>
<tr>
<td>8</td>
<td>$129K</td>
</tr>
<tr>
<td>4</td>
<td>-$310K</td>
</tr>
<tr>
<td>1</td>
<td>-$1,577K</td>
</tr>
</tbody>
</table>

4.1.6 Issues

Choosing the Correct Number of Enclosure Options

The number of enclosure options that Acme Electric decides to actually use, depends on two additional factors besides cost. The first is customer utility. As the number of different options provided by Acme Electric increases, there will exist a point at which customers will not care if an additional product option is offered. For instance, the difference between offering 100 different product options and 105 different product options probably makes no difference in the customer's mind. However the difference between offering 7 options versus 15 different options might make a difference. Figure 4.8 shows this relationship between customer utility and the number of different enclosure options offered. In trying to choose the optimum number of enclosure options to offer, Acme Electric should make sure that they choose a number where the marginal return to the customer of an additional product option is not large.
At a certain point customers do not care anymore

Customer Utility

# Different Enclosure Options

Figure 4.8
Diminishing Marginal Returns for Different Enclosure Options

Given that Acme Electric does not change their pricing strategy and keeps the prices of their enclosures the same, the price sensitivity of a customer also plays a role in determining the number of enclosures that Acme Electric should choose. If a customer is really sensitive to the price of a enclosure then providing that customer with a larger, more expensive enclosure will most likely result in an unhappy customer. On the other hand, if the customer is not sensitive to price then providing that customer with a more expensive enclosure will not have any adverse affect on customer relations.

Pricing Strategy
An additional issue to consider if Acme Electric decides to reduce the number of enclosures is the decision of how to price the remaining enclosures. In a price sensitive market Acme Electric might want to price their enclosures differently than they currently do in order not to offend customers who might otherwise have to pay a higher price for a larger enclosure. They might also want to give
the customer something in return for taking away part of the range of choices previously offered. A pricing strategy to use might be to price the replacement enclosure as the average of the prices of the missing enclosures.

The cost savings that Acme Electric has achieved through the reduction of enclosures also places Acme Electric in a prime position to use price as a strategic weapon. Thus another pricing strategy that Acme Electric might want to use is to price lower than their competition and possibly steal customers away from their competitors.

**Decision of Which Enclosures to Choose**

In reducing the number of enclosures, the decision needs to be made as to which enclosure sizes should be kept and which should be thrown out. Figure 4.8 shows the different type of enclosure options that are available at Acme Electric and the yearly volume of each type. In reducing the number of enclosure types, production volume was chosen as the determinant of which enclosures to use and which to throw out. Thus if Acme Electric only wanted to use three enclosure options, the enclosures with the highest volume would be chosen.

According to Figure 4.8 this would be the enclosures L6, L14 and L20. Note that the L20 enclosure was chosen in place of the L10 enclosure, the next highest volume, because the L20 enclosure can hold all types of internal structures. Volume was chosen as a decision making factor because it is an indication of what the customers prefer. By keeping the option that customers want, Acme Electric can minimize the negative feelings that might occur from reducing the product options available to their customers.
The material cost of each option is another decision making factor that could have been used to decide which enclosure sizes to keep. Since the choice of enclosure size ultimately determines the amount of material dollars that one must give away, a company should choose the combination of enclosure options that minimizes this cost.

4.1.7 Summary

A summary of the major results of this analysis is listed below:

- The optimum number of enclosure options to provide should be between 8 and 12.

- The decision of which number of options to provide within this range depends on customer preference and a customer’s price sensitivity.
Once the optimum number of enclosure options has been chosen, a good pricing and marketing strategy must be chosen to insure the smooth transition of the reduction of variety within the marketplace.

The material cost and volume of various options are two methods that can be used to determine which options should be chosen and which should be thrown away.

Most of the OH savings were achieved through the covers while most of the material cost incurred were through enclosures. This implies that Acme Electric might look for ways to reduce the number of cover options without reducing the number of enclosure options to achieve an even greater cost savings than was achieved in this analysis.

