Strategic Change Management in Ship Design and Construction

by

Matthew P. Tedesco

B.S. Naval Architecture and Marine Engineering. Webb Institute, 1991
S.M. Ocean Systems Management, MIT, 1994
S.M. Naval Architecture and Marine Engineering, MIT, 1994

Submitted to the Department of Ocean Engineering
in partial fulfillment of the requirements for the degree of

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in Engineering Management

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Signature of Author ______________________________
Department of Ocean Engineering
February 13, 1998

Certified by ______________________________
Henry S. Marcus
NAVSEA Professor of Ship Acquisition
Thesis Supervisor

Accepted by ______________________________
Kim Vandiver
Departmental Graduate Committee
Department of Ocean Engineering

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ABSTRACT

This research focuses on elective changes which are introduced to improve productivity. The "quality movement" of the last decade has resulted in a significant increase in both the pace and scope of change throughout the ship design and construction cycle. Recent attention has been given to Production Engineering, Concurrent Engineering, Standardization, and Build Strategy development as means to reduce the amount of downstream engineering rework associated with design changes. These are elements of a "Design for Competitiveness" approach which must also include Change Management. Through an industry survey it is shown that shipbuilders recognize Change Management to be a strategically important capability, but that their performance in this area is relatively weak.

A framework is developed to facilitate the identification and introduction of elective changes. The framework begins with strategic planning based upon responses to the competitive environment. A decision analysis model is developed and tested for the evaluation and prioritization of improvement proposals within the context of a strategic plan. After a review of alternative evaluation methods including traditional Engineering Economy, Utility Theory, Formal Decision Analysis, and the Analytic Hierarchy Process (AHP), the AHP is selected as the decision theory best suited to this application. The output of the model, priority vectors with respect to benefit, cost and risk as well as overall preference, is used to suggest an appropriate implementation strategy for alternative proposals.

An effective Change Management plan can enable a shipyard to implement innovative, productivity-motivated, design solutions faster and more effectively. A successful approach to Change Management is required to avoid paying the price of lost opportunity. It is also equally necessary to avoid paying the price of delays and disruption associated with improperly introduced, or ill-conceived, design changes.

Thesis Supervisor: Prof. Henry S. Marcus
NAVSEA Professor of Ship Acquisition

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This research would not have been possible without the support of industry. The cooperation of "industrial laboratories," otherwise known as shipyards, is critical to work in this field. The effort of those who took time out of their busy schedules to provide me with interviews and to answer my questionnaires was substantial. In the interest of maintaining the anonymity of the text, I do not mention the shipyards or people here by name. Their contribution was the key to this research, however, and I am very grateful for their support. In particular, National Steel and Shipbuilding Company (NASSCO) provided me employment and relevant experience from which I have gained a much deeper understanding and appreciation for design/production integration and the management of change. I have learned a great deal from the entire NASSCO team.

This thesis is dedicated to my extraordinary wife, Cathy. She has shared my excitement when things were going well, and has encouraged me when I needed it most. Her contribution was not limited to motivation, nor to acceptance of the time I needed to devote to my research. Cathy also provided her own unique perspective as an engineer and shipbuilder. I am deeply grateful for her love, understanding, encouragement, and insight, without which I cannot imagine ever having finished.

Family and friends eased otherwise difficult "crunch" times. Many thanks to my parents, my brother, and my grandparents. Their support and encouragement were greatly appreciated. I am also grateful that Cathy's family was always enthusiastic about my efforts.

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Table of Contents:

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List of Figures:

List of Tables:

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1.0 INTRODUCTION

This research examines the management of improvement activities within the context of competitive strategic objectives. A particular emphasis is given to those improvements involving the interface between product and process, as it will be shown that improvements in one necessarily involve the other. Improvement represents change, and this research explores Change Management within the context of the design process.

Machiavelli warned that "...it ought to be remembered that there is nothing more difficult to take in hand, more perilous to conduct, or more uncertain in its success, than to take the lead in the introduction of a new order of things." [Lamb, 1986] This work seeks to contribute to a greater understanding of why this is so, and some means for mitigating these difficulties. The research is focused on the shipbuilding industry, but the conclusions drawn could be easily applicable in a more general context. While design change is emphasized throughout this research, the procedural context and decision analysis model developed are applicable to a broad range of improvement proposals.

The research questions which are its focus include:

- Is Change Management a strategically important capability relative to other competitive capabilities?
- How strong is industry's understanding and skill with respect to Change Management relative to other capabilities?
- What facets of the Change Management process are most critical for success?
- What facets of the Change Management process require the most improvement?
- Can a decision analysis model be developed to significantly improve the process?

1.1 RESEARCH OBJECTIVES AND CONTRIBUTION

Shipbuilders will create and sustain a true competitive advantage only if they rely on improvements rather than temporary subsidy. "The rate at which individuals and organizations learn may become the only sustainable competitive advantage." [Stata, 1989, p.64] A high rate of learning implies continuous and substantial change. Shipbuilders require an understanding of how to identify and implement the changes that are required to compete. In general, these changes can be associated with the shipbuilding processes and facility, the shipyard organization, and the ship designs themselves. As will be shown in chapter 2.0, changes in any one area typically require associated changes in the others. This research is unique in its attention to the interface between product, process, and organization. Elective "Design Change" is considered to occur at that interface. Management of change in the context of the design process is a specific concern of this research. The solution of the problem is developed through the integration of management science, organizational theory, decision theory, and engineering practice.

Webster's dictionary defines the word "change" as follows:

1) To cause to turn or pass from one state to another; to alter or make different; to vary in external form or in essence

2) To substitute another thing or things for

In other words, to change is to MODIFY or to SUBSTITUTE. Change Management in the context of design is then defined as the coordination, organization, and leadership of the processes associated with modifying and substituting design elements.

Shipbuilders recognize the need for change. The problem they face is that "...over half of all major change initiatives prove to be disappointments or outright failures." [Pritchett, 1996, p.1] In this research, the reasons why that statement is true are explored along with the means for effectively managing design improvement.

An effective Change Management plan can enable a shipyard to implement innovative, cost-saving solutions faster and more effectively. A successful approach to Change Management is required to avoid paying the price of lost opportunity. It is also equally necessary to avoid paying the price of delays and disruption associated with improperly introduced or ill-conceived design changes.

> Change that takes longer than expected can cause an organization to miss a window of opportunity, wiping out the need for the change in the first place. Higher than anticipated costs because of the additional time and attention required compound that failure. Finally, a sense of failure frequently permeates an organization ineffectively implementing change, resulting in low morale and, even more damaging, change-shy managers who now believe themselves incapable of implementing change. These are the costs of not managing change - the high costs that many organizations are unnecessarily paying. [Carr, Hard, Trahant, p.162]

The purpose of this research is to explore the ways in which continuous productivity improvement can be supported throughout the ship design cycle through the effective management of design change. Issues related to the introduction of design improvements, and revised or new design standards, which are introduced to reduce construction costs and cycle time will be studied. This research examines the motivations for introducing design changes, the means available for evaluating the proposals, and the implementation of these proposals. Contributing factors for both success and failure will be identified through the use of an industry survey. This research develops a descriptive/cognitive model of the successful Change Management process as it relates to design. The National Science Foundation defines Cognitive/Descriptive models as models of the design process based on, and informed by, close observation of human design activity. [NSF, 1996, p.9]

This research concentrates on elective design changes which are in contrast to mandatory design changes. Elective changes are those changes which are desired due to their perceived benefits, but which are not required for function, to meet a specification, or for production to proceed. Mandatory design changes are those changes which must be made in order to ensure proper function, to meet the specifications, or to allow production to proceed.

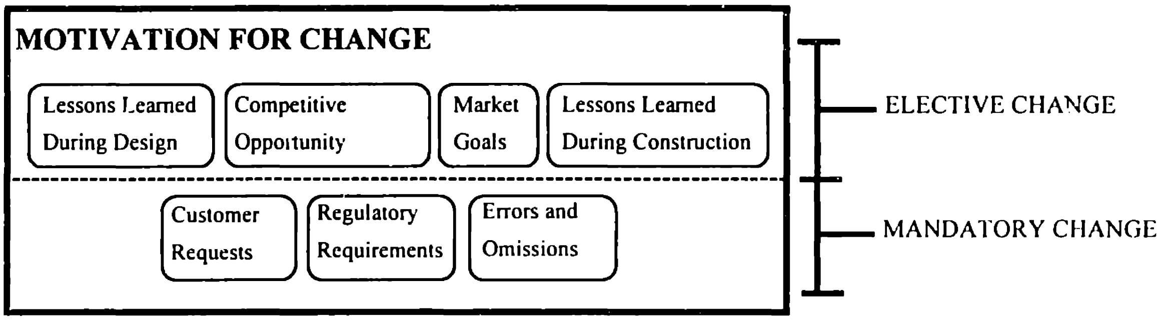


FIGURE 1.0 - ELECTIVE VS. MANDATORY CHANGES

This research draws from supporting theories and procedural contexts for managing change in order to develop a framework and model for the successful introduction of design improvements and lessons learned throughout the design cycle. The conclusions drawn are reinforced through a survey of industry attitudes and practices.

Changes can be implemented using a variety of approaches, ranging from forced, or coercive, to entirely collaborative efforts. The speed with which the changes are identified and implemented can vary, depending on the approach used. Initiatives which are not implemented immediately may represent a lost opportunity. Alternatively, a rushed and poorly managed implementation may do more damage than it is worth. The literature regarding organizational change, which will be shown to offer a foundation upon which Design Change Management can be developed, illustrates the fact that varied approaches have their place. One leading consultant wrote "the caution here is patience. It takes people a long time and a great deal of discussion, independent thought, formulation, trial, reformulation, and retrial to assimilate a significant organizational change...There is little that can be done to leapfrog the step by step process of change, or the assimilation time that people require." [Heifetz, 1993, p.32] Not all of those who have written about organizational change would agree that it is doomed to be a lengthy process. Pritchett wrote, "Gradual change may look like the safest route, but appearances are deceptive. Going slow is usually a big gamble...The third and least promising way to begin is with the middle of the road approach. It's the most common, but the least effective. Basically it amounts to muddling along - being neither subtle, nor bold and dramatic. It offers none of the benefits of the other two strategies. The enemies of change find it the easiest to resist. They see what's coming, and the sight of that mainly serves to mobilize their counter-attack." [Pritchett, 1996, p.7] While it is agreed that there is a step by step process of change, it is clear that some organizations are better at introducing changes than others. The keys to their success are explored.

The tools, methods, and conclusions presented in this research are developed through extensive benchmarking of a variety of firms, the author's experiences with firsthand implementation of design changes in a major U.S. shipyard, and a review of the existing literature and research pertaining to Change Management, product improvement, design for manufacture and assembly, value engineering and design/production integration.

1.2 BACKGROUND AND IMPORTANCE OF THIS RESEARCH

The greatest motivation to change is pain and discomfort. A second motivation is observed opportunity. U.S. shipbuilders must take advantage of opportunities to reduce costs and cycle time rather than focus only on required design changes resulting from the pain of errors and omissions. If it is true that "...the people who change the best and fastest are the ones who have no choice" [Frey, 1993], then U.S. shipbuilders should rapidly become superior managers of change. It is clear that U.S. yards find it difficult or impossible to compete at market prices for international commercial orders at this time. "A comparison of the manhours required to build similar ships in a U.S. shipyard and a Japanese shipyard [in 1987] indicated the Japanese shipyard required 39% of the effort of the U.S. yard. Presently, the gap although significant is not as great as estimated in 1987." [Rack, 1995, p.27-3] Data collected as part of the industry survey conducted in the course of this research demonstartes that cycle times and total employement are dramatically lower in internationally competitive shipyards than in the U.S today. Significant changes to the business processes, production processes, design processes and organizational structure will be required to succeed internationally. Shipyards must embark on a design improvement process concurrently with the routine design effort in support of a Design for Competitiveness philosophy. An effective Change Management plan will allow the shipyard to quickly and effectively utilize the improvements identified. Without effective Change Management, the shipyard's efforts to reduce costs through design will be unguided at best, and will often fail.

U.S. shipbuilders are aware that they must change, and are more willing than ever to make changes to compete in a global market. Shipyards throughout the United States have invested great sums of money into training regarding the philosophy of Total Quality Management (TQM), or Continuous Quality Improvement (CQI). Training regarding the philosophies of Deming, Juran, Crosby and other TQM gurus has successfully created an awareness regarding the need to change. Unfortunately, this willingness to change has been poorly translated into the ability to implement change effectively. Figure 1.1 illustrates the chain of events leading from the pain of market realities to the development of an effective Change Management plan. Shipyard feedback and an extensive literature survey will be shown to support this chain of events in chapters 2.0 and 4.0. This research is important in that it may enable shipyards to introduce lessons learned, new and revised design standards, and design improvements effectively without suffering the significant false starts, delay and disruption, and frustration that is associated with improperly managed change. This research is also important in that it may provide guidance for those shipyards that are presently, or have in the past, suffered through a disruptive and frustrating improvement program and are wary of trying again.

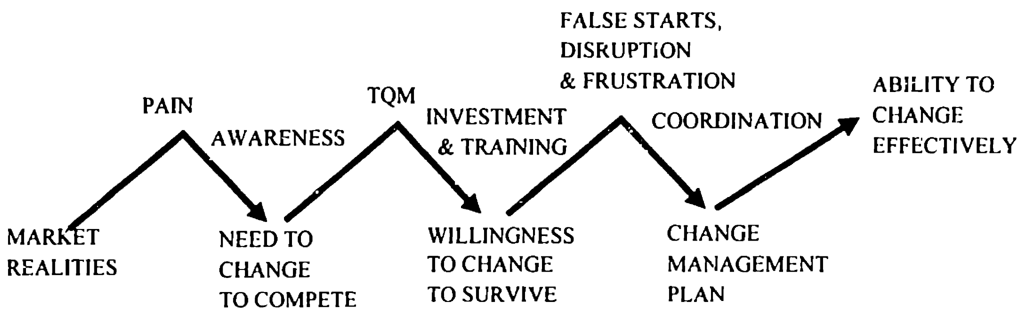


FIGURE 1.1 - CHAIN OF EVENTS LEADING TO CHANGE MANAGEMENT

Successful Change Management in the context of "design improvement" as opposed to "design repair" must clearly understand and assess the current "as-is" state, identify opportunities to improve, identify desirable future states, and facilitate the rapid transformation from the current state to the desired state. As the industry survey will show, the key is for resources to be expended on the most beneficial changes, for these changes to be both rapid and lasting, and for these changes to work together consistently towards an overall strategy for success. A contribution of this research will be a decision analysis model for use in evaluating, prioritizing, decisionmaking and planning which links proposals to such a strategy.

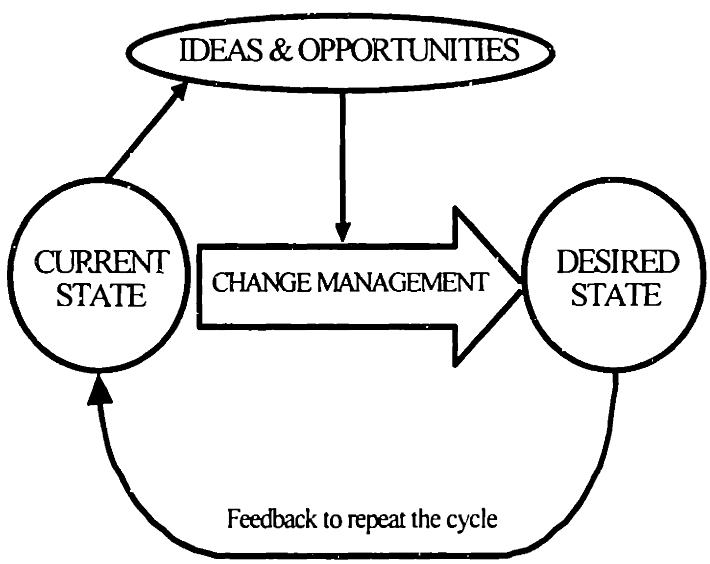


FIGURE 1.2 - CYCLE OF CHANGE

This work will complement other research in this area. It recognizes that there will always be opportunities to improve the design throughout the design cycle. In this way, it will complement research regarding Concurrent Engineering and Build Strategy development. This research focuses on reducing costs and improving efficiency by effectively managing design change rather than by focusing entirely on streamlining organizational structure or downsizing. Organizational structure will be examined, but only in the context of managing design change.

There is a clear need for research in this area, which is supported by the results of the industry survey discussed in chapter 4.0. A recent Marine Board study, "Shipbuilding Technology and Education", found that U.S. shipyards lag behind the international competition in four major areas:

- Business-Process technologies
- System Technologies
- Shipyard Production Process Technology
- New Materials and Product technologies

The study noted that the shipyards appeared to be furthest behind in business-process and new product and material technologies. This research supports improvements in these areas.

An April 1996 National Science Foundation (NSF) report, "Research Opportunities in Engineering Design" also cites the need for further research in this area. The report indicates that competitive factors are forcing drastic reductions in cycle time. This competition is forcing designers to "design on the edge" more and more, demanding improved decision making capabilities under conditions of uncertainty and risk. The decision analysis model developed in this research directly addresses this problem. Engineering Change Management continues to be cited by companies as a major problem and detriment to timely production. [NSF, 1996] Changes in design practice are needed to deal with the amount of information generated for a product and process, and the speed with which that product or process changes.

Change is overwhelming in today's U.S. shipyard. The organization itself is changing, with restructuring occurring so rapidly and so often that one often wonders if it is necessary to add "or current occupant" to each memo. The way the shipbuilding industry does business is changing. Cycle times are being reduced, forcing every department to do more in less time, with fewer resources. Engineering offices are transitioning to Concurrent Engineering. Concurrent Engineering is, as the name suggests, a design approach in which all the players and participants (including customers and suppliers) work together and in parallel towards the development of a product or service. It serves to reduce design cycle time, and if properly implemented can reduce the number of downstream design changes which are required. This transition period often involves departments working in parallel with imperfect communication.

In today's design offices, a greater emphasis and discipline must be placed upon Change Management and configuration control. In the past, sequential engineering would dictate that one group would typically lead the other. For example, development of detailed composite drawings for distributive systems, equipment foundations, and other miscellaneous outfitting would be preceded by detailed development of the ship structure. This would permit the Composite Group to avoid interferences and provide a stable list of changes required of the ship structure. In today's design offices, the schedule for most drawings and engineering disciplines overlap and are not necessarily in a rational sequence from the perspective of a systems based designer. In fact, the traditional drawing has been replaced by product models which permit production information to be delivered as late as possible. Schedules are now based upon setbacks to block erection dates. The Build Strategy dictates the schedule. Working in parallel introduces change in and of itself as each group is forced to react to the iterative design process of the other. In this period of transition, and even in a company which has a greater level of "concurrence" in its Concurrent Engineering efforts, changes due to the iterative nature of design are frequent and must be anticipated. Design groups are finding themselves working very hard to deal with these "iterative" design changes. In such an environment of frequent mandatory changes manifested as an intense and iterative design development period, it is difficult to implement additional "desired" design changes. Change Management skills are more important than ever. The costs of a better end product (one which may have lower overall costs) are incurred in Engineering. In U.S. shipyards, the engineering costs associated with any given contract are already several times that of a world-class shipbuilder. It is difficult to introduce design changes intended to reduce production costs which require additional engineering resources in an environment in which all costs, including engineering costs, must be drastically reduced.

Those who desire design change often hear, "if only we could concentrate on the design at hand and save this new approach or new standard for the next ship or next contract." There appears to be an expectation that while we are busy and overwhelmed today, there will be a lull between contracts which will permit a smoother, less stressful introduction at a later date. Unfortunately, postponing changes may not only represent lost opportunities at present, but may also guarantee that the changes will never be made. As the Detail Design division winds down their design effort, the Systems Engineering division is already working on conceptual and preliminary designs for potential future contracts. Furthermore, manning levels in the design groups are reduced or shifted elsewhere as the design effort related to the first of a class moves further to the right of the peak workload. With this reduced resource level, the introduction of design changes is still a hardship, even for ship two in a limited production run of a class. The design organization is stretched with its reduced resources busy making required changes, as opposed to desired changes. As will be discussed in chapter 3.0, a foundation of successful Change Management is a reduction to this baseline load of change. For design improvement to be managed, it will need to be made part of the design culture.

1.3 CHANGE MANAGEMENT OBJECTIVES

Design changes are more difficult to introduce later in the design cycle, and the potential to impact overall system costs is reduced as time progresses. The 1991 National Research Council report, "Improving Engineering Design: Designing for Competitive Advantage" estimates that over 70% of a product's life cycle costs are determined during concept design. The potential savings associated with the introduction of any given strategic design change, initiative, or revised standard is reduced as a contract progresses. As time goes on, even a good idea will become costly due to delays, disruption and rework. This is illustrated in Figure 1.3.

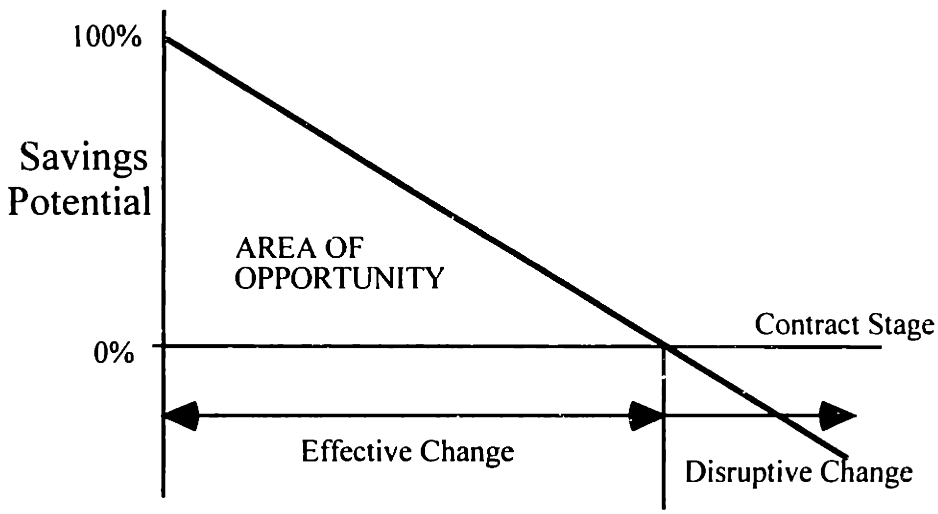


FIGURE 1.3 - DIMINISHING OPPORTUNITIES

The total potential savings, or benefit, is largely a function of the merits of the initiative. Effective Change Management can impact the total actual benefit by allowing the maximum potential to be realized for a longer period of time. It is important to recognize that Figure 1.3 illustrates the reduced effectiveness with regard to a particular contract. Most design initiatives will impact more than one contract, and there will never be a time when it is convenient to introduce changes. A healthy shipyard strives to work on multiple contracts and ideally would have little or no lag time between design efforts. An effective Change Management strategy addresses the need to incorporate design innovations under these circumstances.

Change Management strives to maximize the potential savings or "area of opportunity" in a number of ways. As illustrated in Figure 1.4, the shape of the curve can be modified to reflect an extended period within which 100% or near 100% benefit can be achieved.