4.2 Case 2: Cost of Offering both Copper and Aluminum Bus Bars

4.2.1 Goal

In Case 1, an attempt was made to determine the decision making factors involved in determining how to reduce variety. The purpose of Case 2 will be to take a closer look at the cost of variety by analyzing the cost associated in adding additional variety and the decision making factors involved in whether or not this variety should be added. More specifically, if $A = \{a_1, a_2, \ldots, a_n\}$ where $A$ is a module and $a_1, a_2, \ldots, a_n$ represent the variants of module $A$, then Case 2 studies the impact and cost of adding $a_{n+1}$ to $A$ so that $A = \{a_1, a_2, \ldots, a_n, a_{n+1}\}$.

Acme Electric currently offers both copper and aluminum bus bars to their customers. Although there exists a customer perception that copper is better than aluminum, aluminum is cheaper and costs less. The focus for this case will be to determine if it would be more cost effective to provide only copper and share the cost savings through lower prices or continue to offer both types.
An additional insight into this analysis might be the possibility of providing both copper and aluminum bus bars for certain product options and only copper for other product options. For example, Figure 4.9 shows a sample case of where it would make sense to offer only copper bus bars for the majority of the different product options but offer both copper and aluminum bus bars for a product option that happens to attract a large number of aluminum customers.

Hypothetical Case of Selective Variety

![Graph showing customer utility and material options]

Different Electrical Distribution Panel Options

Figure 4.9
Hypothetical Case of Selective Variety

4.2.2 Approach

The approach used in this analysis is similar to the one used in Case 1. The tradeoff is the increase in material cost of providing copper instead of aluminum and the decrease in overhead and direct labor dollars saved in only having to inventory and handle one material. As in Case 1, the customer’s preference of
copper versus aluminum bus bars will have a large impact on the outcome of this tradeoff. A summary of the changes in overhead dollars and material dollars for Copper and Aluminum bus bars can be seen below in Table 4.6.

<table>
<thead>
<tr>
<th>Increase</th>
<th>Decrease</th>
<th>Unchanged/Uncertain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material Dollars for replacing Al with Cu</td>
<td>Customer Utility</td>
<td>OH Dollars</td>
</tr>
<tr>
<td></td>
<td>Labor Dollars</td>
<td>Buildings &amp; Grounds</td>
</tr>
<tr>
<td></td>
<td>OH Dollars</td>
<td>Depreciation</td>
</tr>
<tr>
<td></td>
<td>Mfg Engineering</td>
<td>Major Maintenance</td>
</tr>
<tr>
<td></td>
<td>Storeroom Transaction</td>
<td>Property Taxes</td>
</tr>
<tr>
<td></td>
<td>Records - Maintenance</td>
<td>Etc.</td>
</tr>
<tr>
<td></td>
<td>Material Movement</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Etc.</td>
<td></td>
</tr>
</tbody>
</table>

4.2.3 General Equation

The general expression that captures the cost tradeoff between offering both copper and aluminum versus just offering copper is as follows:

\[ \Delta OH_{Cu&Al to Cu} + (\Delta L_{Cu&Al to Cu}) \times V + (\Delta M_{Cu&Al to Cu}) \times V + \Delta U_{Cu&Al to Cu} > 0 \]

where:
\[ \Delta U = \text{Change in Customer Utility between the two options} \]
\[ \Delta M_{Cu&Al} = \text{Change in Material dollars in replacing Al with Cu} \]
\[ \Delta OH_{Cu&Al} = \text{Change in Overhead dollars in only providing Cu bus bars} \]
\[ \Delta LC_{Cu&Al} = \text{Change in Labor dollars for only providing Cu bus bars} \]

From a cost standpoint, Acme Electric should provide only copper bus bars if this inequality holds true.
4.2.4 Analysis

Δ Labor Dollars
For simplifications purposes, we will once again assume that labor does not change as one changes from offering both bus bar materials to only one.

Δ Material Dollars
The change in material dollars can be calculated simply by figuring out the dollar amount of copper that would be needed to replace those bus bars made out of aluminum.

Δ OH Dollars

Similar to Case 1, the change in overhead dollars can be calculated by first determining the sensitivity of the cost drivers to the change between the two options and then by applying this sensitivity to the cost pools allocated by these cost drivers. Our analysis will focus on the Internal Bus Structure activity center.

4.2.5 Results

The results indicate that the material cost incurred in trying to provide all copper bus bars exceeds the savings achieved in only having to provide one bus bar material type.

The increase in material cost is equal to $590,000 while the overhead dollars saved is only $59,254. Figure 4.10 shows in detail the calculations for activity center. From a cost standpoint, Acme Electric should continue to provide copper and aluminum bus bars.
**Figure 4.10 Internal Structure Activity Center ($1145K)**

**Tradeoff:** Copper and Aluminum to Just Copper

<table>
<thead>
<tr>
<th>Cost Pool</th>
<th>Total</th>
<th>Key Driver</th>
<th>%Δ Driver</th>
<th>Δ OH</th>
</tr>
</thead>
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<tr>
<td>Maint Material</td>
<td>$62,044</td>
<td>Square Ft Used</td>
<td>0%</td>
<td>$0</td>
</tr>
<tr>
<td>Cost Accounting</td>
<td>$8,006</td>
<td># Hourly Workers</td>
<td>0%</td>
<td>$0</td>
</tr>
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<td>Depreciation</td>
<td>$144,913</td>
<td>Depreciation</td>
<td>0%</td>
<td>$0</td>
</tr>
<tr>
<td>Design ECO's</td>
<td>$16,471</td>
<td># ECO's</td>
<td>0%</td>
<td>$0</td>
</tr>
<tr>
<td>Design</td>
<td>$9,378</td>
<td>Design Support</td>
<td>25%</td>
<td>$2,345</td>
</tr>
<tr>
<td>Div 16</td>
<td>$16,641</td>
<td>Tracked</td>
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<td>$0</td>
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<tr>
<td>Labor Relations</td>
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<td>10%</td>
<td>$861</td>
</tr>
<tr>
<td>Safety</td>
<td>$9,701</td>
<td># Hourly Workers</td>
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</tr>
<tr>
<td>Insurance</td>
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<td>Tracked</td>
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<td>$0</td>
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<tr>
<td>Maint - Equip Repair</td>
<td>$58,829</td>
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<tr>
<td>Mfg Eng</td>
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<tr>
<td>Miscellaneous</td>
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<tr>
<td>General Administration</td>
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<td>Quality Related</td>
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<tr>
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</tr>
<tr>
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<td># Part#</td>
<td>50%</td>
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<td>$0</td>
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<td>$0</td>
</tr>
<tr>
<td>Quality</td>
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<td>Time of QA Support</td>
<td>25%</td>
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<tr>
<td>Storerm Trans P1</td>
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<td># Storeroom Trans</td>
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</tr>
<tr>
<td>Tooling</td>
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<td># Tools</td>
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<td>$0</td>
</tr>
<tr>
<td>Utilities</td>
<td>$95,852</td>
<td>Square Ft Used</td>
<td>0%</td>
<td>$0</td>
</tr>
<tr>
<td>Other</td>
<td>$205,577</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Overhead</strong></td>
<td>$1,145,000</td>
<td>Total Overhead Saved</td>
<td></td>
<td>$59,254</td>
</tr>
</tbody>
</table>

*Note: The Cost Data and Cost Drivers in this Exhibit have been disguised.*
Figure 4.11 shows the demand for copper bus bar lighting panels and aluminum bus bar lighting panels for each type of electrical distribution panel option. As can be seen by the figure, both copper customers and aluminum customers like the same product options, i.e., there is no product option that is particular to aluminum customers or vice versa. This makes intuitive sense when one considers the fact that the decision of what electrical distribution panel to buy is independent of the decision of whether one should have aluminum or copper bus bars.

**Demand for Copper vs Aluminum for Different Electrical Distribution Panel Options**

![Graph showing demand for copper vs aluminum for different electrical distribution panel options.]