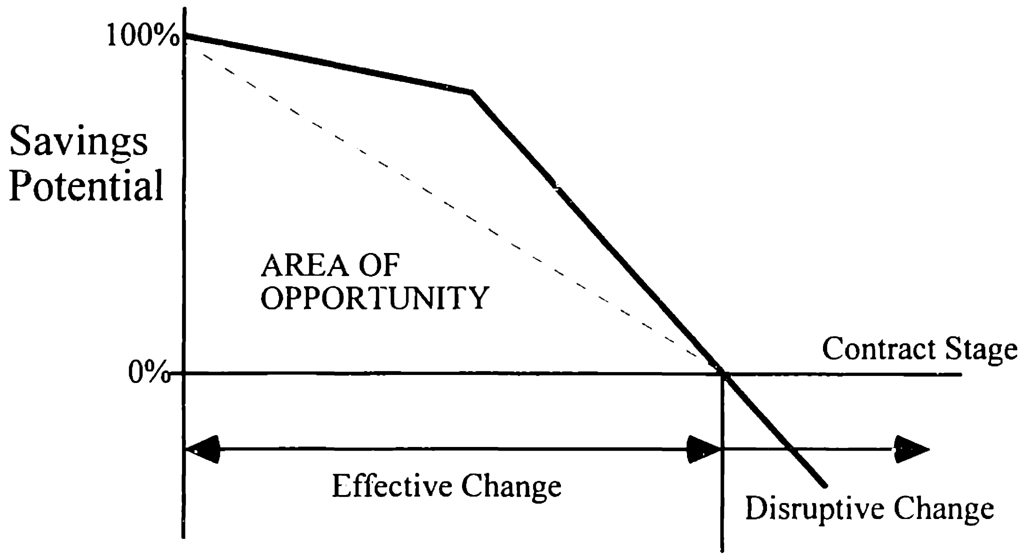


FIGURE 1.4 - CHANGE MANAGEMENT EXTENDING RANGE OF NEAR 100% SAVINGS

In addition, effective Change Management strives to move the intercept of the curve with the time (x) axis further to the right, minimizing the costs associated with delay and disruption as illustrated in Figure 1.5.

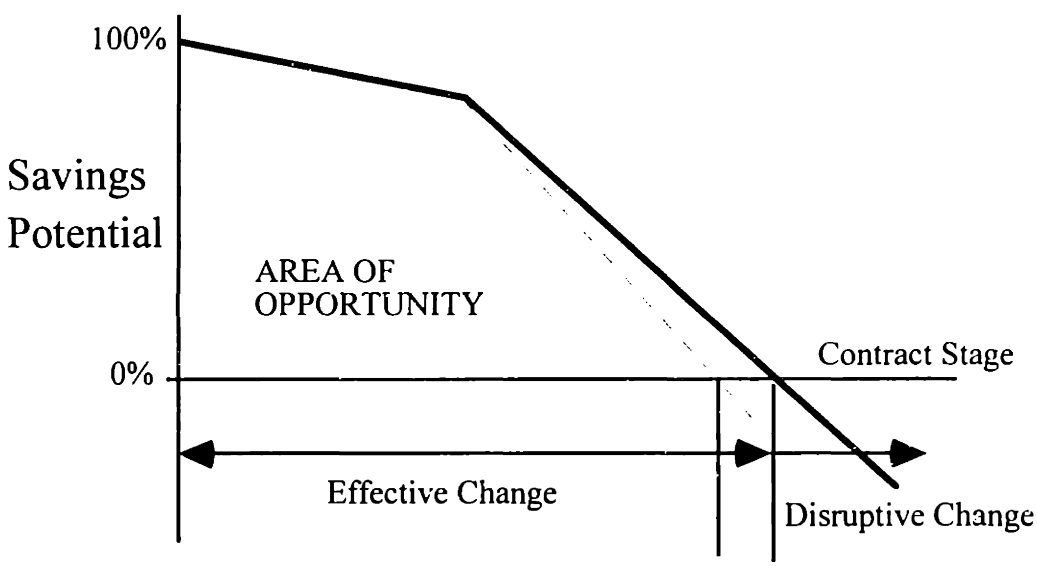


FIGURE 1.5 - MINIMIZATION OF DISRUPTION

An idealized, but admittedly impossible, system of Change Management would permit maximum benefit potential to be realized regardless of the contract stage or timeline as illustrated in Figure 1.6. This would represent a "Super-Adaptable" organization, able to introduce changes at any time and achieve the full positive potential of the initiative.

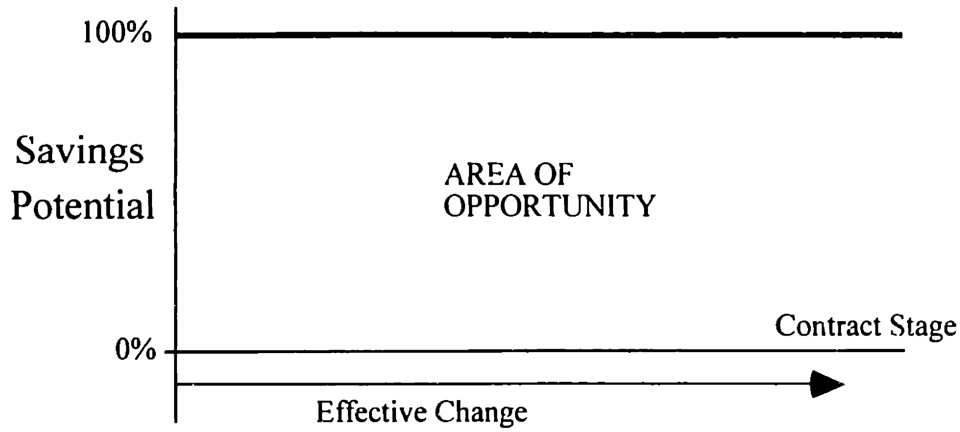


FIGURE 1.6 - AN IDEAL SCENARIO

1.4 A FRAMEWORK FOR DESIGN CHANGE MANAGEMENT

In order to study Change Management, it is useful to first develop a stage model, or framework, describing the overall process. This serves to guide the research. Each of the stages illustrated in the framework serve as a focus for study. In chapter 2.0 the supporting theory from the literature is discussed and placed in the context of this framework. As the research progresses, each of the stages identified in this model will be further refined and described. The research will conclude with each of the stage's procedures and implications fully explored. A global framework of Change Management is illustrated in Figure 1.7.

Motivation refers to the source of the change and the objectives of the change. As has been mentioned, design changes may be mandatory or elective. In order for a change to take place, there must be some mechanism for identifying the potential change. Once a motivation exists, there must be a means for identifying the relevant "universe" of design changes or solutions which address the motivation in question. This is the role of the identification stage. It gathers a set of motivating factors and translates that information into a set of possible design changes and solutions.

Once a set of design changes has been proposed, it is necessary to evaluate each proposal. A mechanism for evaluating the benefits, risks, and costs must be in place which quickly and consistently reflects the comparative merit of proposals within the context of the shipyard's overall strategy. The information developed in this evaluation stage is then used to prioritize this universe of potential changes in order to assure that resources are expended wisely. Effective decisionmaking is then possible, based upon the knowledge gained in the preceding stages.

Once a set of "approved" proposals is decided upon, detailed planning can take place towards implementation of the proposals. Finally, measures of success are needed which can be fed back into the Change Management system for consideration for future changes. Throughout the entire process, support, commitment and direction from upper management in the form of resources, leadership, direction towards an overall strategy and a consistent Change Management infrastructure is required.

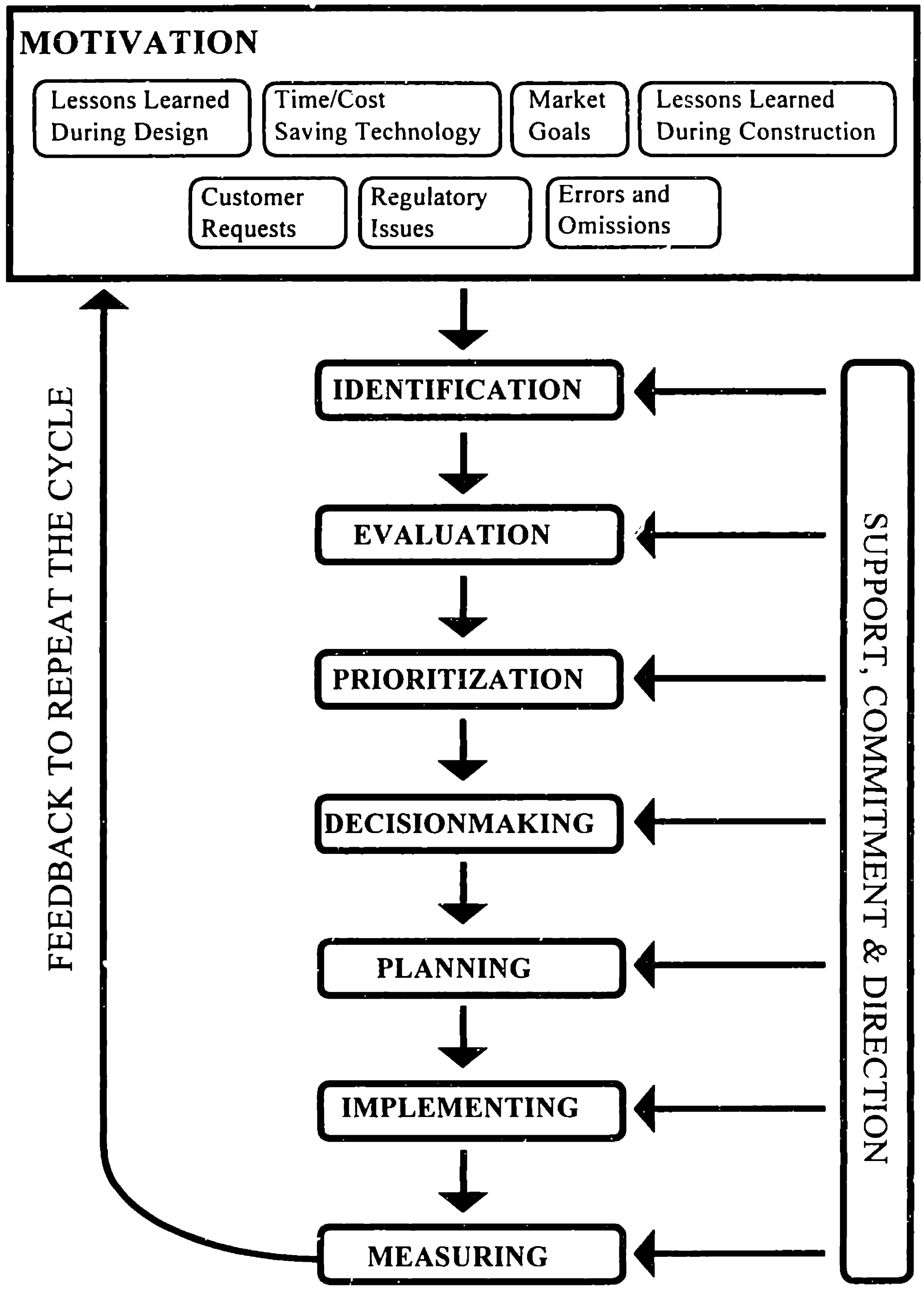


FIGURE 1.7 - DESIGN CHANGE MANAGEMENT FRAMEWORK

1.5 TERMINOLOGY

Change and Change Management:

As noted earlier, to change is to MODIFY or to SUBSTITUTE. "Change Management" in the context of design is then defined as the coordination, organization, and leadership of the processes associated with modifying and substituting design elements.

Framework:

The dictionary defines a framework as "a structure, usually rigid, serving to hold the parts of something together or to support something constructed or stretched over or around it; skeletal structure; basic structure; constitution; adjusted arrangement; system." In the context of this thesis, "framework" refers to a top level flowchart illustrating the steps or phases associated with design change. The framework does not illustrate the means for completing a step or for moving from one step to another. It is a generic document independent of the characteristics of a change or its implementation and is synonomous with "stage model."

Method and Methodology:

Webster's dictionary defines a methodology as "a system of methods" where a method is "a way of doing anything; mode; procedure; process; especially a regular, orderly, definite procedure." In the context of this thesis, a "method" refers to a detailed description and process flow illustrating the means of completing a given step of the framework. A "method" details a process or procedure and a description of the input to, and output from, that procedure. In the context of this work "method", "procedure", and "process" are synonymous. "Methodology" then refers to a particular collection of methods, or procedures, which together comprise a system for managing design change successfully under a given set of conditions. Individual chapters will discuss methods associated with each stage of the framework. The conclusion to the thesis will summarize the methodology comprising the collection of methods presented throughout the thesis.

Tool(s):

The dictionary refers to a tool as "a means." In this thesis the word "tool" to refers to hardware or software which are useful or required to apply a particular method to a framework step. These may take the form of documents, databases, standards, computer programs, forms, quality analysis charts, or anything else that can be manufactured to facilitate a procedure. A tool enables the application of a method and is synonymous with "enabler."

Theory:

The dictionary defines a theory as "an idea or mental plan of the way to do something; a systematic statement of principles involved; a formulation of apparent relationships or underlying principles of certain observed phenomena which has been verified to some extent." In the context of this research, "theory" will refer to an explanation of the reasons, or underlying principles, which justify a particular method or methodology. As the National Science Foundation points out, these principles may be "founded in behavioral studies and social science, or in physical sciences and technology."

Model:

The dictionary definition that is applicable here is "a generalized, hypothetical description, often based on an analogy, used in analyzing or explaining something." A model may be a subset of the "tools" defined above. The National Science Foundation characterizes design process modeling into three broad areas: (1) descriptive/cognitive models, (2) computational models, and (3) prescriptive models/normative theories. Descriptive/cognitive models are models of the design process that are based on and informed by close observation of human design activity. They are representations of how people perform design activities. Computational models express methods by which a computer can perform a design task. Optimization routines are examples of computational models. Prescriptive models specify how design should be done. This research utilizes all three and draws a distinction between a model and a theory. A model seeks to predict outcomes or suggest actions and is valid if it can be demonstrated to be accurate through observations. A theory seeks to explain the underlying principles which drive the behaviors predicted by the model.

Strategy:

In this research, the word "strategy" refers to a set of goals and objectives to be achieved by a methodology or a set of methodologies within the context of an organizational structure, corporate culture and business practices. "Strategy" defines the intent, purpose, or context within which methods are developed and applied.

1.6 CHARACTERIZING PROPOSALS

Design changes can be described in terms of a number of characteristics. These characteristics include:

- Motivation
- Extent
- Timing
- Focus and interdependency
- Focus elements
- Costs
- Benefits
- Risks

1.6.1 Motivation as a characteristic

As was pointed out earlier in this chapter, change is driven or motivated by problems and opportunities which are identified in a variety of ways. This motivation can be in response to a number of different factors, such as:

MANDATORY:

- Errors and Omissions
- Customer Requests
- Regulatory Requirements

ELECTIVE

- Time/Cost Saving Technologies and Competitive Opportunities
- Market Driven Goals
- Lessons Learned

The distinction between these differing motivations is important. The first three listed (error correction, customer requests, and regulatory requirements) represent motivation to change which the shipyard MUST (or is at least compelled to) respond to. The remaining three motivations (competitive opportunity, market driven goals and lessons learned) represent motivations which a shipyard can ELECT to respond to. Most shipyards already have systems in place with varying degrees of success to deal with mandatory changes. The emphasis of this research is on ELECTIVE changes. In chapter 4.0 the results of a shipyard survey are presented which support this focus.

In order to facilitate discussions of engineering change, it is important to develop a consistent set of definitions to use when classifying motivations. The following definitions will be adhered to in the course of this research.

"Errors and Omissions" refer to changes made in response to an error which is unacceptable, and must be corrected in order to meet specifications or permit production to proceed. In this regard it is a mandatory motivation.

"Customer Requests" represent a motivation which the design organizations must respond to. This motivation is brought about by a new requirement requested by the customer. Once the change has been approved by program management, the change is mandatory. The design groups may or may not recover the costs associated with these changes.

"Regulatory Requirements" can result in mandatory changes. New requirements may apply to a work in progress. In addition, the interpretation of requirements may be altered, requiring changes. A failure on the part of the design to address a requirement which has not changed and has no alternative interpretation would result in an "error correction" change rather than a change brought about by changing regulatory requirements.

"Time or Cost Saving Technology", is a motivation to change which is made in response to a previously unidentified competitive opportunity. Such a proposal may or may not be in support of an overall preconceived initiative or strategy. These proposals are characterized as being in support of continuous design improvement. These proposals may present themselves as the result of ongoing research or benchmarking, and not necessarily as part of a focused effort to meet a particular objective.

"Market Driven Goals" represent proposals identified singly or in conjunction with other proposals in support of a strategy or initiative. Changes such as these would be in support of quantifiable targets and goals which the shipyard has identified as necessary to compete. These changes are differentiated from those motivated by "competitive opportunities" in that they are conceived as a direct result of a strategic decision or goal, rather than in response to a previously unidentified opportunity. Changes motivated by "market driven goals" are identified as part of a program to identify and assess potential design solutions to meet a stated objective. Changes motivated by "market driven goals" are examples of objectives generating a set of ideas (design alternatives) or linking other previously identified proposals to goals and objectives.

"Lessons Learned" refer to proposals made in response to experience gained during the design process or during construction. Such a change is made in recognition of greater understanding. Such a change differs from those motivated by "error correction" in that these changes are not necessary to allow design or production to proceed, but are desirable. Such changes differ from those motivated by competitive opportunities and market driven goals in that they are identified through direct experience, rather than alternative means such as benchmarking or vendor proposals.

1.6.2 Extent as a Characteristic

It has been pointed out that the word "change" implies that one of two distinct processes takes place. To change is to MODIFY or to SUBSTITUTE. The approach required to implement a change which involves an alteration is likely to be different from that required to implement a change which is substitutive in nature. "Extent" as a characteristic of change refers to whether an element is simply modified (evolutionary), or has a different element substituted in its place. It is a measure of the degree to which the original configuration can be recognized after the change is made. Extent is associated with the degree to which rework may be required and the degree to which cooperation may be required. It is also associated with the complexity of the change.

1.6.3 Timing as a Characteristic

With regard to Change Management, it may often be true that "timing is everything". Timing is an important characteristic for both the identification of a potential change, as well as the implementation of the proposal.

The point in the design/construction cycle that a proposed change is identified is an important factor. Two similar changes may have different relative impacts depending upon the time at which the change was identified. The type of strategy required to implement the change may also vary depending on the time the change is identified.

Just as the timing of the identification of the change is a key characteristic, so too is the timing of its implementation. The approach required to successfully implement the change is likely to vary depending on the amount of time available to make the change between the change's identification and its proposed implementation. In addition to the time available, the timing relative to the point in the design cycle at which the implementation is to be made will also be a determining characteristic for the approach utilized. Issues associated with timing will manifest themselves as schedule risks and delays. It should be noted that the Change Management approach utilized is one of the driving factors that will determine how long a change takes to implement.

1.6.4 Focus and Interdependency as Characteristics

Changes can be made to any of the processes and products which make up the business of shipbuilding. The focus can be PROCESS oriented, or OBJECT oriented. For example, the focus can be on any of the following.

PROCESS	OBJECT
• Business Process Change	• Facilities Change
• Production Process Change	• Design Change
• Design Process Change	• Organizational Change

While this research is aimed at facilitating design changes, it will be important to recognize that changes in each focus need not be independent of the others. The focus categories serve two purposes in classifying changes.

- Identify the PRIMARY FOCUS of a change (Design Change in the case of this research)

- Help indicate the relative INTERDEPENDENCY of changes

Every change will have a primary focus, which is associated with the change's stated objectives. In addition, a primary focus may require changes in other focus areas in order to be successful. This is an example of interdependency.

The primary focus is important, because the appropriate strategy and tools may vary from one focus to another. Most notably, changes in either the PROCESS or OBJECT categories are likely to require similar strategies and tools as other changes in the same category.

Object oriented changes may be made within the context of existing business, production and design processes, or they may require any combination of process changes to meet their objectives. An object oriented change which can be made within the context of existing processes is likely to be easier to implement than those that require process changes. Similarly, changes to production processes may require design changes to be made in order to support the new production process. Therefore both object oriented and process oriented changes may be made independently or in conjunction with other changes. For these reasons, it is important to understand and recognize interdependency.

A distinction should be made at this point between the term "initiative" and the term "change". For the purposes of this research, the term "initiative" will be used to indicate a goal supported by a collection of related changes. These related changes may be in any of the focus areas discussed. While an initiative is a collection of related changes all in support of a common goal, an initiative need not have a high degree of interdependency. It is possible for an initiative to require changes in only one focus. However, it is likely for an initiative to have a higher degree of interdependency than a single change.

Deming made a similar distinction in discussions related to Total Quality Management. He pointed out that it is not enough to have employees performing their jobs perfectly, it is also critical that they perform the right jobs. Deming suggested that it is the role of upper management to identify the right jobs in support of a corporate vision, while it is the role of the employees to perform these jobs to the best of their abilities and to continuously improve their performance. Similarly, an organization can be very good at implementing changes, but very poor at identifying the changes which are important. Conversely, an organization may be very good at identifying necessary changes in support of initiatives consistent with market driven goals, but very poor at implementing the required changes. Therefore, two issues are critical to overall success. A Change Management plan must address the development of initiatives, and selection of their supporting proposals, as well as the means for implementing changes.

1.6.5 Focus Elements as Characteristics

In turn, each focus can be further subdivided into a variety of elements. For example, the Design Change focus can be further divided into the myriad of interim product families that exist representing trades and zones. Change Management requires that psychological, organizational and technical issues be understood and managed in order to lead an initiative through to success. The "focus element" will serve to better define the degree to which each of these issues is relevant.

Note that some elements are not exclusive, and can be worked together. In some cases there is overlap between elements. For example, system hangers may be improved as a whole, even though one could also examine pipe hangers independently of those for wireways or ducting. This is an example of further defining the breadth of a change by expanding the number of elements that apply.

1.6.6 Cost, Benefit and Risk as Characterstics

The anticipated benefits, costs, and risks associated with a change represent measurable characteristics. These are associated with elements of the competitive environment, to be described in greater detail in chapter 2.0. These characteristics also serve as the basis for evaluating alternative proposals by comparing their relative benefits, costs and risks. The characteristics mentioned in the previous subsections are focused on identification, planning and implementation stages of change. Benefits, costs and risks are used in the evaluation, prioritizing, and decisionmaking stages.

During the evaluation of change proposals, costs, benefits and risks can be estimated and used to compare or contrast different changes. An estimate of the resources required to implement a change can also be used to characterize changes. During the evaluation of proposals, estimates for the requirements for manning, equipment, and expenditures can be made. The level of resources required may impact the type of change strategy utilized.

The risk associated with a particular change proposal is an important characteristic which may impact the strategy used in implementing the change. Risk is a general term which we use to recognize the probabilistic nature of events. Risk can be divided into a number of categories which need to be addressed individually, but together represent the possibility that the change may bring about undesirable results.

Later in this research, specifc parameters will be identified asscoiated with benefit, cost and risk as they relate to the competitive environment and the development of a decision model.

1.7 RESEARCH APPROACH AND ORGANIZATION

This research seeks to develop a descriptive/cognitive model of the successful Change Management process as it relates to design. NSF defines Cognitive/Descriptive models as models of the design process based on, and informed by, close observation of human design activity. The approach is justified, given the current "state of the art" in design research.