**Figure 4.11**
Copper and Aluminum Demand for Different Electrical Distribution Panel Options
4.2.6 Issues

Marketing Strategy

If Acme Electric decides to only provide copper bus bars, the next decision they must face is how to market this new option. Since Acme Electric no longer provides aluminum bus bars as an option, they risk losing all of their aluminum customers. To remedy this, Acme Electric could potentially give copper bus bars to the customers requesting aluminum. However, this solution will cause Acme Electric to lose money by giving away a more expensive option to those customers that would be happier with a lesser option. This marketing strategy may also present problems in the future if customers find out. Acme Electric can also try to educate their customers on the benefits of using copper bus bars and try to persuade their customers of the benefits of this change.

Pricing Strategy

An additional problem that arises is in the decision of how to price the various options. For instance, by keeping pricing the same as before, aluminum customers will not only be faced with receiving a copper bus bar which they did not request, but they will also end up having to pay more for it. This runs the risk of ruining customer relations. On the other hand, if Acme Electric sells to the aluminum customers a copper bus bar electrical distribution panel at the aluminum electrical distribution panel price, Acme Electric not only loses money but risks being accused of unfair pricing policies if the copper customers find out. Thus, the pricing and marketing strategy that Acme Electric chooses to use if they decide at some point to only provide copper bus bars, will be a critical issue for the successful implementation of this change.
4.2.7 Summary

To conclude, a summary of the major results of the analysis of this case are listed below:

- Acme Electric should continue to offer both copper and aluminum bus bars.
- Pricing and Marketing is an important factor in managing the transition between providing both copper and aluminum bus bars to only providing copper.
- In comparing the results of the analysis of Case 1 and Case 2, it can be seen that reducing variety can have very different impacts on the business. For example, assume that a customer places a higher utility on having Cu vs Al bus bars than they do on having different size enclosures. The reduction of different enclosure options will thus, have less of an effect on the customer than will a reduction in the variety of bus bar materials offered which could potentially result in a loss of sales.

4.3 Case 3: Common Component Design vs Single Bus Construction

4.3.1 Goal

The goal for Case 3 is to gain some preliminary insight into the cost tradeoff between a high-variety design constructed from collections of common components and a non modular design.

4.3.2 Approach

The approach used in this analysis is as pictured in Figure 4.12. The cost tradeoff is the difference between what it currently costs to make three different product options versus the the cost of producing a large number of the same module and assembling these together.
4.3.3 General Equation

The general expression that captures the difference between the above two costs is as follows:

\[ V_a(L_a + M_a) + V_b(L_b + M_b) + V_c(L_c + M_c) + OH_{a,b,c} >? \]

\[ (n_a*V_a + n_b*V_b + n_c*V_c)(M_x + L_x) + (n_a + n_b + n_c - 3)*A_x + OH_x \]

where:

- \( n_i \) = Number of \( x \) modules needed to make \( i \)
- \( n_{i-1} \) = Number of Assembly Operations
- \( A_x \) = Assembly cost for assembling module \( x \)
- \( M_x \) = Material $/unit for module \( x \)
- \( L_x \) = Labor $/unit for module \( x \)
- \( OH_x \) = Overhead Dollars for module \( x \)
- \( M_{a,b,c} \) = Material Dollar/unit for products \( a,b,c \)
- \( L_{a,b,c} \) = Labor Dollar/unit for products \( a,b,c \)
- \( V_{a,b,c} \) = Volume for products \( a,b,c \)
- \( OH_{a,b,c} \) = Overhead Dollars for products \( a,b,c \)

4.3.4 Analysis

The accurate determination of this cost tradeoff is largely dependent on the characteristics of the common module \( x \) and the way in which this module relates to the designs it intends on replacing. As a result, a first pass at this
analysis will be a discussion of a particular modular design that can be used by Acme Electric and the impact that using this design will have on the company's competitiveness. Once, this has been determined, then a more accurate assessment as to the change in labor, overhead and material dollars for a modular design versus a non modular design can be estimated.