> There is general agreement that the design process is a synthetic process which is not totally amenable to be studied by the tools of hard science...There is also debate about the nature of a design theory: is it founded in behavioral studies and social science, or in physical sciences and technology?...there is still strong agreement that design research needs to investigate and understand design processes so that strong guidance can be provided for all practitioners. Even fragments of theories, if used appropriately, will be useful. Since, with few exceptions, design is in the pre-theory stage we should not be looking for complete, prescriptive models yet. Instead we need to gather more empirical data (descriptive models). [NSF, 1996, p.18]

By studying the mechanisms which contribute to the success and failure of initiatives, a framework and decision model for managing competitive design changes can be created which shipyards can further develop based upon their own individual cultures. Such a model will be created based upon conclusions drawn in the course of this research combined with appropriate decision theory. It will incorporate the lessons learned from the literature, from a survey of domestic and international shipyards, as well as insights from a variety of non-competing industries with similar objectives and conditions. The resulting decision analysis model will be tested using one of the shipyards in the study as an "Industrial Lab." The research approach is illustrated schematically in Figure 1.8. In chapter 2.0 a detailed review of supporting theory and methods for Change Management from the literature is provided and placed in the context of shipbuilding. In chapter 3.0, Design Change Management is placed in the context of the overall design process and design/production integration. In chapter 4.0 the development and results of the industry survey are provided. Chapter 5.0 examines the identification stage of the design change framework in detail.. Alternative methods for evaluating proposals are examined in chapter 6.0. Of particular importance is the decision model developed as part of this research, which is presented and tested in chapter 7.0. Chapter 8.0 relates the output of the model to the decisionmaking, planning and implementing stages. Finally, in Chapter 9.0, conclusions and recommendations are provided.

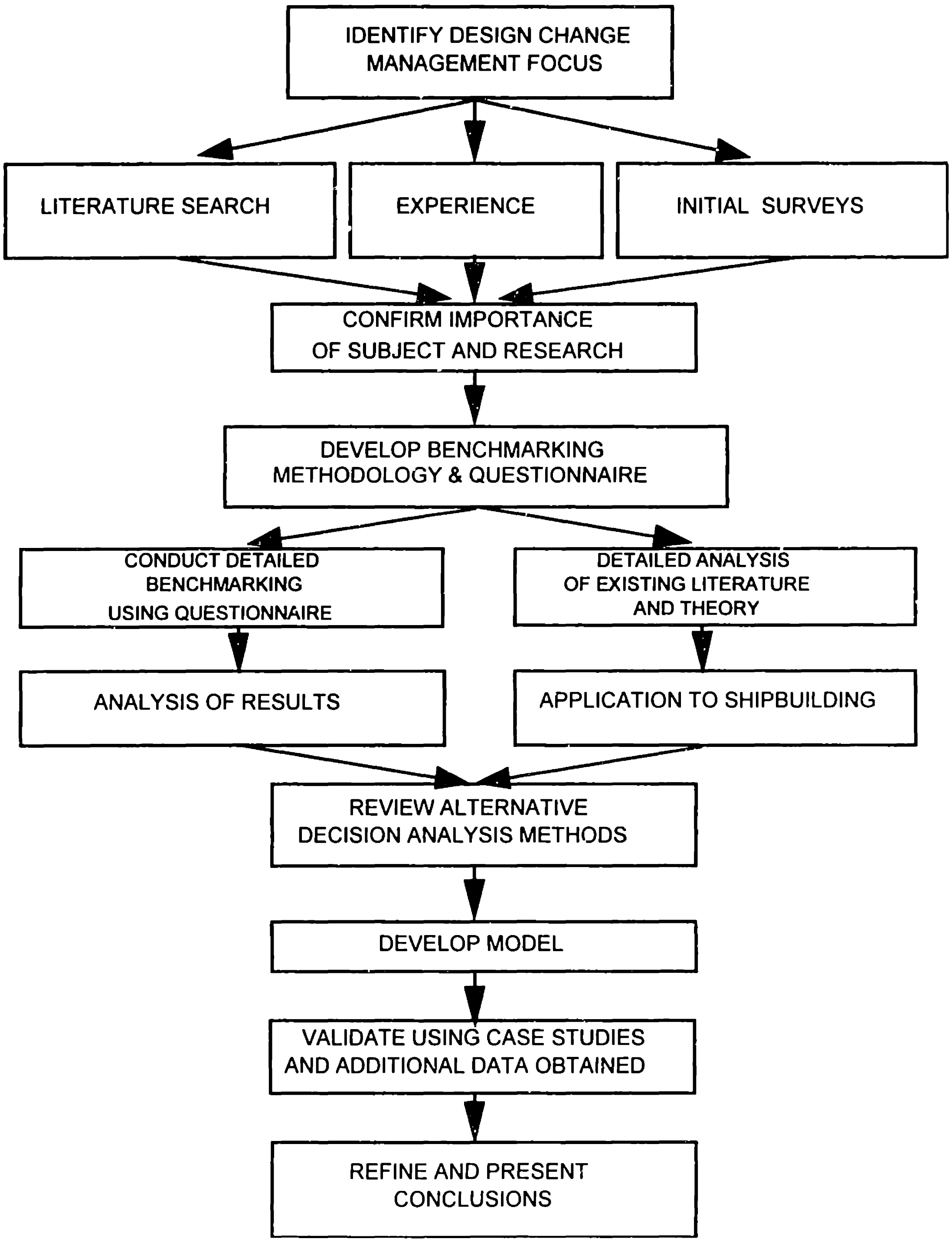


FIGURE 1.8 - RESEARCH APPROACH

2.0 RELATED THEORY AND METHODS FOR CHANGE MANAGEMENT

The material presented in this chapter illustrates relevant thinking and theory from a variety of perspectives. Commonality and linkages between these perspectives will be sought as they relate to managing design improvement. The lessons learned will serve as a foundation for subsequent development of a procedural context and model for managing design improvement.

The nature of competitive advantage is discussed first and placed in the context of shipbuilding and design. A representation of the dynamics of innovation in the manufacturing firm is presented next. This model provides the context within which design and production activities operate and illustrates the correlation between product changes and process changes. The "mass customization" nature of shipbuilding is discussed and contrasted with mass production. Next, the history of the "quality movement" is reviewed and it is shown that a natural progression of events has resulted in a recent realization of the importance of managing change processes within the context of an overall strategy. In subsequent chapters an emphasis will be on methods for linking the design improvement process with strategic planning through the use of a decision analysis model. This is followed by a discussion of traditional and contemporary views of "organizational learning". The methods and tools professed by a number of leaders in the field of Organizational Change are then compared, and related to the problems associated with design change in shipbuilding. The chapter concludes with a synopsis of the key points and a discussion related to "success factors". In chapter 4.0 shipyard feedback is used to illustrate the importance of these success factors and the strength which shipyards judge themselves to have relative to these factors. The lessons learned in this chapter will lay the foundation for the development of a process and set of tools associated with Design Change Management in shipbuilding, which is presented in subsequent chapters.

2.1 THE NATURE OF COMPETITIVE ADVANTAGE

In the introduction to this research, it was suggested that design improvement management is a key ingredient for competitive advantage in shipbuilding today. "As a result of the increasing complexity and instability of external business conditions, the ability to manage internal change and development processes has become vital..." [Berger, 1992, p.32] George Day of the Wharton School wrote that "as advantages become increasingly temporary, managers are shifting their emphasis from seeking an unassailable static advantage to building organizations that continually seek new sources of advantage...An environment of rapid shifts in advantage is a double-edged sword. The shifts create opportunities for companies to establish new advantages in a market, but as the competitive environment continues to change, these new advantages are themselves vulnerable to attack. This is what economists have referred to as the 'Law of Nemesis', by which every situation bears the seeds of its own reversal." [Day, Reibstein, Gunther, 1997, p.48] The implication is that in today's environment, shipbuilders must continuously assess their competitive position, identify their strengths and weaknesses, and plan accordingly. To fully appreciate this statement, it is necessary to understand what constitutes competitive advantage and the means available for maximizing it.

There are two traditional views of competitive advantage. The first emphasizes a firm's 'position' in an industry. The second emphasizes a firm's resources and capabilities. The contemporary view is that there is a dynamic relationship between resources/capabilities and position.

'Position' in the industry traditionally relates to one of two conditions. Either a firm has adopted a low cost position or a product differentiation position. The low cost position presumes the existence of a market for standard (acceptable) products at low cost. The differentiation position presumes the existence of a market for products with key features for which a premium is paid. The principal deficiency of this view has been that historically companies pursue both, and that this is becoming increasingly necessary in today's markets. [Day et. al., 1997, p.55] A second deficiency is that this view implies that greater customer value must come at higher costs, whereas the quality movement of the past decade has demonstrated that this is not always the case. Superior product quality can directly and indirectly lead to lower costs in some circumstances. "Quality improvements may raise product quality while lowering total costs because of lower reject rates, lower costs of adjustments and field repairs, and higher customer satisfaction." [Day et. al., 1997, p.55] In shipbuilding these two positional views have been discussed in terms of "sellers of capacity" and "sellers of products", and similar debates among the shipbuilding community have been prevalent.

During the 1992 Ship Production Symposium, Andersen and Sverdrup of Burmeister and Wain A/S (Denmark) argued that there are two types of shipbuilders. A shipyard that is a "seller of capacity" responds to an owner which requires a ship specifically designed and built for their purpose. A shipyard that is a "seller of products" designs and builds standard ships in accordance with expected requirements in the market and offers the standard designs to potential owners. [Andersen, Sverdrup, 1992, p.46] Limited options are incorporated into the design for a particular owner. They argue that by being a seller of products, the benefits of series production can be exploited. These benefits are associated with an accelerated learning curve (lower costs due to repetition and optimization of manufacturing processes for a particular design), a higher capacity utilization, and a shorter throughput time. As will be discussed in sections 2.2 and 2.5, this view is not shared by everyone in the shipbuilding community, or in manufacturing in general.

A refinement of the positional view expresses the position in terms of customer value. One model of customer value relates to three facets. [Day et. al., 1997, p.56] Customer value is expressed in terms of operational excellence or the ability to provide consistent quality at the least cost (what Shiba refers to as 'fitness to standard' and 'fitness to cost' in the context of Total Quality Management to be discussed later), customer responsiveness which stresses customization (which may be somewhat analogous to 'fitness to use'), and performance superiority which stresses innovation and enhancements beyond customer expectations (which is aligned with 'fitness to latent requirements').

Kaplan and Norton provide a more detailed model they call the "customer value proposition." The customer value proposition consists of attributes associated with three categories, product/service attributes, customer relationship, and image/reputation. Figure 2.1 illustrates the "customer value proposition." [Kaplan, Norton, 1996, p.74]

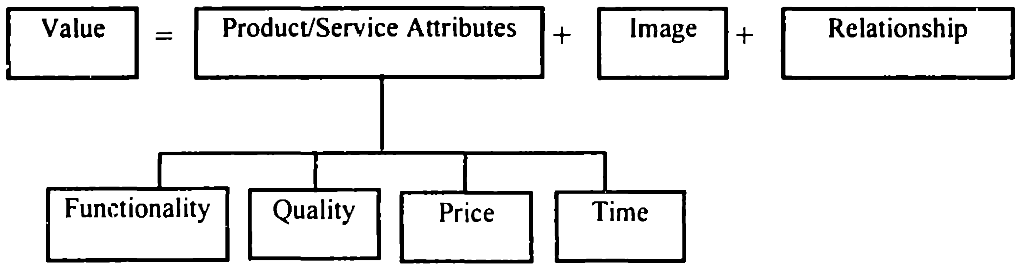


FIGURE 2.1 - GENERIC CUSTOMER VALUE PROPOSITION FROM KAPLAN AND NORTON

The resource/capability view suggests that competitive advantage lies in "the distinctive, hard to duplicate resources of the firm. These resources - comprising integrated combinations of assets and capabilities - are cultivated slowly over time." [Day et. al., 1997, p.52]

The contemporary view of competitive advantage is that "the position and performance of the firm in the industry describes the state of advantage, but this positional superiority is a consequence of relative superiority in the resources a business deploys. In turn, these resources are the result of past investments made to enhance the competitive position...At any time, businesses are endowed with a mixed bag of resources. Some of the assets and capabilities are no better than the competition, others are inferior, while a few are superior to the competition. These superior assets and capabilities are the source of positional advantages...Positions of advantage deal with the what of competitive advantage, while superior resources - assets and capabilities - address the how of competitive advantage. Taken together, these two sources of advantage represent the ability of a business to do more (or do better) than competition." [Day et. al., 1997, p.52]

In the course of this research, six major shipbuilders (four U.S. and two foreign) were asked if they regard themselves to be sellers of capacity or sellers of products. All of them considered themselves to be a seller of capacity which markets their expertise, services and facilities to provide a customer with a tailor made product which has been specifically contracted for. And all of them added an additional caveat that their customers are very cost sensitive as well. Based on the contemporary view of competitive advantage, this suggests that shipbuilders must concentrate on building resources and capabilities which are superior to those of their competition which will contribute to their domination of the industry. To do so will mean cultivating strengths which contribute to the customer value proposition described earlier, which will include capabilities in both low cost and custom/responsive design and production. This is a position of flexibility which emphasizes continuous change. Therefore the capability to manage change well is at least a core competency in today's competitive environment, and a yard that wishes to have a dominant position must cultivate this capability to make it distinctive.

Because forces are at work to continually erode a position of competitive advantage, these distinctive capabilities must be sustainable and/or shipyards must continually work to build their portfolio of distinctive capabilities. "Sustainability is a matter of degree. Most advantages are transitory because they can be readily duplicated. The most contestable are price advantages because they can be readily countered by competitors...Even improvements in internal processes are hard to protect - 60 percent to 90 percent of all learning eventually diffuses to competitors." [Day et. al., 1997, p.67] Capabilities or competency can be considered in four degrees. The first is distinctive competency which is the type just described as being desirable to achieve a position of advantage, the second is an essential core competency which is common and necessary to the industry (a "must have" to play at all), the third is a routine competency which is common to most organizations and the fourth are those competencies which have become so routine that they can be more economically outsourced. [Vollmann, 1996, p.56] Distinctive competencies have a tendency to erode and become core and routine over time.

The highest level activities of management with respect to competitive advantage must then relate to the identification, nurturing, and sustaining of distinctive and core competencies. The identification of distinctive and core competencies and the strategic planning necessary to align the organization to the task of nurturing these capabilities is one of the most important and undelegatable roles of upper management. In section 2.4 the relationship between strategic planning, competitive advantage and what is generally referred to as "the quality movement" is discussed and it is shown that the "latest wave" of the quality movement addresses the need to align initiatives with strategic response. Nurturing and sustaining these capabilities relies on the entire organization as strategic objectives are associated with competencies, which are in turn associated with capabilities, which are in turn associated with processes and resources. Goals and objectives flow down through the organization guiding the activities required to support strategically important competencies.

A tool for visualizing and facilitating the activity associated with identifying, nurturing, and sustaining competencies is the "competency map". Vollmann describes a process of "competency mapping" which involves the construction of a hierarchy. [Vollmann, 1996, p.183] At the top of the hierarchy is a key strategy or strategic response proposed by the highest levels of management. This strategic response is associated with internal or external discontinuities and changes in expectations which collectively represent changes to the competitive environment within which the company operates. An extension of the concept which incorporates the customer value proposition of Kaplan and Norton would be to link such competitive responses to components of the customer value model. It should be noted that while most of the literature links strategic responses to the product market and market conditions, there are a number of other environmental factors to which there may be a strategic response in the manufacturing firm, including such things as the materials market, capital market, labor market, and discontinuities or changes in the regulatory system. [Winch, 1994, p.43] The strategic response is in turn supported by a set of core competencies at the top of the hierarchy, supported by capabilities, which are supported by processes and organizational systems which are further supported by resources. The process of developing the map involves shipyard management first examining the major changes, forces and constraints that will influence the future of the shipyard. I suggest that these influences will manifest themselves in components of the customer value model. In addition, management must consider what the expectations of customers and principal stakeholders are, and how those expectations are changing. Competency is defined as the ability to integrate technical, managerial, and other expertise with capabilities, processes, and knowledge base with the emphasis of enabling a strategic response to the market. [Vollman, 1996, p.185] The focus or nature of "competency" is strategic and a competency in this exercise represents an objective. A capability is operational and supports a strategic competency. It is a means or subcriterion to a competency. Processes are defined as being able to be flow-charted and measured in terms of efficiency and effectiveness. Resources include people, information and technology (i.e. hardware and software). The use of the hierarchical composition facilitates identification of key issues and cause-effect relationships. Research has shown that a hierarchical representation helps to identify issues and values which can otherwise remain hidden (see Keeney, Saaty, or Vollmann).

A second advantage of this approach which was not identified by Vollmann is that it is consistent with the objectives of structured decision analysis. An extension of Vollmann's approach is that careful construction of the hierarchy permits the use of a system of pair-wise comparisons known as the Analytic Hierarchy Process (AHP) to prioritize these competencies, capabilities, processes and resources relative to each other. The use of AHP to formulate decision models is described in further detail in chapter 6.0. This prioritization in turn can be used in strategic planning to determine which capabilities and competencies to concentrate on to support a given strategic response. As will be discussed shortly, a recent outcome of the quality movement in the U.S. is the use of "Hoshin" planning and other strategic planning tools such as the "balanced scorecard" of Norton and Kaplan, which in essence are means of converting the output of a competency map into measurable objectives and goals and the means of achieving them deployed throughout an organization. The results of the competency mapping activity, together with "Hoshin-like" activity provides focus for the organization in terms of measurable objectives which are linked back to strategies and capabilities which will impact upon the ultimate bottom line, competitive position as defined by the contemporary view and customer value proposition.

Having established what core competencies and distinctive competencies exist and need to be nurtured, the next issue is how to sustain them. Sustainability of competencies is associated with five conditions. [Day et. al., 1997, p.69] The first and most obvious condition is that it makes a significant contribution to superior customer value. A competency cannot be distinctive if it does not add value. The second condition is that it is durable and not vulnerable to rapid depreciation or obsolescence. An additional condition is known as causal ambiguity; which means it is unclear to the competition how it works. This is most often the case when the capability requires a complex pattern of coordination among diverse types of resources. The fourth condition is that it is difficult to duplicate even if it is understood because they cannot amass the same assets or capabilities or they cannot find different resources to serve the same purpose. This condition is related both to the existence of resources and the time required to make them viable. A capability which has been developed over a long period of time and involves core beliefs and work habits is difficult to duplicate despite the fact that the competition understands it superficially or even fully. It cannot be realized quickly enough to do any good and any effort to rapidly introduce it may be met with a serious decrease in productivity due to the delays and disruptions associated with improperly managed change (the topic of the later discussion of Change Management). A fifth condition is that early movers are able to deter efforts at duplication with a threat of retaliation provided that the threat is credible. This is not applicable to all industries and generally applies in litigious environments or where cooperation among competitors is necessary under certain circumstances.

The lesson here is that shipbuilders must think in terms of strategic objectives and how these are supported by distinctive and core competencies. They must assess their capabilities in a number of areas and cultivate distinction in those areas which they see as strategically important. This distinction may be due to tangible assets, such as facilities improvements, or may be knowledge and process based. These distinctive competencies will not be limited to either production or engineering in isolated ways, but must be fully integrated into a unified strategic plan that recognizes the dynamic interplay between process and product improvement.

2.2 MODELING THE LINKAGE BETWEEN PRODUCT AND PROCESS INNOVATION IN THE MANUFACTURING FIRM

Process and product innovation are closely related and this relationship has been the subject of considerable study. In 1974, James Utterback (MIT Sloan School) and the late William Abernathy (Harvard Business School) developed a basic representation of this relationship. Their model provides a context within which any design improvement strategy must operate. They hypothesized, and subsequently demonstrated, that the rate of product innovation, or introduction of new features, is highest during an industry's (or product's) early years. This period is referred to as the "fluid phase". During the fluid phase, there is not an established market or set of expectations. During this phase, product function is the basis of competition as the entrepreneur works to develop a marketable design. The fluid phase is followed by the "transitional phase" during which time the rate of product innovation slows and the rate of process innovation increases. "Competitive emphasis in this phase is on producing products for more specific users as the needs of those users become more clearly understood." [Utterback, 1994, p.96] During the transitional phase, a "dominant design" emerges which represents a core set of market expectations or standards. "With the marketplace forming its expectations for a product in terms of features, form and capabilities, the bases on which product innovation can take place become much fewer, and the focus of R&D narrows to incremental innovations on existing features." [Utterback, 1994, p.81] During this phase, the focus shifts from design performance to the means of production. During this phase, a manufacturing process is developed and invested in. Specialization and automation begin to be introduced to the process. The transitional phase is followed by the "specific phase" which is characterized by a reduced rate of both product and process innovation. In the specific phase, differences between products become few, and they become viewed as commodities. During this phase, "the linkages between product and process are now extremely close. Any small change in either product or process is likely to be difficult and expensive and require a corresponding change in the other." [Utterback, 1994, p.96] Thus, as the rate of process change increases, so too will the pressure for product change. "Total Quality Control (TQM) programs, for example, almost always require changes in technology in order for quality to be manufactured into the products..." [Vollmann, 1996, p.65] The Abernathy-Utterback model is illustrated in Figure 2.2.

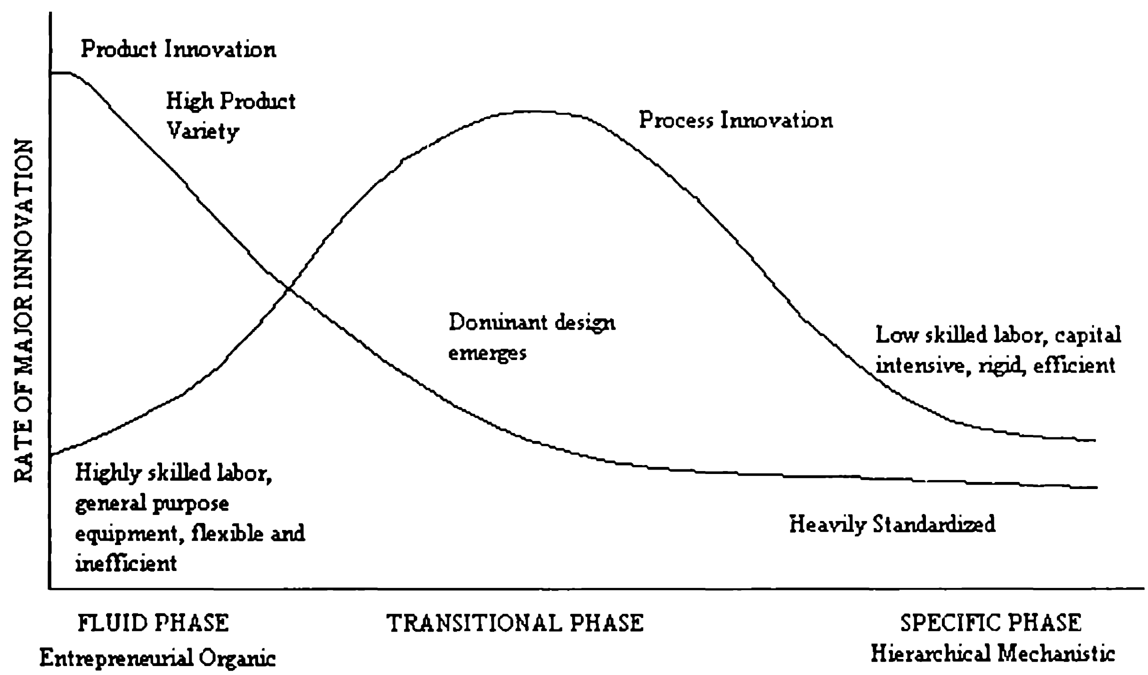


FIGURE 2.2 - ABERNATHY-UTTERBACK MODEL [SOURCE: UTTERBACK, 1994]

This relationship between product and process rates of innovation can be associated with the corporate culture and organization during each of the three phases. The fluid phase represents a time when "unencumbered by universal technical standards or by uniform product expectations in the marketplace, the early participants in these new industries experimented freely with new forms and materials." [Utterback, 1994, p.81] During the fluid phase the organization emphasizes frequent change, invention, and a limited hierarchy. Such an organization is referred to by Burns and Stalker as "organic". [Utterback, 1994, p.84]

With the emergence of a dominant design and increased market demand, the changing focus to manufacturing and distribution emphasizes greater standardization in the transitional phase. "As a product becomes more standardized and is produced in a more systematic process, interdependence among organizational subunits gradually increases, making it more difficult and costly to incorporate radical innovations." [Utterback, 1994, p.85] Informal control gives way to an emphasis on structure, goals and rules; Structure becomes more hierarchical and rigid, and tasks more formalized; and major innovations are less and less encouraged with continuous incremental improvement becoming the norm. The resulting organization is referred to as "mechanistic". [Utterback, 1994, p.84]

The mechanistic firm is characterized by routines established to increase efficiency. These daily routines offer powerful resistance to change, and can be represented as "momentum". "Momentum" is a term often used to describe resistance to change in the study of organizational change. The greater the link between a product design and established routines, complex organizational relationships, and production processes, the greater the momentum that will resist design changes. "Momentum stemming from structure exists in a wide array of forms: policies, procedures, how people are organized to do work, computer systems and so on. In workforce capability, momentum exists in work routines, skills, knowledge, attitudes and values. Try to change any one of these items and you will bump up against momentum." [McCarthy, 1995, p.32] In a period free from transition, momentum serves to keep the operation moving quickly and efficiently. During a period of transition, momentum acts to resist change.

With increased organizational complexity and size, Change Management becomes more about managing people rather than managing the product. In other words the product, processes, and people become inseparable. Any adjustment to one will invariably result in, or require, a change to the others. "When production processes are highly integrated within a system, and a high degree of interdependence exists among subprocesses, the disruption and cost associated with major changes becomes a concern. Innovation and change - prized in the organic firm - are a threat and expensive nuisance in the mechanistic firm." [Utterback, 1994, p.86]

The shipbuilding industry appears to share many of the characteristics of the transitional and specific phases described by Abernathy and Utterback. Table 2.0 identifies the significant characteristics of the three phases of industrial innovation as defined by Utterback. While the industry as a whole could easily be viewed as being mature, and therefore entirely in the specific phase, it shares a number of characteristics of the transitional phase due to the nature of the industry. Shipbuilding is heavily regulated, global in perspective, highly cyclical with changing market demands and a broad range of customer requirements. Shipbuilding is characterized by low margins, a long design/build cycle and a custom "seller of capacity" approach. This alters the relationship of the industry to the model. Even so, when examined closely, shipyards and shipbuilding appear to fit elements and spirit of the model well. As Utterback points out, "not all industries or products pass through these tidy phases." An important objective for any organization should be to examine the means by which they can avoid this pattern altogether and remain in a cycle which balances innovation and control.

	FLUID PHASE	TRANSITIONAL PHASE	SPECIFIC PHASE
Innovation	Frequent major product changes	Major process changes required by rising demand	Incremental for product and with cumulative improvements in productivity and quality
Source of Innovation	Industry pioneers, product users	Manufacturers, users	often suppliers
Products	Diverse designs, often customized	At least one product design, stable enough to have significant production volume	Mostly undifferentiated, standard products
Production Processes	Flexible and inefficient, major changes easily accommodated	Becoming more rigid, with changes occurring in major steps	Efficient, capital intensive, and rigid, cost of change high
R&D	Focus unspecified because of high degree of technical uncertainty	Focus on specific product features once dominant design emerges	Focus on incremental product technologies, emphasis on process technology
Equipment	General purpose - requiring skilled labor	Some subprocesses automated, creating islands of automation	Special purpose, mostly automatic, with labor focused on tending and monitoring equipment
Plant	Small-scale, located near user or source of innovation	general purpose with specialized sections	Large scale, highly specific to particular products
Cost of Process Change	Low	moderate	high
Competitors	Few, but growing in numbers with widely fluctuating market shares	Many, but declining in numbers after emergence of dominant design	Few; classic oligopoly with stable market shares
Basis of competition	Functional product performance	Product variation, fitness for use	Price
Organizational Control	Informal and entrepreneurial	Through project and task groups	Structure, rules and goals
Vulnerability of Industry leaders	To imitators	To more efficient and higher quality producers	To technological innovations that present superior product substitutes

TABLE 2.0 - PHASE CHARACTERISTICS [UTTERBACK, 1994, P.94]

Recall the discussion in section 2.1 of "sellers of products" vs. "sellers of capacity." A shipyard that is a seller of products will more closely resemble characteristics described by the specific phase of the Abernathy-Utterback model. Such a shipyard has optimized its facility for a particular set of designs. The yard will be more highly specialized by comparison to one which is a seller of capacity. Such yards should be a low cost producer for their type of ship. Their vulnerability lies in their market moving to a different type or size of ship. A seller of capacity would more closely resemble the characteristics of the transitional phase of the model. Their vulnerability is that another yard can provide greater value (features or quality for the same or lower price). A seller of capacity would be working in a market which has a baseline set of standards representing what the expectations for a ship type are. They would be competing on the basis of being able to provide a customer "best value" as defined as a tailored ship with desirable design features at a competitive price. This is more aligned with the contemporary view of the nature of competitive advantage.

It would seem natural to assume that there is a progression for shipyards to evolve from the seller of capacity, or transitional phase, to the seller of products, or specific phase. In truth, many make a strategic decision to be one or the other. Andersen and Sverdrup argue that a seller of products has greater profit potential due to the economies associated with a learning curve. [Andersen, Sverdrup, 1992, p.46] This is a debatable position which may also be rooted in an old paradigm regarding what constitutes learning. One must remember that such a yard must first obtain the opportunity to become a seller of products. To have this opportunity, they must become a low cost producer for a particular type of ship. This requires that they either evolve to become the low cost producer for a given ship type, or that they invest heavily to target a given market. The seller of capacity maintains a general purpose facility with pockets of automation and specialization, while a true seller of products will tend to optimize and specialize their facility. This is consistent with the Abernathy-Utterback model. Frank Rack of summed up this point at the 1992 Ship Production Symposium in response to the position taken by Anderson and Sverdrup.

> In addition, what course of action do the authors propose the shipbuilders should take during the years (estimated up to five) required to become competitively productive, notwithstanding that the competition is also improving? The Theory of Constraints (TOC) looks at a company as a money making machine, and as such its resources are available for anything they are capable of servicing. It is hard to believe that a shipyard that has an opportunity to obtain a profitable contract for a ship (navy new construction, repair, or conversion) or for any other product would turn it down based on a 'seller of products' policy. [Andersen and Sverdrup, 1992, discussion]

With respect to the U.S. shipbuilding industry, there are significant hurdles which would need to be overcome to adopt a "seller of products" policy. Rafael Gutierrez-Fraile of Astilleros Espanoles (Spain) pointed out, in response to the paper by Andersen and Sverdrup at the 1992 Ship Production Symposium, that there is little demand at this time for large numbers of identical ships. He also points out that standard ships are in general very simple ships. Complex ships are seldom built in large numbers. Under these circumstances it is difficult to compete with low cost, low technology, semi industrialized countries which emerge to build ships. The future for U.S. shipyards appears to be more closely aligned with a seller of capacity approach. As will be discussed shortly, a view of the shipyard as engaging in what is now known as "mass customization" may bridge the gap between the seller of products and seller of capacity viewpoints. While these two views are tied to the traditional view of market positions, the mass customization approach is aligned with the notion of best value and balancing flexibility and control.

The need to stay within an optimal zone of organizational development is also the subject of considerable research and literature. Winch writes that "the paradox of productivity and flexibility is at the heart of the matter. As Ford showed, a highly time compressed production process is consistent with a singular focus on productivity, so long as product variety is minimized." [Winch, 1994, p.25] Winch also points out "the paradox that organizations that are good at innovation are not necessarily good at implementation - the flexibility required for the former undermines the integration required for the latter." [Winch, 1994, p.35] Horwitch and Pralahad expressed this idea as the paradox between continuity and chaos observed in successful high technology manufacturing firms. "Some of the behavioral patterns that these companies displayed seemed to favor promoting disorder and informality, while others would have us conclude that it was consistency, continuity, integration and order that were the keys to success." [Roberts, ed., 1987, p.149] "On the one hand, business focus, organizational cohesion, and integrity imply stability and conservatism. On the other hand, adaptability, entrepreneurial culture, and hands-on top management are synonymous with rapid, sometimes precipitous change. The fundamental tension is between order and disorder." [Roberts, ed., 1987, p.161] They concluded that the successful firms alternate between the two points of view at different times.

Ichak Adizes has popularized the term "prime" as indicating this optimal stage of development where there is an appropriate balance of flexibility and control. Before this stage, organizations are in stages of development which are flexible with little discipline and few controls. After prime the organization has discipline but has lost its flexibility.

A key element of remaining "prime" is maintaining flexibility with as many of the benefits of control and standardization as possible. Therefore, a "mass customization" model which emphasizes the flexible use of standard components may be a more desirable model for shipbuilding than "mass production".

2.3 Mass Customization Model of Production

A ship can be considered to be an assembly of standard, or relatively standard, interim parts. These parts can be produced and assembled based upon standardized processes. These parts can be designed based upon standard design guidance and procedures. Shipbuilders, by the very nature of their business, are operating in an environment more closely aligned with the approach of "Mass Customization" than with the approach of "mass production". Pine's book "Mass Customization: The New Frontier in Business Competition" popularized this phrase and approach in 1993.

Pine points out that the system of mass customization reinforces the emphasis on process innovation, and in this way is consistent with the notion that shipbuilding fits into the transitional and specific phases of the Abernathy-Utterback model.

> Technological innovation plays a vital role in mass customization...the application of new product technologies...that increase the adaptability of products can also reinforce greater variety and shorter development cycles. Similarly, the application of new process technologies...reinforce the system's drive toward greater variety by making it increasingly economical to produce such variety. Indeed, in this new system processes are more important than products...Customers in increasingly heterogeneous markets demand customized products, which creates the

need to re-engineer processes for mass customization. Individual new products then flow from these flexible, responsive but long term and stable processes. In mass production, products are developed first and then the processes to manufacture them are created, each process coupled to each product. In mass customization, the processes are generally created first and remain decoupled from the ever changing flow of products. [Pine, 1993, p.47]

	MASS PRODUCTION	MASS CUSTOMIZATION	SHIPBUILDING
FOCUS	Efficiency through stability and control	Variety and customization through flexibility and quick responsiveness	Variety and customization through flexibility and quick responsiveness
GOAL	Developing, producing, marketing and delivering goods and services at prices low enough that nearly everyone can afford them	Developing, producing, marketing, and delivering affordable goods and services with enough variety and customization that nearly everyone finds what they want	Developing, producing, marketing, and delivering affordable ships with enough variety and customization that nearly every shipowner can get what they want
KEY FEATURES	Stable demand, large homogeneous markets, low-cost standardized products of consistent quality, long product development cycles, long product life cycles	Fragmented demand, heterogeneous niches, low cost high quality customized goods and services, short product development cycles, short product life cycles	Fragmented demand, heterogeneous niches, low cost high quality customized ships, long product development cycles, long product life cycles

TABLE 2.1 - MASS CUSTOMIZATION AND SHIPBUILDING [ADAPTED FROM PINE, 1993, P.47]

Abernathy has written about witnessing "de-maturity" of companies and industries when they re-engineer their processes to re-enter a more fluid or transitional phase. [Pine, 1993, p.57] In many regards, other industries are benefiting by applying what shipbuilders have done historically by necessity. Under a system of mass customization, processes are coupled with interim products rather than with the final product. Pine points out that mass customization does not overcome the benefits of economies of scale associated with mass production, it simply shifts the focus from the final product to standard interim parts.

The best method for achieving mass customization - minimizing costs while maximizing individual customization - is by creating modular components that can be configured into a wide variety of end products and services. Economies of scale are gained through the components rather than the products; economies of scope are gained by using the modular components over and over in different products; and customization is gained by the myriad of products that can be configured. [Pine, 1993, p.196]

In shipbuilding, standard or parametrically scaleable interim parts can be found throughout a ship. Even more parts that can be grouped by a common standard process can be found. Thus a process change is still likely to require a comparable change to the way the interim part is developed. In this way, the conclusion of the Abernathy-Utterback model that product, process and organizational structure become nearly inseparable is still valid under the mass customization model of product development, but under the mass customization model this process is much more efficient. Mass Customization enhances the benefits of value analysis, industrial engineering and Production Engineering activities by focusing on interim parts which can then be utilized in a variety of end products. By enhancing standardization capabilities, shipyards can take advantage of mass customization. Furthermore, it provides a means for design improvement in a controlled manner which reduces the stress associated with change. Standardization contributes to the management of expectations, which will be shown to be a key to managing change well.

2.4 History and Lessons Learned from the Quality Movement

The history of the quality movement is both interesting and informative. It is rooted in developments in the U.S. during World War II and subsequent efforts to rebuild Japan. During the war, the United States achieved record efficiencies and accomplishments. This has, in retrospect, been attributed largely to the overwhelming sense of urgency and the cohesive effect which it had on organizations and our society as a whole. After the war, the U.S. largely ignored the lessons learned. It was in Japan that the quality movement flourished and grew, only to be recently revisited in the U.S.

2.4.1 Quality Movement in Japan

Total Quality Engineering, Inc. credits the movement's origins in Japan with Homer Sarasohn, an engineer from MIT, who headed the Civil Communication Section charged by MacArthur with disseminating information throughout Japan. Sarasohn arrived on the scene in February of 1946. One of the CCS' first orders of business was to develop the capacity to manufacture radios for dissemination of American education programs. The environment was not conducive to the task.

> No port city was less than 70 percent destroyed, no industrial city less than 40 percent destroyed, and many were worse than that. [Dobyns, Crawford-Mason, 1991, p.11]

> Never in history had a nation and its people been more completely crushed. [MacArthur from Dobyns, Crawford-Mason, 1991, p.12]

Production facilities and materials were scarce and management was unskilled because more experienced managers with wartime experience were precluded from responsible positions. CCS established a National Electrical Testing Laboratory to "inspect in quality". In 1949, Frank Polkinghorn from New Jersey's Bell Laboratories, joined the team as Sarasohn's boss. [Dobyns, Crawford-Mason, 1991, p.11] Shortly after that the emphasis shifted to education in management methods, particularly those of Shewart. W.A. Shewhart formalized continuous improvement through statistical methods in the 1930's while working at Bell Laboratories.

Their training manual quoted Collis P. Huntington, founder of Newport News and Shipbuilding, to help emphasize their key interest; "We shall build good ships here; at a profit if we can, at a loss if we must, but always good ships." [Dobyns, Crawford-Mason, 1991, p.11] In other words the focus was on quality rather than cost, and at this time quality was defined as conformance to standards.

This early work emphasized "fitness to standard" as evaluated through Statistical Quality Control (SQC). [Shiba et. al., 1992] The focus of the CCS was to build up Japan's capability to mass produce goods as quickly as possible, starting with radios, and get them into the hands of the Japanese. The emphasis was the development of standards and specifications, and development of a hierarchical organizational structure in which engineering developed specifications and handed them over to production and QA assured conformance to the specifications. The emphasis was on reproducing an efficient mass production industry. CCS worked with the Japanese Union of Scientists and Engineers (JUSE) to conduct training. JUSE later asked Sarasohn to recommend an expert to facilitate and accelerate the training of a broader segment of their industrial population.

W. Edwards Deming had already visited Japan in 1947 as part of a survey mission associated with establishing Japanese population Figures, and Japanese officials were familiar with him. He was a friend of Shewhart and a former statistician with the U.S. Census Bureau. [Dobyns, Crawford-Mason, 1991, p.15] Deming was recommended when Shewhart was not available, and he came back in 1950 for two months of intense training for Japanese managers, engineers and academics regarding the Plan-Do-Check-Act (PDCA) cycle, causes of variation and statistical process control (SPC) in addition to SQC. [TQE, Inc.] The emphasis of SPC is the process, rather than the output of the process as is the case with SQC. Subsequently the Deming Prize was established in Japan in 1951 as a means of recognizing significant improvement.

Professor Shiba of MIT suggests that Fitness to Standard as a sole emphasis has two weaknesses. First, it generally leads to overemphasis of inspection which in turn can lead to demoralizing of workers and shifting of responsibility for quality away from the doers. Secondly, it does not address the degree to which the standard is itself correct or fulfills market needs. Both of these weaknesses existed in Japan and were exacerbated by an overemphasis of SQC, standardization and inspection. While this emphasis was appropriate for the goal of ramping up mass production capability, it would not lead to satisfaction of market demands when Japan moved to re-enter the commercial markets. While significant improvements were made, workers resisted the efforts of the engineers charged with implementing SQC and top management began to lose interest. The efforts were still focused on inspection. In 1954 JUSE invited Joseph M. Juran to lecture.

Juran emphasized management's role and responsibility. A key element of this focus was the establishment of a quality policy and assurance that everyone in the organization understood it. Peter Drucker's book, "The Practice of Management" was translated into Japanese at this time and the concepts of management by objectives were blended with those promoted by Deming and Juran. Juran's lectures continued and in 1960 he made another visit where he stressed the importance of setting goals and planning for improvement. [TQE Inc.] At this time, Japanese companies were acting to correct the weaknesses of Fitness to Standard emphasis by emphasizing Fitness to Use. [Shiba et. al., 1992] Fitness to Use stresses the satisfaction of market needs and customer requirements. This shift was associated with the fact that by the early 1960's Japan was no longer urgently concerned with replacing essential goods and now desired to compete. Manufacturers started competing, not on how many usable units they could make, but on the variety of goods they made. [Shiba et. al., 1992] During this time the concept of Quality Control Circles developed in Japan. Juran wrote about the approach in the 1960's in his paper, "The QC Circle Phenomenon". The circle is a small group of departmental work leaders and line operators who have volunteered to spend time outside of their regular hours to help solve departmental quality problems. The movement originated in Japan in 1962.

At this time Japanese planning techniques continued to improve. In 1965 Bridgestone Tire published a report analyzing the planning techniques used by the Deming Prize winners and coined the name "Hoshin Kanri" which means a course, policy, plan or aim (Hoshin) associated with administration, management and control (Kanri). [TQE Inc.] Hoshin management forces managers to run the PDCA cycle on high level business processes as part of their function, aligns all the people in the organization toward key company goals with such a sense of urgency that even the lowest level employees are influenced to choose activities with strategically important objectives, and it aligns all jobs and tasks with these key company goals focusing and coordinating efforts and resources. [Shiba et. al., 1992] The concept of Hoshin is entirely consistent with the concept of identifying distinctive and core capabilities as described earlier in the discussion of the nature of competitive advantage and the concept of competency mapping. It is also similar to the goal-setting process described by Juran and Gryna in "Quality Planning and Analysis" (1993 ed.). For a detailed explanation of Hoshin, the reader is referred to Shiba or the book by Yoji Akao which is credited with bringing emphasis of the concept to the U.S. in 1991. The concept will be explored in greater detail later in this research when identification and prioritization of proposals is discussed.

Shiba refers to the next level of quality as Fitness to Cost with an emphasis on controls and direction from the top with consideration of market needs, low variability and low costs taken as a whole. Shiba suggests that this emphasis was triggered by the oil embargoes of the 1970's. Japan, with no alternative domestic sources, was forced to focus on reducing costs in order to export in an environment that stressed market needs. During this time, the use of Quality Circles became more popular in Japan along with what are now known as the "Seven Quality Control Tools" and an extension to the PDCA cycle known now as the "Seven Steps." [Shiba et. al., 1992] The tools are widely understood; the reader is referred to popular textbooks for further explanation of the tools and steps. By 1975 Hoshin was a widely accepted practice in Japan. [TQE Inc.] Shiba writes that "With Fitness to Cost there was an evolution requiring everyone to focus on cost goals and moving information for improvement activities up and down the hierarchy." "Vertical alignment is about the rapid deployment of business strategy that is manifested in the actions of people at work. When vertical alignment is reached, employees understand organization-wide goals and their role in achieving them." [Labovitz, Rosansky, 1997, p.26]

In the 1980's Japan was facing two new challenges. Japanese goods became more expensive in world markets due to exchange rates. Secondly, the more basic technologies and management methods that had been distinctive core competencies for Japan in the 1970's were easily transportable elsewhere. As was discussed in section 2.1, the erosion of distinctive capability is generally inevitable. The transportation of these competencies to the rest of Asia which enjoyed lower labor costs represented a serious threat to Japan. This resulted in an emphasis of "fitness to latent requirements." [Shiba et. al. 1992] This emphasis focused on predicting market needs before the market knew what it wanted and shortening product development cycles in an effort to develop a distinctive capability to predict needs and provide for them before the competition. This resulted in the concept of leading the market rather than following it. By leading the market, one could control the rules of the game rather than be constrained by them. During this period, horizontal integration was strengthened and the customer was made an integral part of the process. What are now known as the Seven Management Tools came into frequent use at this time. Again the reader is referred to texts for additional information. The main point is that while the tools of the 1970's were really focused on problem solving, the tools of the 1980's were proactively focused on opportunity identification and alignment of the organization with key opportunities or strategies.

2.4.2 Quality Movement in the United States

Meanwhile in the U.S, the murmurings of the quality movement began in the 1970's. The quality of U.S. products had deteriorated significantly to the point that the country slowly began to take notice. The U.S. balance of trade in manufactured products went negative for the first time this century in 1971. [Hayes, Wheelwright, Clark, 1988, p.1] Prior to this point, the postwar economy had triggered a quantity based rather than quality based mentality. Dr. Juran, who had played a key role in Japan and had been trying to spread the word in the U.S. wrote in his paper "Mobilizing for the 1970's";

> We approach the 1970's with the apprehension that we are about to encounter some very uncomfortable experiences with respect to quality of products and services...The foregoing is the central theme for the 1970's. The user has made his decision to live behind those dikes of quality control, and the dike builders are in a new ball game. The stakes are simply enormous. It is not merely that huge sums are at stake in product failures, in down time, in recalls, in law suits. The biggest stakes are in share of market, in the very existence of the companies who produce the goods and services in question. [Juran, 1969, p.1]

In 1980 the video "Juran on Quality Improvement" went on the market. This was also coincident with the television documentary "If Japan Can, Why Can't We?" which appeared in the summer of 1980. Most observers see this as the point when the movement exploded in America.

The movement in the U.S. began with Quality Circles which were observed by Americans who visited Japan in the 1970's. Recall the discussion of the nature of competitive advantage and sustainability of distinctive competencies. Japanese firms had built a distinctive capability over a period of time with respect to a total quality system. When the U.S. companies visited Japan, they picked up on only the most superficial aspects of this system. "Since total quality is largely an attitude and mental process, American visitors to Japanese plants could not see it and therefore did not import it." [Dobyns, Crawford-Mason, 1991, p.15] Berger suggests that "...history tells us that transferring concepts from one organizational context to another can lead to (more or less) complete failure." [Berger, 1996:4, p.2] The Japanese approach defied rapid duplication just as the theory of competitive advantage would predict. Subsequently two key ingredients were lost in the translation. The first is that the word "control" was dropped from the original name, forecasting the lack of emphasis on control and coordination that was to follow. [Dobyns, Crawford-Mason, 1991; also Lillrank, Kano, 1989] The second is that while in Japan management was heavily involved in the process, the U.S. visitors only came away with the knowledge that teams of line workers were being tasked with gathering to discuss and troubleshoot problems on their own time. They were thoroughly impressed by the level of commitment of the workforce, and lost sight of the equally impressive level of commitment of upper management in Japan.