Three scenarios in which using modularity can potentially make the most impact for Acme Electric will be discussed.

**The Regular Electrical Distribution Panel**

Approximately 30% of the entire cost incurred by the manufacturing plant can be attributed to the design, manufacture and production of Acme Electric's main electrical distribution panel product line. As a result, the use of modularity in the design of these regular lighting panels will most likely have a large impact on Acme Electric's costs. One option for a modular design would be to make three modules, one module that consists of twelve circuits, one power input module with six circuits, and one ground plate module with six circuits. Every electrical distribution panel design in the main product line can then be made, depending on bus size, by using some combination of a set of three modules.

**“Split Bus” Panels**

By using this same set of common components, Acme Electric can also produce every different type of “split bus” panels that is currently offered to their customers. The overhead dollars used in producing these panels is extremely large due to the low volume and special processing that is required. By being able to assemble a “split bus” panel board from the same set of components as is used by the regular electrical distribution panel, Acme Electric can manufacture these panels at a lower cost and save in supervision time, number of setups,
manufacturing engineering time etc. Likewise, by designing a set of common modules that can be used in other non-main electrical distribution panel designs, Acme Electric can potentially further increase their efficiency.

**Intermix different types of switches**

Currently, Acme Electric produces two types of switches. Although one of the switch types is more convenient to use and technologically superior to the other, the industry has not yet standardized on either type and Acme Electric has been forced to providing electrical distribution panels that fit both types. By using a modular design strategy, Acme Electric can design two modules, one that fits the first type of switch and the other that fits the second type. If these two modules can then be connected together, Acme Electric can now intermix both types of switches on the same panel. This flexibility can save Acme Electric from having to offer two separate different electrical distribution panel designs and will reduce their dependence on having the industry standardize on one or the other.

**4.3.5 Issues**

**Automation**

Part of the tradeoff in cost savings in using a modular design over a non-modular design depends to a large extent on whether a company intends to automate the production of the common module. Automation will cause a large change in the overall plant operations and current plant organization. As a result, in addition to the cost tradeoff analysis outlined in this chapter, an in-depth analysis should also be done to determine if automation is a feasible solution and how much cost savings can be achieved.
Interface

The interface between two common modules is another important issue that a company using a modular design strategy should pay attention to. For instance in the use of a modular bus bar design, for instance, one must insure that two bus bars can be mated safely and effectively. In order to achieve the full benefit of a modular electrical distribution panel, one must insure that the interface between the two modules is well defined.

4.3.6 Summary

An initial cost analysis method was outlined in this section as well as a potential modular design strategy for Acme Electric's electrical distribution panel product. A next step in this analysis will be to gain an estimate as to the changes in plant operations that will occur in moving from the current design to this new design and perform an in depth analysis of the cost tradeoffs involved using the equation described here as a basis.

4.4 General Conclusions

The results of the three cases analyzed in this chapter meet the general intuition that the less variety a company has to produce, the lower the cost. The cost benefits of reducing variety, however, is only part of the story. In order for a company to achieve the full benefit from a reduction in variety, a company must also have an effective pricing and marketing strategy and the ability to manage their customers perceptions and expectations of their product line.

Two additional conclusions can be drawn in studying the results of all three cases. The first is the observation that if the material cost of a product is a high
percentage of the overall cost of the product then reducing variety does not save one any money. This is simply due to the fact that the increase in material cost given away outweighs the overhead dollars saved in taking advantage of economies of scale.

The second is that the accurate allocation of overhead dollars to product attributes is a critical factor for a successful analysis. The assumption was made in the analysis that the potential decrease in overhead dollars was directly dependent on the cost driver used its sensitivity to the various options. If the cost driver chosen does not reflect the true overhead cost that should be allocated to that product, then the decision based on this data will be inaccurate or simply wrong. Since the cases studied in this chapter have a large impact on Acme Electric's customer, a wrong decision can severely hurt the company's future success.
5. General Rules for Using Modularity and Commonality

In trying to gain a better understanding of some of the decision making factors involved in using modularity and commonality effectively, it is also important to study product decomposition. How a product is chosen to be broken down into modules has a large impact on the decision of where modularity can be used. The goal of this chapter will be to determine some of the rules in determining how a product should be broken down into modules and then determine some general rules that can be used to decide how to best use modularity and commonality in product design.