The first quality circle in the U.S. was established in 1974 [Dobyns, Crawford-Mason, 1991, p.11] Publication of quality circle experience in the shipbuilding literature appeared in the REAPS transactions of 1982. By the publication of Crosby's "Quality Without Tears" in 1984, quality circles had lost their luster. Crosby wrote "there is nothing wrong with QC and SQC. They are excellent tools in the battle for quality improvement, but they are only tools. They are not management tools, yet they do not work unless management becomes completely involved. I meet few managers who understand how these techniques work, let alone how to properly implement them." [Crosby, 1984] Cultural differences and a lack of key management support and direction integrated within a total system lead to a string of failures. For example, American culture stresses individuality. Many people had a hard time working on teams. This is also reflected by the explosion of employee suggestion programs that sprang up at the same time as quality circles which rewarded individuals rather than teams for cost cutting ideas. Companies had difficulty understanding how to motivate and reward a team.

Most of the shipyards visited in the course of this research expressed disappointment with employee suggestion programs and quality circles that were developed during this time period. Feedback collected by one yard regarding their employee suggestion program at the time indicated that there was dissatisfaction with the program for a variety of reasons including an ineffective and slow evaluation process, poor or no response, a poor management attitude and repeated implementation failures after approval. A senior manager at another shipyard commented that quality circles and team building had mixed results. "Some improvement was seen on micro issues, but the overall quality performance of the company...was not fundamentally improved. These efforts died away as we got busy with project work, or as the champion lost influence." Stresses between management and labor were often made worse rather than better. Questions as to the legality of the approach were actually raised with respect to the National Labor Relations Act by some unions which saw them as a ploy to encourage workers to put in more hours and negotiate with management without the benefit of representation. These quations continue today, with consideration being given to new and revised legislation to protect the concept of quality teams. [See Fuldner, 1996 and the Teamwork for America Initiative]

An additional problem, and the primary issue to be addressed by this research, is that within the context of ship design/production integration the bottom-up and uncoordinated approach of quality circles and subsequent waves of the quality movement have had a destabilizing effect in engineering. The emphasis was placed on production and improvement of production methods without an equal emphasis within engineering. In the discussion of the Production Engineering function in chapter 3.0, it will be shown that this is in part due to the nature of the entire industry in the U.S. which prior to the 1970 maritime bill had little or no incentive to do up front design work within a shipyard. Concepts regarding ship construction which experienced designers, many of whom were at design firms rather than the yards themselves, had come to understand over time were becoming increasingly irrelevant.

As the Abernathy-Utterback model showed, product and process change are linked. Even when production processes could be successfully improved through QC suggestions, Engineering and Management did not follow through and make the corresponding changes in design required to best take advantage of these processes. No management process had been established to effect elective design change in a timely manner. The increased rate of change coupled with schedule pressure often resulted in poorer engineering quality which resulted in significant production rework. This would in turn spark additional work in production to improve their processes to make them more robust and flexible, while Engineering struggled with the concept of doing more with less. With the introduction of quality circles, not only did Engineering need to reduce their own costs and address design for production to compete, they also needed to address design for production when the production methods were unstable and in a continuous state of flux. There was significant resistance to this continuous change.

Books such as Feigenbaum's "Total Quality Control" published in 1983, Crosby's "Quality Without Tears" introduced in 1984, Deming's "Out of the Crisis" introduced in 1986, and Juran's "Juran on Planning for Quality" introduced in 1988 are representative of the next wave of the quality movement in the U.S. This next wave focused attention on some of what had initially been missed in the transfer of the Japanese quality tools. The causal ambiguity which made it difficult for the U.S. to duplicate their results was steeped in the culture that had been developed in Japanese corporations over time and the activity of management that was required to nurture that culture. All four "quality gurus" focused greater emphasis on culture and upper management support. This was the start of "Total Quality Management".

Reference to TQM in the shipbuilding literature first appears in the mid to late 1980's. This wave corrected some of the problems associated with the earlier introduction of quality circles. It fostered an environment of greater cooperation and a greater willingness to change. Management measured success during this time with metrics associated with number of employees trained, established entire departments to run the 'quality program', and tracked the number of improvement ideas identified and implemented. "It was the perfect way to help organizations move from a newly awakened stage to a more active one." [Labovitz, Rosansky, 1997, p.11] Unfortunately, this wave suffered from two significant problems. First, it geometrically increased the rate of change throughout organizations and "they inadvertently fell into the 'activity trap' - lots of teams working on lots of problems but with no connection to the Main Thing of the business...Because TQM focused on cycle time and defect reduction without a clear link to strategy, senior managers often failed to make the ongoing commitment critical to any TQM effort. The responsibility was often delegated to quality zealots for whom short term results became a goal unto itself." [Labovitz, Rosansky, 1997, p.11] Secondly it focused on incremental, continuous improvement. Meanwhile the competition was not standing still. "A 1986 survey of manufacturing...showed that quality had become American managers' chief concern. But it was also the chief concern of Japanese and European managers. Hence, American producers were chasing a moving target..." [Hayes, Wheelwright, Clark, 1988, p.8]

2.4.3 Reengineering Wave of the Quality Movement

The thirst for more significant achievements ushered in the next major wave of the quality movement. The focus turned from continuous incremental improvement in many organizations to the search for breakthrough, order of magnitude, improvement. "Let's face it - steady incremental improvement is not something that rivets executive interest..." [Labovitz, Rosansky, 1997, p.12] This move began in 1990 with Michael Hammer's Harvard Business Review article "Reengineering Work: Don't Automate, Obliterate" and built widespread momentum after the 1993 introduction of the book "Reengineering" by Hammer and Champy. Hammer wrote in 1990, "Instead of embedding outdated processes in silicon and software, we should obliterate them and start over. We should 'reenegineer' our business: use the power of modern information technology to radically redesign our business processes in order to achieve dramatic improvements in their performance." Reengineering was defined as "the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures of performance, such as cost, quality, service and speed."

The major thrust of reengineering efforts in the US were in the area of organizational structure and reducing manpower despite the fact that Hammer and Champy stressed "processes, not organizations, are the object of reengineering." [Hammer, Champy, 1993, p.117] Hammer and Champy also wrote

> Today, fragmented organizations display appalling economies of scale, quite the opposite of what Adam Smith envisioned. The diseconomies

> show up not in direct labor, but in overhead." [Hammer, Champy, 1993, p.29] "Companies today consist of functional silos, or stovepipes, vertical structures built on narrow pieces of a process...Classical business structures that specialize work and fragment processes are self perpetuating because they stifle innovation and creativity in an organization...For an idea to win acceptance, everyone along the way must say yes, but killing an idea requires only one no." [Hammer, Champy, 1993, p.28] "Companies take a natural process...and break it into lots of little pieces-the individual tasks that people in the functional departments do. Then the company has to hire all the king's horses and all the king's men to paste the fragmented work back together again. [Hammer, Champy, 1993, p.29]

Businesses focused on the structure rather than the processes that had resulted in that structure. Reengineering was interpreted as a means to significant cost savings through staff reductions. The euphemism 'rightsizing' was developed to describe the downsizing that was inevitably associated with these efforts. While Hammer and Champy had suggested that the question that needed to be asked first was "If I were re-creating this company today, given what I know and given current technology, what would it look like?" [Hammer, Champy, 1993, p.31], many believe that the question that was generally asked first was "If I cut x% of people out of the organization, how must I modify my processes to pick up the slack?" While the formal definition of reengineering included the words cost, quality, service and speed; most companies were focused on cost. "In many cases, companies have simply used reengineering as a convenient cover for the cost cutting they needed to produce short-term, bottom line improvements." [Labovitz, Rosansky, 1997, p.13] The unfortunate truth is that a comparison of US and foreign 'best in class' manpower levels suggests reductions are inevitable in many industries, including shipbuilding. While we produced less than 1% of the world market for shipbuilding in the U.S. in 1994, the U.S. private shipbuilding industry employed 20% more people than Japan which produced 30% of the world shipbuilding output at that time. [Frankel, 1995, p.2] Manpower reductions should be the result of rationalization of the processes rather than the objective in and of itself.

Concerns with the necessity to manage change had been building throughout the quality movement, as each successive wave either reacted to or increased the rate of change. This is evidenced by an increase in the number of publications associated with "Change Management" in the late 1980's. This turned into an explosion in the mid 1990's. Hammer and Champy recognized that an entirely new way of looking at Change Management would be required for reengineering to be successful. "Reengineering involves, as well, a different approach to Change Management..." [Hammer, Champy, 1993, p.49], "Once processes are identified...,deciding which ones require reengineering and the order in which they should be tackled is not a trivial part of the reengineering effort. No company can reengineer all its high level processes simultaneously." [Hammer, Champy, 1993, p.122] They offered three criteria for prioritizing processes (dysfunction, importance, and feasibility) and also discussed the importance of five roles in the process (leader, process owner, reengineering team, steering committee, reengineering czar) but they offered only rudimentary advice as to how to actually perform this effort. Those companies with particularly good insight into the processes and intricacies of change, which are able to link strategic response with objectives and means, would succeed while others would fail at their reengineering efforts.

Management of change could be considered to consist of two components, a procedural context and the organizational psychology associated with resistance and reaction to change. The procedural context is associated with issues identified in the design change framework introduced in this research like identification, evaluation, prioritization, decision-making and implementation. The field of Organizational Change Management evolved to deal with issues associated with the resistance of people and the organization to change. What became popular at this time was research and books associated with the psychological and organizational aspects of managing change, largely as a reaction to the extraordinary disruption and de-motivation that reengineering had achieved. "Perhaps its greatest weakness had been its utter disregard for people, both managers and workers alike...Hammer pointed out 'I wasn't smart about that...I was reflecting my engineering background and was insufficiently appreciative of the human dimension." [Labovitz, Rosansky, 1997, p.13] In section 2.5 lessons learned from the body of work on Organizational Change Management are reviewed. The next wave of the quality movement focuses on issues associated with the procedural context for linking activity to strategic objectives.

2.4.4 Current Trend in the Quality Movement

The latest wave of the quality movement has been referred to as the "Age of Alignment" by Labovitz and Rosansky and the "Age of Paradox" by Handy. The present efforts emphasize a systems approach, managerial responsibility for goals and objectives linked directly to an understanding of the competitive environment rather than broad uncoordinated activities, and a change of focus away from cost reduction and even quality in the traditional sense of the word. The essence of this perspective is that the many initiatives underway at any given time must be aligned to the strategic purpose of the company by management and that they must have specific goals and objectives. Recent articles such as that by Nohria and Berkley (1994 HBR), "Whatever Happened to the Take-Charge Manager?", and the 1994 Quality Digest article "Why Teams Don't Work" by Uhlfelder are indicative of a call for managerial responsibility and a shift in focus. While the early history of the quality movement was about bottom up improvement throughout the organization and reflected a misunderstanding of the concept of "empowerment", today's movement is toward top down assignment of goals and objectives followed by bottom up efforts to achieve them. "Many management teams in organizations have become initiative junkies. They have no real formula or process...Rather than let the needs of the organization drive their approach to transition, the transition is driven by the independent directives of various initiatives." [McCarthy, 1995, p.3]

This perspective has its roots in Hoshin Kanri begun in Japan in the late 1960's and popularized there in the 1970's. It would not be until 1991 when "Hoshin Kanri: Policy Deployment for Successful TQM" by Akao was published in English that this approach began to gain popularity and lead to other related research in the United States almost 30 years after the development of Hoshin in Japan. After 1991 numerous articles and books related to Hoshin and other strategic planning approaches related to improvement initiatives have appeared. This concept is not new in the U.S., but the intensity and focus of effort on it is. Deming emphasized the need for constancy of purpose in the early 1980's. Only recently is this being fully appreciated and put into practice by following a procedural framework. For example, a 1992 MIT 13-B study, which the author participated in, concluded that with respect to Naval shipyards, "in general, the strategic plans have brought an awareness of long term goals to the yards; the plans have not been fully implemented." The same study concluded that there was a "lack of understanding of what to measure, there is no prioritization of processes." More recently, shipyards are conducting Hoshin training.

Kaplan and Norton have developed a system for "translating strategy into action" which they call the "Balanced Scorecard." Note the reference to balance, which was discussed earlier as it relates to keeping an organization "Prime". The "balanced scorecard" has evolved over time since first being studied in 1990 when the emphasis was on an alternative accounting or measurement system rather than on a strategic planning system. It evolved into a "Hoshin-like" system which is consistent with the concept of competency mapping described earlier and was introduced through a Harvard Business Review article in 1992. Their recent book "The Balanced Scorecard" was published in 1996. Some excerpts follow.

> Currently, many organizations have a myriad of initiatives underway...Unfortunately, these initiatives are frequently not linked to achieving targeted improvement for strategic objectives. Thus, the efforts are managed independently, sponsored by different champions, and compete with each other for scarce resources, including the scarcest of all, senior management time and attention. [Kaplan, Norton, 1996, p.230]

> The Balanced Scorecard complements financial measures of past performance with measures of future performance. The objectives and measures of the scorecard are derived from an organization's vision and strategy...Corporate executives can now measure how their business units create value for current and future customers and how they must enhance internal capabilities and the investment in people, systems, and procedures necessary to improve future performance...they are derived from a top-down process driven by the mission and strategy of the business unit. The Balanced Scorecard should translate...mission and strategy into tangible objectives and measures. [Kaplan, Norton, 1996, p.8]

Labovitz and Rosansky developed an approach which they describe in "The Power of Alignment" published in 1997. Their approach, like that of Kaplan and Norton, seeks to align initiatives with what they refer to as "The Main Thing". "The main thing for the organization as a whole must be a common and unifying concept to which every unit can contribute. Each department and team must be able to see a direct relationship between what it does and this overarching goal. The main thing must be clear, easy to understand, consistent with the strategy of the organization, and actionable by every group and individual." [Labovitz, Rosansky, 1997, p.43] They discuss their approach in terms of vertical and horizontal alignment. "Vertical alignment is about the rapid deployment of business strategy that is manifested in the actions of people at work. When vertical alignment is reached, employees understand organization-wide goals and their role in achieving them." [Labovitz, Rosansky, 1997, p.26] Horizontal alignment refers to the integration of customer requirements in processes across the organization. One of their contributions is a diagnostic tool for assessing the condition of the organization with respect to alignment. The second is a process they refer to as the PDR cycle (Planning, Deployment and Review) which is an adaptation of the PDCA cycle and Hoshin planning. Their process starts with identifying "the main thing" for the organization, establishing critical success indicators which support it, stretch goals which support those and activities and tactics that support the stretch goals. "Stretch goals should be few...since organizations cannot successfully pursue more than that at one time...The planning phase of PDR identifies the main thing and a few critical stretch goals." [Labovitz, Rosansky, 1997, p.87]

They utilize a hierarchical model in much the same way as Vollmann (competency map). They stress that stretch goals are ambitious, highly targeted opportunities for breakthrough improvements in performance. They also suggest that every level, department or unit of the enterprise must have its own tree or hierarchy which can be connected to that of a higher level unit. In this way organizational strategy is deployed throughout the organization in terms of measurable objectives. High level trees will be framed in more general terms. The stretch goals for a higher level tree may serve as the "main thing" for a lower level unit. As was mentioned earlier, the hierarchical structure will allow decision analysis tools to be used to prioritize tactics and means. This will be described in more detail in chapter 6.0.

In addition to the renewed focus on strategy, an emphasis on measures other than cost has become prevalent. About the same time that Juran, Deming, Crosby and Feigenbaum were becoming popular, Eli Goldratt first published his book, "The Goal" in 1984. The goal introduced the Theory of Constraints (TOC), which emphasized a systems approach and move away from the perspective of cost-cutting. The concept of TOC has been refined over the years and has resulted in additional problem solving tools. Goldratt published "What is This Thing Called the Theory of Constraints?" in 1990 to further emphasize the point. Additional books and papers further refining TOC were published since. The very name of the book 'The Goal' makes an important point, that the focus must be goal oriented rather than activity oriented, and ultimately the goal must be described in broader terms than cost. Furthermore, goals should be defined in terms of an understanding of the nature of competitive advantage in order to assure success. Otherwise, TQM and reengineering can generate a much improved process for competing in an environment that no longer exists. [Garvin, 1995] If cost is not the most important measure in today's environment, then traditional accounting and cost/benefit measures are no longer the most relevant issue in decision making.

> The quality movement made much of the issue of cost. Juran emphasizes quantifying the Cost of Quality (COQ) as a means of motivating and rationalizing continuous improvement. The central theme of Crosby's book, 'Quality is Free', is largely the cost saving aspects of quality...There is evidence to suggest that the emphasis on the cost-reducing benefits of quality improvement may be excessive, short sighted, and misplaced...While cost reduction produces an instant impact on the bottom line, equating quality with cost reduction oversimplifies a complex economic relationship. Moreover, quality alone is not sufficient for ultimate success in an increasingly competitive business environment. Witness the fact that a recent Malcolm Baldridge National Quality Award winner filed for bankruptcy...A lesson to be learned here is that it is important to distinguish between a goal and a necessary condition. [Dettmer, 1996, p.1]

> The performance improvement efforts of many companies have as much impact on operational and financial results as a ceremonial rain dance has on the weather...This rain dance is the ardent pursuit of activities that sound good, look good, and allow managers to feel good...At the heart of these programs, which we call 'activity centered', is a fundamentally flawed logic that confuses ends with means, processes with outcomes. [Schaffer, Thompson, 1992]

Goldratt defined the operation of a company in terms of throughput, inventory and operating expenses which are defined as the rate the system generates money through sales, money that is tied up within the system and money being spent. While the traditional emphasis of the quality movement was on cutting costs, Goldratt emphasized that improvement must be tackled first by increasing throughput, then by reducing inventory, and finally by reducing operating expenses. The general principal is that throughput has no theoretical limit while costs and inventory have a theoretical limit of zero. In addition, he made the point that the company must be viewed as a system, and optimization of a system does not stem from the independent optimization of its parts. This implies that there must be a means for determining which parts to concentrate on, how they relate, and an understanding of what is constraining the system as a whole.

Schaffer and Thompson suggested that there are major problems with activity centered programs. They are not keyed to specific results and are often too large scale and too diffused. Associated measurements and expectations are often delusional. The focus on activities as ends in themselves leads to a staff and consultant driven philosophy rather than one which involves upper management. And finally "...because of the absence of clear-cut beginnings and ends and an inability to link cause and effect, there is virtually no opportunity...to learn useful lessons and apply them on future programs." [Schaffer, Thompson, 1992] By contrast they suggest that a results driven program be instituted in which innovations are introduced as they are needed, where empirical testing proves what works, utilizing shorter term successes to frequently reinforce the improvement process, and where management creates a continuous learning process for building the lessons of previous phases into the next phases of programs.

2.5 ALTERNATIVE VIEWS AND MODELS OF LEARNING

Thinking regarding the impact of learning and experience on productivity has also evolved over time. This effort has been focused on examining the effect of learning as a means of predicting future costs. This information is of importance to both the builder and the owner. While the quality movement was focused on developing problem solving and continuous improvement through active change, the topic of learning has traditionally focused on how productivity improves while repeating the same or similar tasks.

More recently, the research has focused on explaining how the rates at which competing organizations learn is different. Change Management, as a concentration for research, is concerned with taking advantage of this improved understanding of how organizations' rates of learning are different to achieve a competitive advantage by managing learning and implementing productivity enhancements faster than the competition.

The traditional learning curve is "founded on the presumption that individuals and organizations learn and performance improves solely as a result of experience gained through repetition of similar work." [Spicknall, 1995,p.209] Learning has been defined as "the ability to do the same task faster and better as experience is gained." [Erichsen, 1994, p141] Thurstone developed the experience curve function in 1917 as:

$$Y_n = a \cdot n^b$$

Where:

n	=	Sequential production number
Y_n	=	Objective measure of performance for Nth unit of production
a	=	Value of Y for first unit produced
b	=	Fractional exponent describing rate of improvement

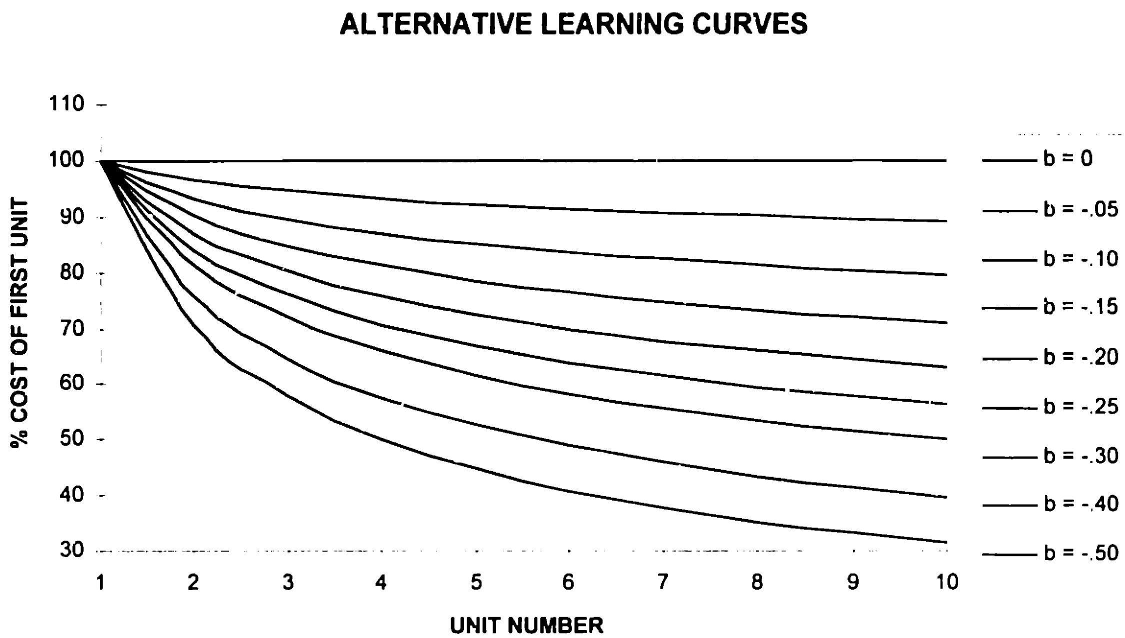


FIGURE 2.3 - LEARNING CURVES

Wright reinforced the notion of the learning curve in 1936 with the publication of "Factors Affecting the Cost of Airplanes" in the Journal of Aeronautical Science. A review of Figure 2.3 illustrates that the traditional learning curve effect is more significant early in a series rather than late in a series. This implies that there is greater benefit in adding a hull to a short series than in adding a hull to a long series. This is because the curve flattens as units are added to the series. This can be illustrated mathematically as a derivative which shows that as the number of units increases, the incremental savings decreases;

$$\frac{\partial Y_n}{\partial n} = b\frac{an^b}{n} = \frac{bY_n}{n}$$

The traditional learning curve points out that experience improves performance due to repetition of the same or similar tasks. It is suggested that the learning curve effect comes in addition to savings obtained through improvements in the construction methods, documentation or managerial approach. [Erichsen, 1994, p.141] Alternatively, the learning curve effect would need to be considered in conjunction with losses associated with changes to production methods and corporate policy as well. The traditional view of learning as illustrated in Figure 2.3 suggests that there is a disincentive to introduce change, particularly during the earlier portion of a multi-hull contract for fear of disrupting the learning effect.

Past experience has shown that actual productivity returns often do not follow the pattern predicted by the model. This is due to factors other than repetition that can affect learning. Erichsen observed this when examining returns from a number of Norwegian shipyards which were involved in series production during the late 1970's. This is illustrated in Figure 2.4 which shows the impact on "normalized" series production costs of adding a longer forecastle for hulls five through seven, and lengthening the ships themselves for hulls thirteen through fifteen. The actual cost data is compared to a learning curve with b=-0.12, which Erichsen observed to be appropriate through regression analysis.

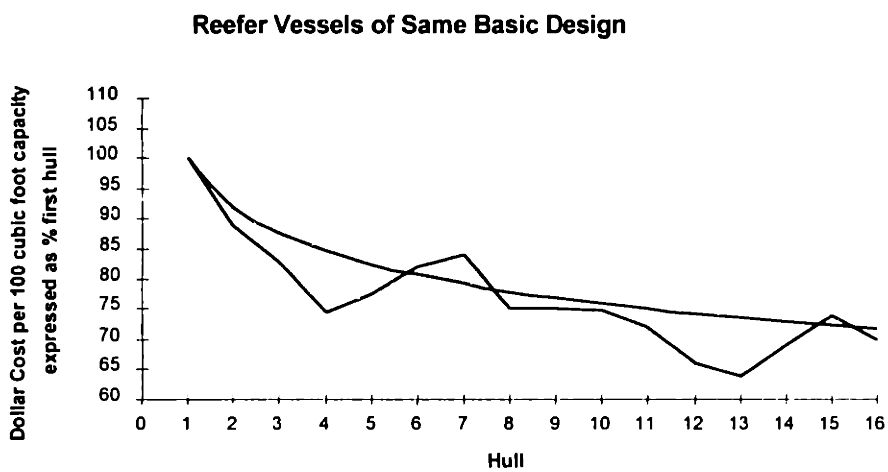


FIGURE 2.4 - EFFECTS OF CHANGES ON THE LEARNING CURVE [ERICHSEN, 1994, P.144]

Among the factors that Erichsen was able to link with rises in cost off the learning curve were:

- Interruption of series production by an odd contract
- A shift to a new owner for the same basic ship in a series
- Turnover of the workforce
- Shift of subcontractors
- Changes in the seasons
- Changes to the wage system
- Introduction of new laws and regulations
- Changes to vacation and benefits system

> Although all curves show a clear tendency toward less hours per ton as the number of units increases, there are great variations in the hours from ship to ship within each series...When the building of a series of standard vessels was halted in order to build a non-standard ship, the hours would rise almost to the level of the first one when the building of standard vessels was taken up again. The cost of interrupting series building by accepting odd contracts may thus be considerably higher than the cost of the contract itself. [Erichsen, 1994, p.145]

In the course of researching this research, data was collected from one shipyard related to weld rates for two recent series of ships. The weld rate represents a composite of hours billed to "welding". These may include hours spent doing things other than welding due to production inefficiencies, such as rework or logistic delay times. Figure 2.5 illustrates actual returns superimposed over appropriate learning curves, with all values normalized to start at 100% for the first hull. Ship series A is representative of a series which did not involve a great deal of disruption or customer change orders. Ship series B shows variation off a learning curve similar to that observed by Erichsen. In this case, the series was interrupted between the second and third ship. This disruption was a significantly different type of ship which was begun towards the tail end of production of the second ship. Furthermore, the last ship in the series included major customer change orders. In addition, series A was begun in parallel to the completion of the final ship of series B and this was noted to be a difficult period for the yard. Ship series C is similar to series A. In this case the series did not witness major disruption from interrupting contracts or change orders.

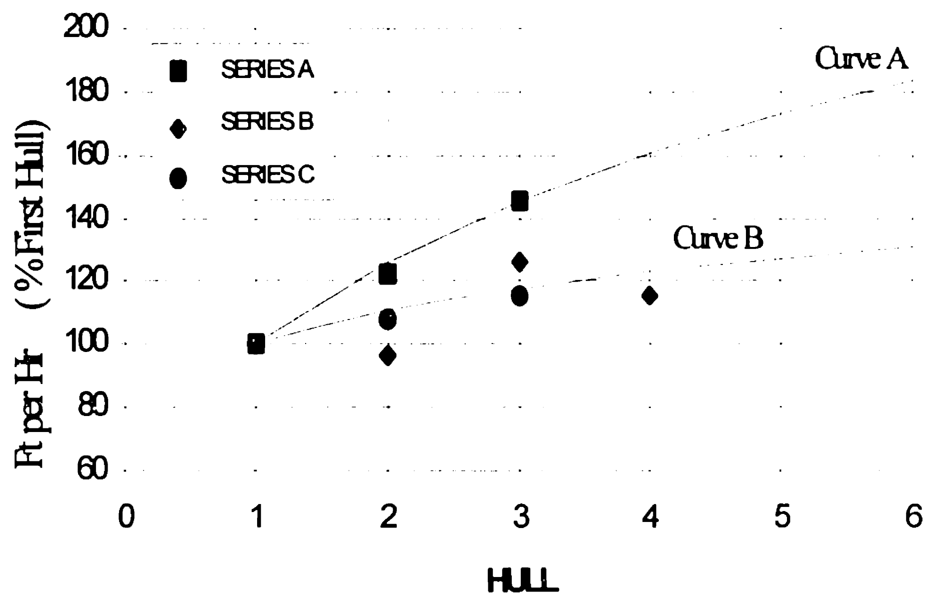


FIGURE 2.5 - WELD RATE LEARNING CURVES

The accelerated rate of learning for ship series A is of interest, since all of these series were built in the same yard. Series C is the earliest of the group, followed by B and finally A. Had series B not suffered from significant disruption, it is possible that the learning curve may have fallen between that described by series C and A as suggested by the rate returns for the third hull of series B. The accelerated rate of learning for series A could be attributed to two factors which were present at the time. The first of these is that at the start of series A, the shipyard had significantly increased production manning. This labor, which was relatively "green", would be expected to "learn" at a faster rate than more experienced labor. This explanation is further illustrated when the actual weld rates, rather than percentages of the first hull, are examined. Series A rates are 83% and 74% lower than those for series B and C respectively (looking at the first hull), possibly attributable to the manning situation. An additional factor that contributed to the accelerated learning curve was a concerted effort on the part of the shipyard to improve its processes between the first and second ship in the series. Some of these improvements related to weld processes. The final ship in series A had weld rates which were greater than the final ship in series B or C.

The examination of weld rates illustrates two important points regarding learning curves. The first of these is that data illustrating a rapid learning curve does not suggest high productivity, but it could simply be indicative of poor initial performance. When comparing learning curves, the data is significant only if the starting point is the same. Secondly, the introduction of new contracts and "green" labor clearly had a disruptive effect while the introduction of process improvements appears to have had positive effects.

Erichsen suggests that two conditions must be satisfied in order to have a significant learning curve effect. The first of these conditions is that the work must have some degree of difficulty and the second is that there must be a high proportion of manual labor. If the work is not difficult, then learning will not be significant since peak efficiency will be attained early, possibly with the first unit. Manual labor is necessary to see a significant learning curve effect because the effect is defined as the ability to do the same tasks faster and better as experience is gained, and implicit in that definition is the idea that people are gaining the experience. This would imply that the importance of the learning curve effect decreases with the degree of automation and that the learning curve effect is more significant for complex ship types than less complex ones. In addition, Erichsen reported research by Gustmann in the 1970's that illustrated that the savings attributed to doubling the number of units produced varied based on the conditions existing at the shipyard. The effect of learning was found to be least when building ships of a type well known to the yard. When more complicated ships were built, the effect of the learning curve was found to increase. The effect of the learning curve was found to be greatest for yards starting to build ships from scratch of a type they are unfamiliar with. The effect of learning was found to be almost as great as that for a new ship type when a significant new technology was introduced to a previously existing ship type. These insights suggest that the traditional notion of the learning curve is becoming significantly less relevant today with rationalized production planning and tasking. The traditional learning curve model has at its roots the notion of mass production. The greater the degree to which a shipyard adapts to a mass customization model of production as described earlier, the less relevant the traditional notion of the learning curve becomes. By taking advantage of standard interim products and rationalizing production around tasks and "group technology" rather than the craft approach which existed many years ago, learning is taking place on the interim parts rather than the contract itself. The learning effect still exists, but it will be more a function of the mix of skilled to "green" labor and stresses on the organization's capability to manage a complex or intense workload. Learning from experience becomes more of a reflection of improvements in relationships and information flow rather than improved performance or skill associated with individual production tasks. Learning curves today likely serve as evidence of active productivity improvement efforts and the introduction of lessons learned into subsequent hulls rather than repetition of identical unchanged tasks associated with a contract.

The traditional concept of the learning curve has proven to be useful by illustrating that "all other things being equal", productivity will improve predictably with the number of units produced. The current competitive climate has forced organizations to seek improvements in productivity beyond those that the traditional learning curve could explain. Recent research has focused on the fact that "all other things" are rarely equal, and identified the problems that this can cause for the traditional learning curve model. This new research emphasizes the model's problems in an effort to explain why competing organizations can have widely different levels of performance.

The deficiencies of the traditional learning curve were discussed by Spicknall as well as by Lapre (et. al.). These deficiencies are associated with the fact that an organization's level of performance cannot be solely attributed to the number of units produced while the traditional learning curve is entirely empirical. While it can be shown that series production results in improved performance for a given organization, research has shown that this cannot explain why some organizations perform better than others. Additional deficiencies include its failure to predict two often observed patterns of initial downward concavity and a plateau effect. Learning rates have been shown to vary widely from one company to another and over time within a single company and not necessary connected to the number of units produced. Research has shown that investments and scale-up of production generally triggers an accelerated learning rate.

The traditional model implies that "an organization's capability in producing a product is only a function of its capability when it started to produce the product, and the number of products it produced since it started." [Spicknall, 1995, p.209] This has been proven to be incorrect, as data from a variety of industries has shown that two firms competing in the same industry, both with similar production histories that started at similar rates of productivity can have widely different rates of productivity years later. Furthermore, the competitor which has produced fewer units can, and often does, take the lead contrary to what the traditional model would predict. Spicknall illustrated this concept using a shipbuilding industry example of price data for the LSD-41 class of ships. In Figure 2.6, the data Spicknall obtained is superimposed over applicable learning curves (b = -0.19, -0.3 and -0.5 respectively). The Figure illustrates that there are other factors that influence productivity than are accounted for in the traditional model. It is these other factors that may have allowed Lockheed to reach its bid price. The only way to reach their target would be to improve beyond the learning curve indicated by their first three ships. In addition, it is these differences that would allow Avondale to produce their lead ship at less than half the cost for Lockheed to produce their lead ship (even when non-recurring engineering costs were included).

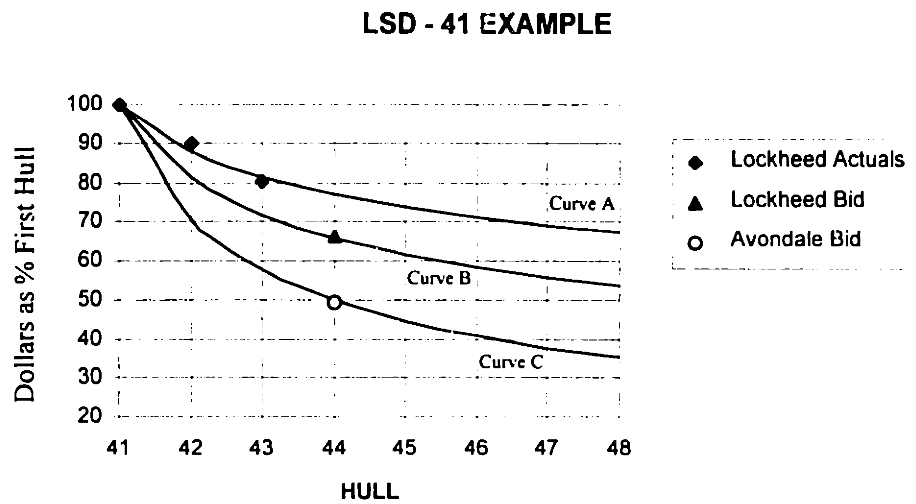


FIGURE 2.6 - LSD-41 CLASS PRICES [ADAPTED FROM SPICKNALL, 1995]

By looking only backward in time to project future performance, the model in essence only recognizes "unconscious" learning. It does nothing to foster or account for "conscious" learning. "Unconscious" learning is "accomplished through experience, either through imitation, or more formally through reaction to reward and punishment." [Spicknall, 1995, p.210] This type of improvement is continuous, incremental, and reactive in nature. On the other hand, "conscious" learning is proactive. It recognizes future requirements and initiates the changes necessary to get there. Conscious learning "relates to formal education and problem solving." [Spicknall, 1995, p.210]. Conscious learning is evidenced by discontinuities in the learning curve, either as a step (order of magnitude improvement) or as a significant change in the rate of improvement.

Conscious learning permits an organization to learn from the experiences of others. Conscious learning is promoted through the use of structured problem solving techniques. Such problem solving techniques and their application have been the subject of the "quality movement." The notion that there are a variety of types of learning is not new. Argyris and Schon described three types of learning in 1978. The first of these is "single-loop learning". This type of learning involves the detection and correction of errors followed by no significant changes in policies or goals. "Double-loop learning" involves questioning followed by changes to procedures and objectives. It is related to "generative learning" as defined by Senge in "The Fifth Discipline." It involves expansion of capabilities beyond simple error correction. "Deutero-learning" is learning that is associated with how to conduct single and double loop learning better. It is learning about learning. The traditional notion of the learning effect is associated with single-loop learning.

The current movement is with respect to double-loop and deutero learning. VonHippel and Tyre also made a distinction between two types of learning in their 1995 article in Research Policy. They refer to these types of learning as "behavioral" and "cognitive". Behavioral learning is the learning that the traditional model explains. Cognitive learning is associated with increased productivity of tools, processes and organizations due to problem solving. Lapre, Mukherjee and Wassenhove referred to conceptual and operational learning in 1996. Conceptual learning involves developing an understanding of why a problem occurs (acquisition of know-why). Operational learning involves developing a skill of how to fix a problem (know-how). It could be suggested that in addition to the types of learning identified above, two additional classes should be considered. The first of these is proactive and the second is reactive. Reactive learning is the type generally discussed above. It is learning that is triggered by an identifiable event. That event may then lead to single or double-loop learning (and either conceptual, operational or both). For example, in the model illustrated in Figure 2.7, reactive learning includes both the unconscious learning that takes place after production begins as well as any deliberate double-loop learning that takes place after a performance gap is recognized due to production results. Proactive learning, on the other hand, is not triggered by an event in the traditional sense but by the recognition of opportunity. It would always involve double-loop learning and generally both conceptual and operational learning. In the model, it is represented by deliberate activity that results from recognition of a performance gap that is not the result of production having been begun but rather the anticipation of a gap through strategic planning or benchmarking. One is associated with failure to meet targets while the other is associated with the creation of those targets and the planning activity associated with anticipating how they will be met. These activities often occur prior to production, but can also take place throughout the entire cycle. The quality movement has resulted in significant efforts associated with proactive learning. Activities at a shipyard will generally involve both. Note that "start production" could also refer to design, where performance gaps will also exist.

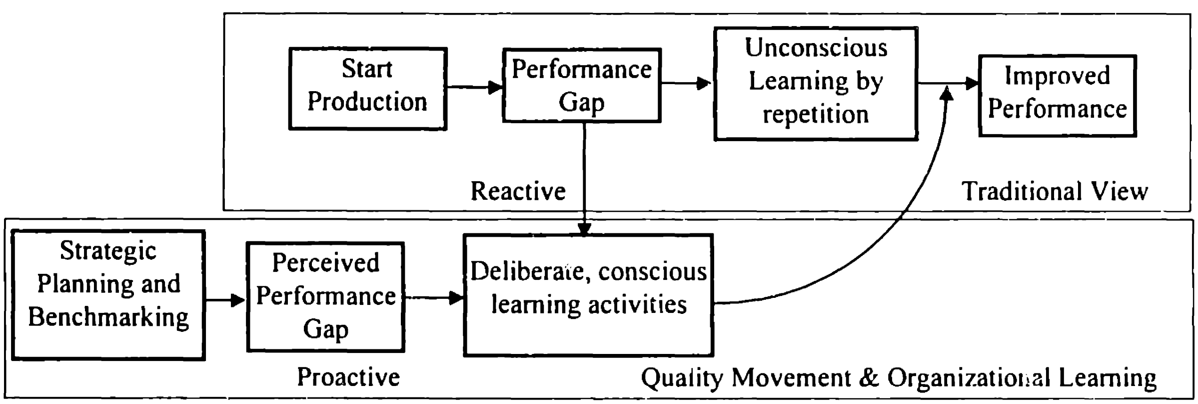


FIGURE 2.7 - NEW MODEL OF LEARNING [ADAPTED FROM LAPRE ET. AL.]

Recent research has been referred to collectively as the field of "Organizational Learning." In a 1954 Harvard Business Review article Andress described learning in terms of the traditional learning curve. "The basic theory of the learning curve is simple: a worker learns as he works; and the more often he repeats an operation, the more efficient he becomes..." [Andress, 1954] It is interesting that at that time, Andress noted the existence of additional factors. "A distinction must be made between a) learning in the literal sense...and b) a whole series of other factors of which management innovations appear most significant...For example, new machinery introduced by the company will bring about savings in labor hours; so may time studies or design changes." [Andress, 1954] For the most part, these additional factors were dismissed. "The significant fact is the consistent behavior of the curve, which indicates that of the various factors learning in the literal sense is the predominant influence." [Andress, 1954] These finding were perpetuated despite the changes in industry including automation, a rationalization of tasking and the adoption of significant standardization of interim parts and "mass customization". In 1985 Fiol and Lyles defined learning as "the process of improving actions through better knowledge and understanding". Thus the emphasis had evolved from error correction to improvement in general.

The field became popular with the introduction of Peter Senge's "The Fifth Discipline: The Art and Practice of the Learning Organization" in 1990. In large part, the field of organizational learning centers on three guiding principals. The first is the "primacy of the whole", or the notion that the whole must be the focus rather than the parts. The second is the "community nature of the self" which is a focus on relationships and interdependency. The third is the "generative power of language" which focuses upon the role of observation and communication. Research in the field of organizational learning attempts to integrate issues associated with different types of learning (single-loop, double-loop and deutero as described earlier), different learning processes, different learning focuses and different levels of learning ranging from individual to trans-organizational. As of 1994, almost one hundred books and journal articles on organizational learning had been published, sixty percent of them since 1991. [Roth, 1996] There have been two primary focus areas for research. The first area of focus is in improved analytical models for predicting learning effects that take into consideration both behavioral and cognitive factors. The second focus has been on the theory, means and methods for nurturing learning in organizations. Examples of work on improved modeling techniques include that by Levy (1965), Adler and Clark (1991), and more recently Lapre, Mukherjee and Wassenhove (1996). An example of research regarding methods associated with cultivating learning in organizations is the extensive recent work on "learning histories" (see the work by Roth of the MIT Center for Organizational Learning). Research regarding learning histories deals with how documentation is used to capture, assess, facilitate, diffuse and sustain organizational improvement initiatives. [Roth, 1996]

Huber identified four processes that contribute to organizational learning in 1991. These include knowledge acquisition, information distribution, information interpretation, and organizational memory. Nevis, DibElla and Gould similarly identify three stages of learning. The first is knowledge acquisition, the development or creation of skills, insights and relationships. The second is knowledge sharing, the dissemination of what has been learned. The third is knowledge utilization, the integration of learning so that it is broadly available and can be generalized to new situations. Schein has extended this concept with the "adaptive coping cycle" which consists of six steps. [Schein, 1996] The first of these steps is accurate sensing of changes in the external or internal environment. This requires that some sort of sensing structure be in place. The second step is getting information to the right place where it can be acted upon. The third involves analysis and drawing conclusions from the information available. The fourth step involves making transformations without creating undesirable side effects. The fifth step involves exporting new products or services that incorporate the transformation. The final step involves obtaining feedback on the success of the measures. Pawlosky and Reinhardt provide a similar model involving identification and creation, diffusion, modification and integration, and finally action. These cycles can be seen to be similar to the PDCA cycle in many respects, as it would relate to a learning process.

Lapre et. al. developed a learning curve model which has a theoretical basis associated with recognized performance gaps and conscious initiatives to improve performance. Their model seeks to recognize that a performance gap "induces the organization to search for alternatives to reduce this gap. A larger discrepancy spurs the organization to exert more effort in searching for better knowledge. The effectiveness of acquiring new knowledge depends on the learning rate...Consequently, we can model the rate of improvement as the product of the learning rate and performance gap." [Lapre et. al., 1996] Furthermore, they modeled the learning rate as the sum of an autonomous, or unconscious, factor and the sum of a set of induced learning factors associated with individual initiates. In addition, they linked the learning rate with time. They then utilized their model in a number of manufacturing firms to identify the contributions of a variety of projects to the learning rate. Their findings suggested that projects which relied on operational learning alone had little impact on the learning rate, while those that relied on both conceptual and operational learning enhanced the learning rate. They also found that "unproven theories", or projects that relied on conceptual learning without an operational or empirical component had a tendency to disrupt the learning rate.

When examining the "learning effect", it is therefore important to consider the effects of cognitive as well as behavioral changes, conceptual and operational learning, proactive and reactive modes, and the means for accelerating the rate of learning associated with each. Earlier in this chapter Erichsen's points regarding the detrimental effects of changes were discussed. These detrimental effects come about because change introduces a period of disruption which must be managed properly. Research by Lapre et. al. suggested that projects which acquired both know-why and know-how, empirically proven theories, accelerated the learning rate while others had no impact or impeded the learning rate. For this reason it is important to focus on both conceptual and operational learning in projects, more easily done when projects are aligned to shared goals and objectives as described earlier, and to understand the theory and methods associated with Change Management to insure implementation with minimal disruption.

2.6 Theory and Methods for Organizational Change

Alvin Toffler coined the term "future shock" in 1965 and later wrote a book by the same name in 1970; "Future shock is the shattering stress and disorientation that we induce in individuals by subjecting them to too much change in too short a time." [Toffler, 1970 from Conner, 1992, p.51] Conner elaborated that "future shock relates to the overlapping impact of too much change that is too complex to deal with and occurs at too rapid a pace. The results are high levels of stress...and the inability to act quickly enough...Essentially, future shock occurs when people are asked to absorb more disruption than they have the capacity to take on....future shock is that point when humans can no longer assimilate change without displaying dysfunctional behavior" [Conner, 1992, p.51] So the field of Organizational Change Management is largely concerned with the human reaction to change and how it manifests itself in organizations seeking to implement changes. As was discussed with respect to the quality movement, the ability of Engineering to adapt to the twin requirements of facilitating improved production methods and reducing design cycle times has resulted in "future shock" in many engineering offices in shipyards. For this reason, an examination of the lessons to be learned from research in Organizational Change Management will assist in the formulation of procedures, methods, and models for managing design improvement in shipbuilding.