5.1 Product Decomposition

In almost every design book, one of the principles of good design is to design using modules. Surprisingly, however, little has been actually written to directly address the rationale for a particular product decomposition. Seemingly the possible reasons for choosing certain modules by designers is too fundamental an issue and is based more on common sense and intuition than any real conscious thought. As a result many of the decision making factors cited in this Chapter are based on interviews with design engineers and simple observation.

5.1.1 Rationale for Product Decomposition

Perhaps one of the most obvious rationale for product decomposition is functional. As one engineer said...

"A module can be viewed as a black box. The purpose of the existence of this module is that it performs some function and given a certain set of inputs will provide predictable known outputs
with know accuracy. The components within the black box may change over time but the module itself stays relatively constant throughout time.

Richard Gustavson

This method of decomposition is probably the most widely used because breaking tasks down by function is a natural thought process of human beings.

The rate of technological change and the use of different technologies in one product also affect the decision of what to make a module. If the rate of technological change is different for different parts of a product then designers will break the product down along these lines in order to take advantage of past designs, eliminate the time wasted in reinventing the wheel and allow for these new technologies to be easily inserted.

If the technology used differs from one part of the product to the next, then breaking the product down along these lines will enable firms to take advantage of knowledge and/or expertise in the production and use of these technologies.

For example, the electrical components of a product are almost always separated from the mechanical parts of a product.

The ability to predict future changes in product design will push designers to choose certain modules over others in an attempt to simplify the move to successive product generations. Technological breakthroughs such as surface mount technology is one example of a future change that can be utilized in a product almost immediately, without major redesign, if the printed circuit board is designed as a separate module.

The need to isolate parts of the product from each other due to safety factors or individual part performance such as excessive heat or high voltages is another obvious factor in the decision of what to make a module. For example, the
power supply of a computer is a separate module, is insulated from the electronics and is designed to remove heat.

In certain products, there exist certain parts that are consumed more quickly than the rest of the product. Examples of this might be the vacuum bag of a vacuum and/or the film in a camera. The ability to make this part of the product a module will allow designers to develop products that last a long time and that are not dependent on the length of the most quickly consumed part of the product.

The cost differential between parts is also a factor in determining a particular product decomposition. Take the camera example for instance. The cost of film is usually inordinately less than the cost of the camera itself. Thus designers made film a separate module to enable the user to simply replace the film and not the entire camera. For a disposable camera, however, the cost of the film is approximately the same as the camera itself and the two parts were not designed as separate modules.

Constraints from how a product is used in the field will also dictate product breakdown. As mentioned in the previous Chapter, customers install the enclosure at a different point in time than the internal structure. This specification by the customer prevents designers from integrating the two modules together into one.

Another reason in determining product decomposition is to provide the ability to make ones product flexible enough to accept a variety of suppliers' products. The making of two tape holders for a VCR, one to hold VCR tapes and the other to hold Beta tapes is a prime example of this concept.
A product's *attractiveness* is another rationale used in determining a particular product's decomposition. For example, Acme Electric's decision to provide four different types of covers was chosen to add additional functionality to the product but might also have been chosen to enhance the general looks of the electrical distribution panel. Similarly, the use of different materials in clothing is sometimes often more for looks then for function.

### 5.2 Decision Making Factors for using Modularity and Commonality

Given our understanding of product decomposition, the discussion will now turn to trying to put some insight into the decision making factors of when to use modularity.

#### 5.2.1 Modularity

In general, the overhead cost to manufacture a family of products is proportional to the variety of products offered. As a result, the use of modularity and commonality in design will have the most benefit if it is used strategically in product lines where the *overhead dollars allocated to these product lines is high*.