The field of Organizational Change Management has become popular in recent years as a reaction to the rapid pace of change evident today. This pace has been increased as a result of the quality movement, or more precisely changes in the competitive environment that motivated companies to embrace the quality movement. Conner wrote "...the change encountered in previous eras was different. What has changed about change is its magnitude, the approach it requires, the increasing seriousness of its implications, and the diminishing shelf life of the effectiveness of our responses to it." [Conner, 1992, p.38]

> A broad study reviewing 'total quality' programs in 584 U.S. companies...released by Ernst & Young and the American Quality Foundation in early 1992, found that because many quality programs are overly broad and undefined, and because they are not implemented in a consistent and focused way, they fail to achieve their intended results... [Jick, Cohen ed., 1993, p.343]

The field of Organizational Change Management approaches the procedural context with respect to cycles of change beginning with the identification of a need through sustaining implementation. It is a significantly different perspective than that offered by configuration management. Configuration management is merely the process for incorporating changes on documents, identifying revisions and communication revisions. Configuration management may be a component of a broader Change Management process, but alone does not insure success. The Change Management literature generally addresses the following facets of Change Management:

- Anecdotal advice, or common features of those that succeed
- Procedural context and phases or cycles of change
- Differing roles of stakeholders involved in change cycles
- Psychology of the resistance to change and the means to combat it
- Organizational readiness for change and the means of measuring it

Carr, Hard and Trahant suggest that successful companies address change in a comprehensive manner, meaning they address both procedural and psychological aspects of change. They follow a systematic process for introducing change. McCarthy offered the following as seven objectives which successful firms address when introducing change:

- Align organizational strategy, structure, and workforce capability
- Maintain organizational momentum
- Upgrade employee skills
- Minimize instability by anticipating change
- Identify and follow an efficient transitional sequence
- Communicate clearly and frequently
- Minimize unnecessary disruption

2.6.1 Change Management Stage Models

Several researchers and writers have discussed procedural contexts for change. Conner writes that "you will be much more effective if you approach change as a manageable process with definite structures and outcomes that can be reliably anticipated." [Conner, 1992, p.61] Several of these stage models were reviewed in the course of this research. Heifetz in "Leading Change, Overcoming Chaos" (1993) proposes a seven stage model which is representative of those reviewed. The approach promoted by Heifetz represents an example of a typical "collaborative mode" Change Management process which emphasizes teambuilding and empowerment. The significance of motivation, patience, and commitment are emphasized. The motivating force is described by Heifetz as "discomfort", and a variety of researchers have concluded that pain and discomfort are strongly linked to success because the effort required to make the change must exceed the discomfort with the status quo. This will be discussed in more detail as it relates to alternative implementation strategies in chapter 8.0.

> While the desire for change can be linked to recognized opportunity, discomfort is more often the motivating factor. [Heifetz, 1993, p.6]
>
> The caution here is patience. It takes people a long time and a great deal of discussion, independent thought, formulation, trial, reformulation, and retrial to assimilate a significant organizational change...The kind of communication required spans the entire change cycle and cannot be rushed...There is little that can be done to leapfrog the step by step process of change, or the assimilation time that people require. [Heifetz, 1993, p.32]

Motivation is described as being discomfort brought about by either internal pressures or external pressures. He suggests that the proposed change cycle can be successful regardless of the motivation to change, provided that the pressure is strong. His experience suggests that external pressures present greater levels of discomfort and therefore are most often the motivation to change. In examining the internal pressures listed more closely, it appears logical to assume that employee expectations, employee skill levels and company size are themselves a function of external pressures. The key lesson is that without significant pressure, or a "sense of urgency", it is unlikely that efforts will be successful. Motivation initiates the seven stages of the change cycle, which are presented as:

1. Choosing the target
2. Setting goals
3. Initiating action
4. Making connections
5. Rebalancing to accommodate the change
6. Consolidating the learning
7. Moving to the next cycle

The first stage represents the initial response to the motivation. At this point a proposed change is identified, evaluated and selected from alternative possibilities for responding to the motivating force. During this stage, preparation is made for the next stage by clarifying, formulating and refining the idea. Heifetz suggests that by the end of stage one, a small core group of people should emerge that has defined a target. The word "target" is used to describe both the idea, and the objectives of the idea. Heifetz emphasizes that there must be a sufficient level of interest and visible commitment from leadership in order for this core group to emerge and start the process of change. This is referred to as sponsorship by others in the field. During this stage the vision should be made clear. There must be definition of the corporate, agency or departmental direction being discussed, as well as a clear understanding of how the organization will be different after the change is successful. The scope of the change must be understood. Does the change represent a major shift in focus or only an adjustment? The alternatives must be recognized. What directions will not be taken as a result of this change? Finally, a target must be defined for what is to be accomplished. The output from this stage is a proposed change responding to the motivation which has been defined to a degree meriting further study. This is consistent with the concepts of competency mapping and Hoshin management discussed earlier in this chapter.

In the second stage, greater definition and planning of the purpose, scope, outcomes and implementation is developed for the proposed change. The core group that emerged in stage one evolves into a design, planning and implementation team. Heifetz suggests that at this stage, while the team will interact with others, much of their work will be accomplished as an independent entity. While acting as an independent group, the team must be staffed cross-functionally to achieve adequate representation. Heifetz warns that not integrating the appropriate people into the team could ultimately lead to failure, but that the size of the team must also be limited to allow a viable plan to be formed prior to the organization as a whole developing strong resistance. In chapter 3.0, the implications this has for the Production Engineering function at a shipyard will be discussed in more detail. In this stage the capabilities of the organization are analyzed to determine if they are in alignment with the proposed change. This analysis includes an assessment of the impact of the change upon the products, policies, priorities, customers and internal systems of the corporation. During this stage the team analyzes the change and organization to determine where resistance is expected to be encountered. A plan is developed for addressing roadblocks. Heifetz proposes that the significant difference between the first two stages is that the first stage is broad based and emotional while the second stage is data driven. During this stage questions of time, effort, and expense are given serious consideration. These issues all relate to the three areas of emphasis for Heifetz' model of change (motivation, patience and commitment). The change proposal will either be dropped or given even greater definition at this stage. The output from this stage is commitment to the proposed change from the stakeholder leaders.

> The will of the organization is given a more severe test now, as the resource level needed for the project becomes clearer. Your organization should either assure the resources required to accomplish the goals of the project, or reconsider its position with respect to those goals. [Heifetz, 1993, p.9]

The third stage, "initiating action", is characterized by an unmistakable shift from planning into action and the involvement of the organization as a whole. An output from this stage could be thought to be the "clarity of purpose" described by Deming. This clarity of purpose is measured both in terms of the clarity of the vision and the clarity of commitment of the organization.

> The effectiveness of the goals and plans of stage two lies in large part in their ability to stimulate interest and appropriate action within the organization beyond the stage two planners. [Heifetz, 1993, p.9]

In the third stage many new individuals will get their first significant exposure to the change. Heifetz makes the point that these individuals need to reach "alignment with the core team" (otherwise known as clarity of purpose) and will need to move through their own personal stages one and two. "They need to integrate the project into their own work lives and commit energy and talent to move it forward." [Heifetz, 1993, p.10] This could take time and energy on the part of the sponsors of the change. There must be incentive for the rest of the organization to take action. This often requires restructuring jobs around the project, evaluating employees based on progress towards achieving the change's goals, and insuring that the organization as a whole understands why the change is important and how it fits into an overall plan. Understanding is necessary in order for restructuring and evaluations to be effective rather than demoralizing.

It is not enough to ignite commitment. To be successful commitment must be sustained. Heifetz argues that during implementation it is vital to provide everyone with feedback on a continual and ongoing basis. This will maintain momentum and interest in those already on board and make it difficult for those that are not yet supporters to become roadblocks.

2.6.2 Change Management Roles

Associated with the stage process models are roles that must be fulfilled. Considerable research has been conducted regarding the roles necessary for successful change and innovation. Conner suggests that there are four roles associated with managing change. These include sponsors, agents, targets and advocates. LaMarsh refers to only three roles including sponsors, agents and targets. A sponsor has the power to legitimize a change. They are the decisionmakers who should have the authority to decide which changes will happen and what the priorities are. An agent is the person or group responsible for making the change happen. They are distinct from the targets who actually must change. In the context of design change, the agents would be those responsible for developing the proposal and managing its implementation. The advocates are those who want to achieve a change but lack the power to sanction it. The general concept is that an advocate identifies a need, convinces a sponsor to support it, an agent manages the project and the target performs the change. In the context of shipbuilding, the advocate for a design change may be production or Production Engineering. The agent is generally Production Engineering, the target is design engineering and the sponsor may be a director or VP in production, planning or engineering. To be successful using this terminology, sponsorship must include engineering executive management. Furthermore, to consider the agent and the target to be entirely separate entities is not often successful. Production Engineering as a separate function cannot make a change happen in engineering without their cooperation. This leads to a variety of issues associated with how to organize for Production Engineering. These will be discussed in chapter 3.0.

Roberts and Fusfeld identify five critical roles in the innovation process which must be fulfilled with respect to R&D organizations and processes. [from Roberts ed., 1987, p.27] The roles they identify are similar to those identified by other researchers who have studied innovation in firms. They are useful when one considers the Production Engineering function to be similar in many respects to a research and development function. These roles include Idea Generating, Entrepreneuring or Championing, Project Leading, Gatekeeping and Sponsoring or coaching. Idea generating is associated with analysis of the environment and identifying an idea. The person best in a position to identify a new idea will have special knowledge of the focus of the idea and be able to deal with conceptualization and abstraction. The champion role deals with selling ideas to others and acquiring resources. Such an individual possesses a wide range of interests and is less likely to contribute to the basic idea but is aggressive and has the determination actively pursue support. The project leading role is associated with providing leadership and motivation and the planning/organization skills required to implement a proposal. They have an understanding of the organization and what is necessary to get things done. They are sensitive to the needs of the organization and can integrate a broad range of disciplines. Gatekeeping involves gathering information which is passed on to the other roles. They keep abreast of what competitors are doing and what has been published in the journals. These individuals are "connected" and approachable and serve as an information resource for all the other roles. The sponsor provides access to the power base within an organization and provides the needed encouragement. They are senior individuals who help the team get what it needs. They noted that some people may serve multiple roles and that some roles may require multiple people. As will be discussed later, the intensity of the roles required vary from one phase of the stage model to the next. Understanding these roles and their relationships to the stage model will have implications for how a Production Engineering function might be staffed and organized.

2.6.3 The Psychology of Resistance to Change

In addition to an understanding of the procedural context and the roles that people throughout the organization play, Organizational Change Management research has yielded a psychological or theoretical understanding of how people react to change which is useful in managing the implementation of changes. A common theme throughout the literature regarding Change Management is that change is in the eyes of the beholder.

> There are inherent difficulties in describing development efforts only in terms of "gradual" and "radical"...or in terms of "increments" and "steps", due to the dependence upon the level of analysis and perception...Developing new routines in a work team may be perceived as very radical by an indiviudal who is used to ten-year-old working habits, while it passes unnoticed by even the first line manager. [Berger, 1996, p.6]

Conner relates the resistance of change to issues associated with expectations, capabilities and control.

> When the challenges we encounter are matched equally with our capabilities, we are usually able to predict what the outcome of the situation will be. When challenges are greater than our capabilities, this balance is upset and we are usually not able to accurately anticipate what will happen. When our equilibrium disintegrates, our expectations are disrupted and change is at hand...Change is minor when it does not significantly disrupt what you anticipated would happen. In these circumstances, you simply fine-tune your expectations and adapt to the change...If the disruption is major...it invalidates your expectations...Regardless of how conscious or unconscious the effort,

when you gain a sense of control over your life it stems from your ability to match expectations with perceived reality. [Conner, 1992, p.69]

In the context of introducing design changes, this equilibrium is broken when an engineer or engineering manager is not able to predict the stability of their processes, the reaction of their superiors, and the availability of their resources with respect to the outcome of the decision to move forward with a change. For this reason, a significant component of managing design improvement proposals is managing expectations. This will include creating an expectation that producibility motivated change WILL occur, and an emphasis on creating an expectation within engineering of the types of changes that these will be. Furthermore, an environment must be created within which engineering staff know what to expect from their superiors with respect to commitment to addressing these changes.

The benefits of Concurrent Engineering, Standardization and Build Strategy development include providing a means for managing these expectations. Incorporation of new approaches and explicitly stating that new standards or design details are to be implemented in the Build Strategy assists in managing expectations and reducing resistance. Furthermore, future changes should be identified in the Build Strategy as well, and it should be shown how these link back to strategic objectives, in order to manage expectations. While the precise changes may be unforeseen, areas of priority should be identified for which it is desired to reduce costs or cycle time. The Build Strategy should explicitly identify areas where future improvements are anticipated but were not yet at a stage of development to be incorporated. There should be a method in place regarding the potential introductions during mid-cycle, either due to further development of an existing concept during detail design/production of the first hull or as a result of lessons learned during production of the first hull. The Build Strategy for a multi-hull contract should set targets for improvements between hulls and the focus areas which may result in changes between hulls to support these targets. For example, a concept may be piloted on the first hull with the understanding that it will be re-evaluated for full introduction into the second. Doing so will help to manage expectations and assist engineering in developing budgets which anticipate improvement activities. This will be discussed in more detail later in this research.

There are two "personality types" which are associated with attitudes towards change and the amount of change an individual can assimilate. The traits exhibited by someone will be a function of their personality and their function in the organization. To the extent that an organization is structured functionally in "silos", these differences are intensified because people perceive their roles as being champions for tasks and functions rather than the achievement of the whole or the goal. In utility theory and decision analysis these are often referred to as risk prone and risk averse. Later, in chapter 6.0 it will be shown that these two distinct personality types do in fact exist in shipyards and have a direct impact upon the ability to introduce change. Conner refers to these personality types as type-O and type-D, or opportunity oriented and danger oriented. [Conner, 1992, p.232] A type-D person has a lower threshold for assimilation of change and perceives change as threatening. A type-O person has a higher threshold for assimilation and sees change as opportunity. The failure of a type-O person (such as a production engineer tasked with identifying and implementing improved methods) to appreciate the perspective of a type-D person generally results in misunderstandings and serves as a roadblock for any further activity. There is a common concept of a cycle such that misunderstanding leads to confusion and anger on the part of the targeted type-D individual or group, which ultimately leads to blaming and alienation of that group which leads to future hostility and misunderstanding. Therefore, it is important to understand the needs of the type-D individual before proceeding to initiate other activity. It is important to recognize that a type-D individual can entirely agree on the magnitude of the benefits, but is preoccupied with the risks. The type-O individual needs to focus on the means of averting risks which are what the type-D individual actually cares about. They need to be shown how this change fits into their framework, or expectations. This means showing them the true costs and difficulties associated with the change and working with them to explore how they can accommodate it. This is easier when expectations have been managed properly and upper management has developed strategic goals which the changes can be shown to support.

Everyone has a limit or cap on the amount of change they can assimilate, or the amount of activity one can handle which is not aligned with one's expectations or sense of control. "The dysfunctional behavior associated with future shock is not usually due to a single change event. It more typically occurs from the effects of multiple, overlapping changes." [Conner, 1992, p.81] This explains the frustration of production and production engineers who cannot understand why a seemingly simple change proposal faces such extraordinary resistance from the design departments. The "simple" proposal is actually major because it causes the organization or the people involved to exceed their allotment of "assimilation points" [Conner, 1992, p.81].

> The problem is that management doesn't collect the proper information to develop a complete picture of what is about to happen...If you haven't built a comprehensive picture of the total assimilation drain on the people affected by multiple changes, you may be seduced into thinking that a particular project will be assimilated without much of a problem. [Conner, 1992, p.82]

The lesson for managing design change is that those interested in introducing changes must be sensitive to the total assimilation drain. This implies that the capability to screen, prioritize and link efforts is critical. If a change causes major disruption for any of its constituencies, then it must be approached as a major change. In addition, there are two issues which the shipyard must deal with. The first of these is how to increase the number of assimilation points people and organizations have available to them and the second is to reduce the number of points expended in introducing changes. [Conner, 1992]

One common theme throughout all the research into change processes is that the implementation of change requires a background of stability to succeed. The argument implies that prior to engaging in significant change efforts, it is first necessary to nurture a stable environment or an environment which is understood. The processes, procedures and design elements already in place must be understood and predictable before change can truly be managed. Otherwise change is not being managed, but is ad hoc. This is a concept related to the "change readiness" of an organization. "Pettigrew argues that 'change processes can only be studied against a background of structure or relative constancy'...Organizational change only exists in relation to organizational stability - change is from a state towards a state." [Winch, 1994, p.38] The risk that a change may not be successful due to organizational factors such as instability or a lack of understanding of fundamental processes must be considered during the evaluation and implementation phases.

2.6.4 Alignment and Other Factors Critical for Success

The consulting firm Coopers and Lybrand suggests that there are five primary "critical success factors" that help to differentiate successful from failed change efforts. All of these relate to the "change readiness" of an organization.

> The following formula illustrates the critical success factors for overcoming resistance to change:
>
> $$SC = V + N + M + R + F$$
>
> Successful Change = Vision + Need + Means + Reward + Feedback
>
> Successful change will follow when:
>
> V: A shared vision of the desired change has been developed, articulated, and communicated by the change leaders.
>
> N: The compelling need for the change has been developed and is shared by all employees.
>
> M: The practical means to achieve the vision has been planned, designed and implemented.
>
> R: The reward systems of the organization have been aligned to identify and encourage appropriate behaviors compatible with the change vision.
>
> F: Feedback is given at each stage of the process to monitor progress and provide information for continuous improvement. [Carr, Hard, Trahant, 1996, p.157]

Coopers and Lybrand also identify the importance of assessing the organization's "readiness for change". "The odds of successfully implementing change grow as the similarity grows between the existing culture and the behaviors and assumptions required by [the] change initiative." [Carr, Hard, Trahant, 1996, p.165] They refer to a "baseline load factor" and a "culture climate survey" as two tools useful in evaluating change readiness. "The baseline load factor shows that the implementation phase of a change effort can be jeopardized if its sponsors, agents, and targets are experiencing work-related stress before the change is announced...The Culture Climate Survey (CSS) measures the readiness of an organization for change and the likely cultural resistance factors that might inhibit full achievement of the specific change objectives." [Carr, Hard, Trahant, 1996, p.163]

McCarthy has also suggested the importance of organizational preparedness in his book "The Transition Equation." He identifies the importance of aligning three critical components in order to achieve success. The degree of the alignment of these factors can be considered to be a measure of "organizational risk." "The importance of alignment and the need for transition planning becomes clear as one examines the repeated failures of initiatives and other undertakings in organizations." [McCarthy; 1996, p.19] In evaluating preparedness "a translation needs to occur that accomplishes two things: identifies what we are required to do and how capable we are of doing it." [McCarthy, 1996, p.53]

> A technique I use to boil down all of the issues to an understandable level is based on three critical components: strategy, structure and workforce capability.
>
> Strategy is a specific course of action necessary to help achieve vision or mission statements.
>
> Structure refers to the tangibles, such as systems, processes, standards, brick and mortar, policies, procedures, training programs, and equipment necessary to support the strategy.
>
> Workforce Capability is made up of the skills, knowledge, attitude, commitment, and values necessary to work within a given structure in support of the strategy. [McCarthy, 1995, p.15]

In examining how well a change proposal is aligned with an overall strategy, organizational structure and workforce capability, it is often found that:

1. Most aspects of the organization will not need to be altered dramatically in the short term.

2. Some aspects of the transition need immediate attention.

3. Some aspects of the desired change require significant departures from how the organization is accustomed to operating...

4. Many skills ingrained in the organization's workforce may have little or no relevance to the future state. [McCarthy; 1996, p.83]

The extent to which each of the above is true is a representation of the organizational risks associated with a particular change proposal. McCarthy defines a "preparedness scale" which he uses to describe how prepared an organization is to implement a proposal given their current experience, demonstrated capabilities, and existing resources. [McCarthy, 1996, p.93] This scale can be considered to be a "constructed attribute" as defined by Keeney. "Most constructed attributes are meant to measure more than one facet of a complex problem" and they tend to describe subjective conditions. [Keeney, 1992, p.104] Such scales can be utilized for screening projects. This particular scale is defined from A through E and is applied to each of the three "critical factors" as follows:

A = No experience. Don't think we are ready to do this. Many unknowns.

Strategy:	Strategy is not formulated
Structure:	Structure is not defined, or necessary structure does not exist
Capability:	Skills, knowledge and capabilities necessary to perform this activity are absent or unclear

B = Marginal capability, no direct or related experience. Not sure of our capability to perform this activity.

Strategy:	Strategy formulation is incomplete. It is difficult to see how or why we might do this.
Structure:	Most aspects of the required structure are unclear. It is obvious that there are gaps in information over what is required.
Capability:	It is apparent that the workforce is not equipped with all of the skills and knowledge necessary to perform this task and that external input and training will be necessary.

C = Partial capability, no direct experience. Seems feasible but not completely thought through.

Strategy:	The overall strategy and the reasoning behind it are apparent. It is relatively easy to see the logic to do this and how it will be approached.
Structure:	Most of the key systems, processes, equipment, etc., necessary to perform this activity are known and appear doable.
Capability:	Some skill and knowledge is required in order to perform this activity. No critical skill and knowledge gaps are seen. Some workforce development will be necessary.

D = Some familiarity with subject. Have experience applicable to the requirements of this activity.

Strategy:	The strategy is clear and most aspects of it can be easily translated into specifics.
Structure:	Most of the structural aspects of this activity are known and have been done before.
Capability:	Workforce is equipped with most skills and knowledge requirements or can readily learn them.

E = Have performed before or have experience doing this activity. Have a successful track record with this activity.

Strategy:	Strategy is formulated and is very clear and specific.
Structure:	Structural components are identified, and how to create, acquire, or logistically position them is known.
Capability:	Workforce currently has the skill sand knowledge necessary to support the named strategy and structure.

Nadler and Tushman echo the concept of the importance of alignment of the change proposal with corporate strategy, structure and capability in their book "Competing by Design." Their work focuses on organizational structure and its influence upon adaptivity and competitiveness. They propose what they call the "congruence hypothesis" which states that "Other things being equal, the greater the total degree of congruence, or fit, among the various components, the more effective the organization will be. Put another way, the degree to which the strategy, work, people, structure, and culture are smoothly aligned will determine the organization's ability to compete and succeed." [Nadler, Tushman, 1997, p.34] This is entirely consistent with the concepts of Hoshin and strategic planning introduced earlier.

LaMarsh has also written about the need to integrate proposed changes within an overarching vision or strategy. "Think about the changes in your company. Look at your picture of the vision/mission. Does each of these changes help achieve that vision/mission? Is its contribution clear?"[LaMarsh, 1995, p..23] There is an organizational risk associated with the degree to which a change impacts four key elements. "The changes required in Engineering will be based on those four interrelated department aspects: process, structure, people, and culture. A change in any one aspect sets off changes in every other one. Therefore framing the change and fitting it into a larger future must start by looking at engineering as an entity made up of process, structure, people and culture. Then each proposed change in any one aspect must be examined to determine its impact on the other three." [LaMarsh, 1995, p.20]

2.7 SYNOPSIS

Shipbuilders must think in terms of strategic objectives and how they are supported by capabilities and competencies. The design improvement process and decision analysis models must address the means by which competitive advantage, and therefore capabilities, will be supported by proposed design improvements. This is a strategic concern which will require analysis that goes beyond traditional engineering economic cost/benefit considerations.

Product and process are linked, and therefore process change generally requires product change to support it. A shipyard which emphasizes continuous or breakthrough improvement of production processes must be equally concerned with engineering support. A mechanism for introducing design improvements must be put in place. Doing so will require shipbuildiers to balance flexibility and control. A mechanism for alternating between disorder/informality/innovation and stability/conservatism is required.

Shipbuilding appears to be more closely aligned with a mass customization model of production. Making standardization a distinctive competency will provide the shipyard with a greater capacity to balance flexibility and control. Concurrent Engineering, Standardization/Mass Customization, Build Strategy development, and the Production Engineering function address this issue (in part by managing expectations) and will be discussed in chapter 3.0.