As the number of different variants of a module increases, the marginal utility to that customer diminishes. Therefore, a firm should use modularity to reduce cost in cases where the *decrease in product variants results in minimal loss of customer utility*.

The relative importance that customers place on certain product features also has an impact of what part of the product a customer should design using modular techniques. For instance, in Acme Electric's case, reducing the number of enclosures is less important to a customer than reducing the number of circuit
options available. Likewise, offering a variety of steering wheel options will have less of an effect than being able to vary the number of engine options. An increase in variety through the use of modularity should be made in those areas where the customer preference and desire for the change relative to other changes is high.

Certain industry characteristics influence the decision of how much variety a firm should provide. For instance, in the VCR industry, the two different tapes types available force a company into making a decision on whether or not they want their product to use both types of tape or only one tape. The risk a company takes in only providing one of the options is that the industry might standardize on the other option as is currently occurring in the floppy disk market. (5.25 inch disk to the 3.5 inch disk). The use of modularity can help to diminish this risk by making a company less dependent on changing industry standards and characteristics.

5.2.2 Commonality

If the cost of a module is enormous relative to the other parts of the product then making that particular module common will allow companies to reduce the cost/unit of manufacturing that module by sharing the development expense across an entire product line.

Modules that have long lead times should also be chosen to be common across all products and should be made to stock. Variability to the product should then be achieved at the last moment through modules with short lead times. This will provide a company with the competitive advantage of being able to simultaneously offer a variety of products and keep the time between customer order and shipment to minimum. Figure 5.1 exemplifies this concept.
5.3 Conclusion

There are seemingly many issues to consider in determining how to use modularity and commonality in the design of a product. An initial attempt was made in this Chapter to capture some of these rules. The hope for the future is that designers will begin to use these rules to make more effective design decisions.
6 Conclusion

The recent trend toward global competition and the need to produce a large variety of products in order to compete effectively has changed the focus of manufacturing and design into looking for new ways to manage this change. Many companies are turning toward the use of modularity and commonality in design as a way to increase their manufacturing efficiency.

Although widely used, this particular design strategy has never really been studied in depth. The focus of this thesis has been to make an initial attempt at studying the critical issues involved in using modularity and commonality effectively in design.

As clearly presented through the case study, there are many advantages and disadvantages to using this particular design strategy. The major advantage is that it provides companies with the ability to reduce cost without significantly reducing the variety or product features offered.

In addition, this design strategy can also impact the overall competitiveness of a firm by providing them with a more flexible product line which can easily change in response to market demands and technological advances.

An effective use of modular design benefits the customer as well as the company. The flexibility of modular design enables customers to delay the obsolescence of their products. They can easily reuse modular parts or expand the capabilities of their product by adding additional components.
In order for a company to achieve the full benefits from a reduction in variety, it must also have a supporting marketing strategy. By emphasizing the advantages of the new modular design, customers will perceive the change positively. Together with an appropriate pricing strategy, this will insure a smooth transition in customers' expectations.

6.1 Future Work in this Area

Several possible extensions exist for future work in this area. The first would be a continuation of the work presented in Chapter 4. An indepth cost analysis of the tradeoffs between a modular design and a regular design will help Acme Electric to better understand the overall implications of using modularity in design.

Another and perhaps more insightful extension, might be to incorporate the decision rules captured in Chapter 5 into a Rule Based Expert System which can then be used by designers in the decision making process of how to best use modularity and commonality in the design of their product.

An additional idea would be to compare the use of modular design techniques between two companies. This will provide additional insight into the reasons for using modular design and broaden the scope of this initial study.

As the business environment becomes increasingly competitive, firms will struggle to balance the tradeoffs between providing a large product diversity and the associated increase in cost. The ability for modularity and commonality to resolve many of these issues ensures that this design strategy will play an increasingly important role in companies in the future.
References

General


[16] Redford, Dr. A., "Software Aid to Design for Assembly", *Assembly Automation*, Vol.6 No. 2 May 1986


**Activity Based Costing**