Vollman suggests that those organizations that succeed at balancing flexibility with control are in a position to dominate their industry. He identifies a number of observable characteristics of dominance:

- Anticipation of, and quick response to, changes in marketplace conditions
- Proactive, opportunity seeking atmosphere
- High rate of learning
- Flexibility, responsiveness and speed
- Internal sense of urgency, nonbureaucratic
- Team Spirit
- Setting of standards that competitors try to follow
- Changing the rules
- Growth of capabilities and competencies

Significant productivity advances are achieved through a combination of both incremental and major innovations. "All the evidence points to the need to innovate both with breakthrough products and processes and with regular incremental improvements. Any firm that plans to win the race to commercial success by being either a steady plodding tortoise or a swift-footed hare will find itself outpaced by firms that have developed the virtues of both." [Utterback, 1994, p.135] This implies a systematic approach to Change Management which addresses issues associated with how the organization can learn effectively, without disruption, and faster than the competition. Projects must focus on both conceptual and operational learning.

The preceding history of the quality movement demonstrates that the chain of events introduced earlier in the research is valid. It is further validated through shipyard interviews. The introduction of TQM led to greater rates of change, which ultimately was perceived as having many disruptive effects as well as successes. This has led to the latest wave of the quality movement which emphasizes coordination (Hoshin) and Change Management. In effect, these realizations could be considered to be a series of cycles through Crosby's Quality Management Maturity grid (see HBS 1986 note 9-687-011 for definition of the grid) with uncertainty, followed by an awakening, followed by enlightenment, followed by wisdom followed by certainty. The issue is that the final point in his grid, certainty, represents quality improvement being a regular and continuous activity with the majority of problems being prevented. Unfortunately, more is necessary to compete than to prevent problems as defined by looking backward, because new problems will always present themselves due to a dynamic competitive environment. Thus, certainty is brief and followed by a new period of uncertainty in reaction to changes in the environment. It is a continuous cycle.

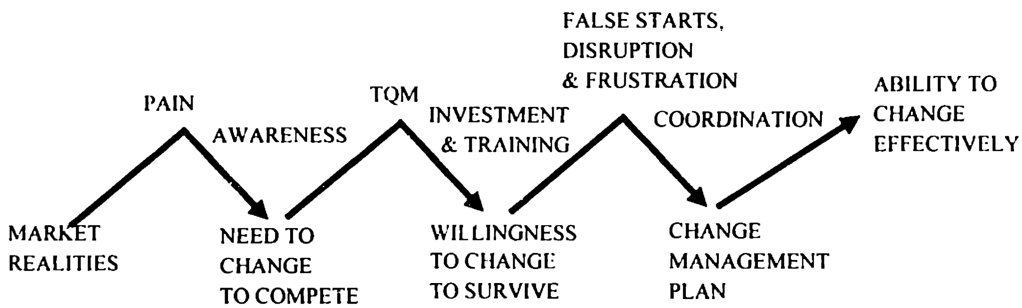


FIGURE 2.8 - CHAIN OF EVENTS LEADING TO CHANGE MANAGEMENT

The total quality movement was a reaction to changes in the competitive environment and changed the pace of change. The engineering organization was unable to cope as well as it might have with the increased pressure, in part due to a lack of an overarching strategy which clearly associated change proposals with strategic objectives and in part due to the lack of a Change Management process. Shipyards must address this issue by adopting a strategic planning process which links means with objectives, which in turn are linked to responses to changes in the competitive environment. They must also adopt a procedural context for change that facilitates linking design improvement proposals with strategic responses, and prioritizes proposals to reflect an understanding that organizations have limits to the amount of change they can assimilate. Change implementation procedures must address both procedural and psychological roadblocks.

The changes in the ship design and production cycle, increases in automation, and development of standardized interim parts and work processes signaled a move away from craft production and the increasing irrelevance of the traditional learning curve model and notion of learning. While traditional thinking suggests that changes always disrupt the learning curve, it has been shown that today more learning is associated with deliberate rather than unconscious activity. This would suggest that changes introduced as part of a deliberate learning process can accelerate the learning rate. To do this successfully will require an understanding of the theory and methods for enhancing organizational learning as well as Change Management.

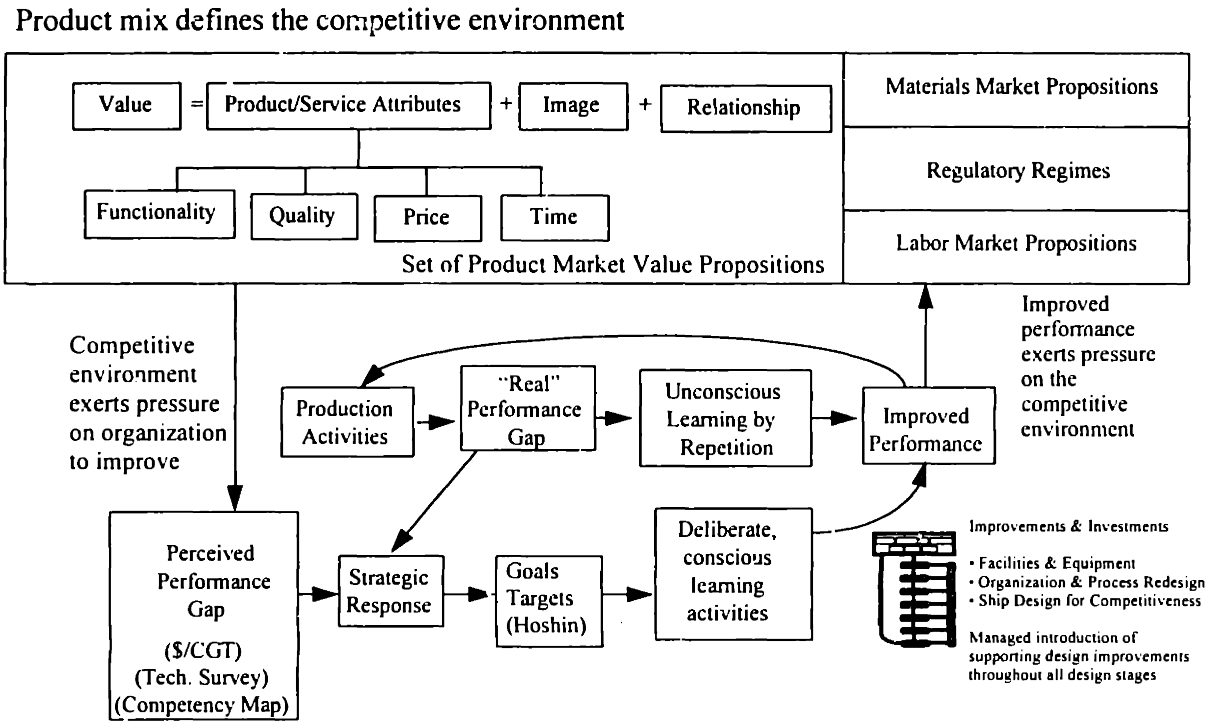


FIGURE 2.9 - MANAGED IMPROVEMENT PROCESS

As was made clear in this chapter, a key element of success is the development of a procedural context for managing change. The lessons learned and discussed in the preceding sections regarding the change process were important in developing the design change framework introduced earlier in this research. Furthermore, the advice of Winch was considered.

> Any stage model is an analytic device to segment a flow of activity through time. The point of transition, or inflection between stages, therefore, ought to be meaningfully specifiable. Many stage models attempt to describe the content of each stage, but do not specify the outcomes of the activities within each stage. The inflection points, therefore, tend to be arbitrary. A simple, but related, point is that the nomenclature of the stages ought to be intuitively meaningful as well. There are, therefore, three basic criteria by which to assess stage models - they should be theoretically justifiable, robust, and specify clearly both the content and inflection points of each individual stage. [Winch, 1994, p.127]

Therefore, in developing the design change framework, it was desired to assign stages which were intuitive. It was desired that the input, the content, and the output of the stages was clear and definable. And finally it was desirable that the stage model be robust, or applicable under a variety of circumstances. The lessons learned and these considerations yielded the following stage model, which has been verified as workable through discussions with shipyard personnel. This stage model begins with a motivating force which leads to identification of a change proposal. This is followed by periods of evaluation, prioritization, decisionmaking, planning, implementing and measuring. A key element of this stage model is the evaluation phase. This research will review a variety of evaluation techniques and develop an evaluation model that is consistent with the strategic planning techniques described earlier. All of these phases, and the roles and tools required to successfully address them, are discussed in detail in the chapters that follow.

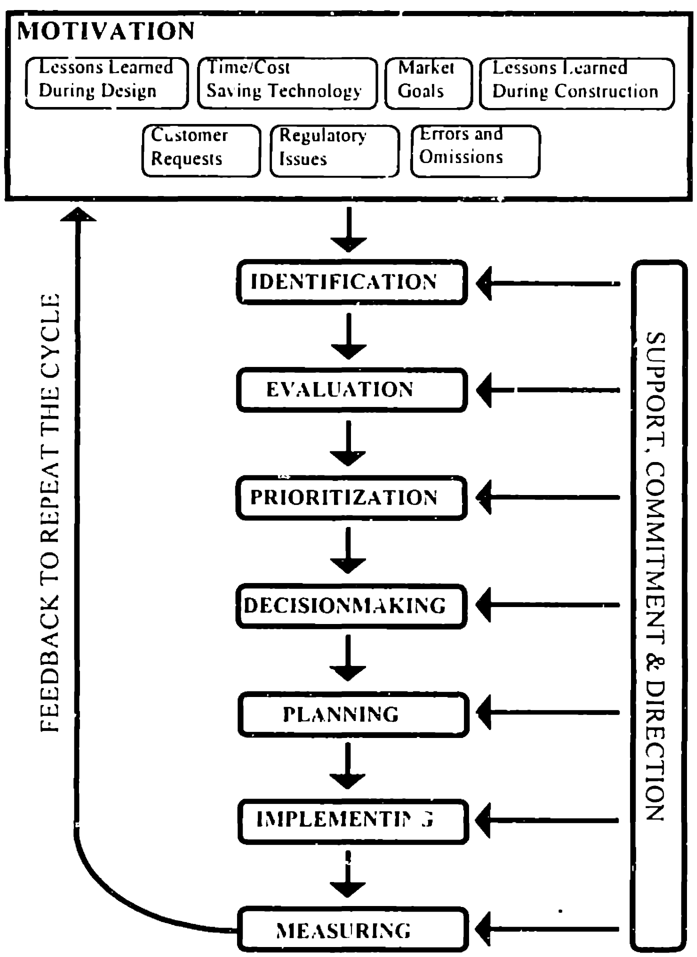


FIGURE 2.10 - DESIGN CHANGE FRAMEWORK

3.0 FOUNDATIONS FOR MANAGING DESIGN IMPROVEMENT: PRODUCTION ENGINEERING, STANDARDIZATION, CONCURRENT ENGINEERING, AND BUILD STRATEGY DEVELOPMENT

Design Change Management is an integral part of a design philosophy aimed at improving competitiveness.

> Change has become an increasingly important consideration in a product's life cycle...In a design-for-change approach, the design team seeks to make the inevitability of change compatible with the need for a stable and disruption free manufacturing environment...Hard to control factors include:
>
> 1. Changing day-to-day production, customer and market needs
> 2. Competitive pressure
> 3. Availability of new technology and materials
> 4. Design iteration due to uncertainties
> 5. Design iteration due to continuous improvement in product and process
>
> Several strategies for designing a product and process to be robust against change appear to be possible. One of the most effective of these is standardization...However, at some point in the design,...new needs and opportunities begin to emerge. This broadens the scope of design to include many new possibilities and generally triggers a variety of redesign activities. Recognizing the narrowing and broadening of design scope as a natural tendency of product development, we see that the best time to plan for redesign is during the early stages... [Ettlie and Stoll, 1990, p.104]

Design Change Management should be thought of as part of an overall scheme incorporating Production Engineering, Concurrent Engineering, Design/Build Strategy, Standardization, and Change Management. Such a scheme might be referred to as "Design for Competitiveness." Numerous books and papers have been written about the merits of these associated methods. The purpose of this chapter is to place Change Management in the context of the design process as it relates to these other elements of design for competitiveness rather than to provide an exhaustive review of each. The focus is on showing how the objectives of Design Change Management are supported by these other facets of Design for Competitiveness, and how Design Change Management enhances their effectiveness.

A distinction is made between "Design for Production", "Engineering for Production", "Isolated Engineering" and "Integrated Engineering" in NSRP 0219 "Engineering for Ship Production" by Lamb. Design for Production refers to "taking into account production methods and techniques which reduce the work content, simplify the complexity of the work, and fit it to the facilities and tools available, yet meet the specified requirements and quality. Engineering for production determines the best technique to transmit and communicate the design and engineering information to the various users in a shipyard." [Lamb, 1986] Isolated Engineering refers to a sequential approach where design details incorporate little production input and are not in a form directly usable by production. Efforts to streamline engineering products resulted in Integrated Engineering, where the information provided is in a format compatible with the way the ship is to be built and considers Design for Production. More recently, Concurrent Engineering and Build Strategy development have become popular, which seek to integrate Design for Production into the earliest possible design stage through a teaming environment.

Much of the literature discusses the benefits of various approaches as they relate to shortening design cycles and mitigating downstream rework. These activities can also be linked to an effective Change Management plan. In Chapter 2.0 it was demonstrated that any organization has an "assimilation budget" which is drawn down by change. Change Management seeks to minimize this assimilation drain as well as to increase the total available assimilation budget. The elements of Design for Competitiveness assist both of these objectives. They are aimed at moving consideration of issues earlier into design development. This acts to reduce the number of downstream changes decreasing the assimilation drain, thereby increasing the organization's capacity to handle changes which are identified later. It also provides an opportunity to manage expectations early, which was shown in Chapter 2.0 to increase the assimilation budget.

3.1 DESIGN FOR PRODUCTION AND PRODUCTION ENGINEERING

It should be noted that Design for Cost, or Design for Production, is not the same as the notion of Design to Cost. Design to Cost has existed for quite some time and is typically associated with trade-offs between functionality and budget. It is the activity that is associated with "cost-down" efforts during the contract design phase while functionality and price are being negotiated with the owner. Design for Production, on the other hand, is focused on reducing costs and cycle time while maintaining a given level of functionality. It is generally associated with efforts to improve shipyard profitability while Design to Cost is associated with efforts to negotiate a price or develop an agreed upon understanding of functionality consistent with budgetary constraints.

At about the same time as the quality circle movement in the late 1970's, a steady stream of material associated with "producibility" appeared in the shipbuilding literature. Papers focused on Production Engineering or Design for Production appeared at the 1979 REAPS technical symposium in San Diego and have been prevalent ever since. Two significant changes occurred in the 1970's which can explain this increased interest. The first is consistent with the Abernathy-Utterback model's suggestion that as the rate of process change increases, there must be a comparable level of product change. The quality movement which began in the 1970's applied additional pressure on the shipbuilding community to change the way ships were designed. In addition, the introduction of the 1970 Maritime Bill changed the way the design was developed and organized.

Tom Lamb provided an interesting historical perspective on Production Engineering in "Engineering for Ship Production." The 1936 Maritime Bill required shipowners that desired government financial assistance to submit preliminary data to MARAD, which MARAD would subsequently approve. At that point, the shipowner was required to submit a contract design package to MARAD who would handle distributing the package to shipyards for bids. These bids were submitted to MARAD. The unfortunate outcome was that shipbuilders had no incentive to spend time preparing contract designs. The majority of the designs were prepared by design firms, which did not focus the design on taking advantage of any particular yard's facility. The 1970 Maritime Bill permitted shipowners and builders to work together. The outcome was a new focus on Design for Production, as shipyards worked with design firms to develop designs that took greater advantage of their facilities.

Rack discussed the early focus of Production Engineering efforts at REAPS 1979. These efforts were aimed at developing an understanding of the production processes and designing to take advantage of them. Objectives included planning and scheduling work upstream and/or in parallel to remove it from the critical path, erection of larger blocks and units, utilization of better jigs and fixtures, improvements in manning and manpower assignments, more automated welding equipment or better processes, and increased levels of pre-outfitting. It is interesting to note that the focus generally remains the same today, but with a greater sense of urgency and expectations. As the quality movement increased the rate of improvement of the production methods, the Production Engineering function would evolve to focus on improving production methods and integrating these improved methods with the design work. The development of shipyard standards has permitted the results of Production Engineering efforts to be formalized and distributed in such a way as to capture the information regarding optimal approaches for use in other contracts.

The Design for Production function was also described by MacDougalll and Carss at REAPS 1979. Like Rack, they pointed out that productivity can be improved in four areas including designing work content out of the ship, improving efficiency of production processes, making better use of working hours and reducing ship production cycle times. They defined the Design for Production function as an extension of the ship design process with the following objectives.

> To produce a design which represents an acceptable compromise between the demands of performance and production. To ensure that all design features are compatible with known characteristics of shipyard facilities. To apply individual Design for Production procedures in so far as they are relevant to the particular shipyard where a vessel is to be built. To coordinate the inter-relationship between the engineering and outfitting work with the structural work, in order to create a fully integrated design. [MacDougall, Carss, 1979, p.465]

MacDougall later refined the definition and objectives of Production Engineering as follows. [MacDougall, 1980]

a) To assist production to achieve the targets and goals set out in the corporate plan
b) To monitor production technology developments in the industry
c) To identify opportunities for cost reductions in production processes

Furthermore, MacDougall and Carss identified a number of general rules for the application of Production Engineering. Such an axiomatic approach to Design for Production is popular in a variety of industries and has become known as "Design for Manufacture and Assembly", or DFMA. They also recommended that "the development of improved producibility must parallel the design development work and will influence it at every stage. Aspects of Design for Production are also capable of further development during the production phase but even at the contract design stage, attention should be given both to achieving a generally production-kindly design and allowing and encouraging further Production Engineering work in a post contract context."

The emphasis during the early 1980's was still on the detail design phase after contract drawings had been developed. As Lamb pointed out, the slow acceptance of Production Engineering methods as a means to seek improvement was probably due to reliance on outside design firms. [Lamb, 1986] For example, in 1981 a paper was published describing a cooperative effort between A&P Appledore and Norshipco to examine producibility for a floating drydock after design drawings had been obtained from a naval architectural consultant. [Bell, Flora, 1981]

The link between Production Engineering and Design Engineering at this time was through design reviews. These design reviews are often referred to as "Value Engineering". Value Engineering was the precursor to DFMA. Value Engineering is an orderly review process involving an interdisciplinary team which offers alternatives to improve project value. Thus Value Engineering could also apply to improving quality, reducing weight, and other objectives. However, as practiced Value Engineering is largely equated with reducing cost. [Shillito, De Marle 1992] The key point is that it is a review process. Value Engineering was developed in 1947 by L.D. Miles and applied at General Electric. In the 1950's, the Navy established Value Engineering departments. The effectiveness of these departments was limited by the fact that the facility being utilized for construction was not known at the time of design. Value engineering as applied by production engineers at shipyards could be thought of as part of the production planning process as well. It involved both identifying alternative design details as well as identifying the production processes best suited to the given design.

According to the Engineering Design Handbook of the U.S. Army Material Command, Value Engineering consists of six phases. Phase I is concerned with collecting essential information related to the project. Phase II consists of reviewing the design and conducting "functional analysis". This analysis is concerned with questioning the function of design features and the value of those functions to determine if the details are really necessary. Phase III is known as "speculation" and involves identifying alternative details for the functions and details identified in phase II. Phase IV is the evaluation phase, where the original design features and the alternatives developed in phase III are evaluated with respect to feasibility and resource requirements. Phase V involves selling the results of phase IV to gather support for change proposals. Phase VI involves implementation of value engineering change proposals. This phase generally involves getting management approval for the change proposals and tracking of the results of the change proposal. The activities identified in these six phases describe well the Production Engineering function as it related to engineering in US yards until very recently. Currently, efforts are focused at bringing Production Engineering earlier into the design cycle.

As the quality movement continued to pick up momentum and production processes and technologies changed, it became increasingly difficult for Engineering to keep up. MacDougall commented that "as technology continues to change, the task for technical departments is to keep abreast of these changes." [MacDougall, 1980, p.9] The Value Engineering approach met with difficulties because the number of change proposals identified continued to increase as the pace of the quality movement increased. This was due to both the rate of production process improvement as well as changing expectations and goals for productivity improvement. "Designing for cost has two dimensions, attitude and implementation. Attitude relates to the environment which fosters consideration of cost in the design process. Implementation is the set of processes by which cost is used as a design parameter." [Dean, Unal, 1991, p.1] The momentum built by the quality movement both intensified the attitude and added to the "toolkit" of processes used to identify alternative details. The pressure to do better continually increased and the Production Engineering function was tasked with facilitating this improvement. Meanwhile the pressure for engineering to reduce design cycle time also increased.

With this increased pressure, the paradox of the necessity to maintain a separate group as well as the need to integrate the function within Engineering has been the subject of much debate. This is evident in both the literature and shipyard feedback. The crux of the debate does not appear to be whether such a function has its place, but rather the timing of its input and how it fits into the structure of the yard.

> While the correct application of Industrial Engineering techniques to shipbuilding will be of significant benefit, its application has in many cases only increased the isolation of the Engineering department from the production activity and resulted in increased cost due to its being applied after the design is completed and the development of the detailed engineering well underway. This is equally true of the situation when Production Engineering groups are established within the production department. For this to be done, the shipyard management must first believe that it is beneficial to split and specialize engineering into two parts, namely design and production...There is only one kind of acceptable technical engineering, and that is when its producibility is fully and adequately considered from its conception. [Lamb, 1986, p.13]

But is it realistic to assume that a designer can keep abreast of all that is desirable to support a given yard, particularly in a time where shipyard turnover in design personnel is cyclic? While management must not allow Engineering to delegate or not fulfill its responsibility to Design for Production, assistance may be required from specialists who may devote their time to identifying means and methods and can coordinate activities across department and contract lines. Lamb recognized the paradox and wrote, in the very same document as the previous quote:

> Most ship designers will not have either the experience or the time to use work measurement techniques...However, if an Industrial Engineering capability exists in their shipyard, they should take every opportunity to use it, and to work with the Industrial Engineers to arrive at the best design for their shipyard. If such a capability does not exist in the shipyard or it is too preoccupied with the many other areas they are involved in, and it is not reoriented by management, Design for Ship Production can [still] be performed. The ship designer with a team from planning and production can examine the different ways to design a detail, and rank them on the basis of a merit factor considering various producibility and cost aspects. When complete, the selected 'best' design and the selection analysis can be sent to other departments that are involved in the process, for their review and concurrence. It is strongly recommended that a Design for Ship Production team be established to review and maintain a shipyard's existing standards, and at the early stage of all new ship design development to ensure that the design will be the most producible and cost-effective design for their shipyard. [Lamb, 1986, p30]

Some have commented that the difficulties associated with a separate Production Engineering group are a necessary evil in the transition from an design organization with a poor Design for Production track record to one in which Design for Production is everyone's job. In organizations where drastic improvement is required, the introduction of a separate group may be the only means of improvement. Unfortunately, this is precisely the time when the organization's "assimilation budget" is lowest.

> The workplace culture of the producibility engineer is generally in the spirit of successful new product development, but with particular built in conflicts. The producibility engineer's role is akin to that of an ambassador seeking adequate representation for his homeland (manufacturing) among those of foreign soil (product design). To be effective, such ambassadors must be excellent communicators. They are likely to be judged on their ability to stop the equivalent of a foreign invasion. This type of manufacturing engineering, aimed directly at the design-manufacturing interface, is a necessary step in a traditional, functionally-dominated organizational structure. It is the manufacturing organization's attempt to gain parity in the 'chimney's of power,' whereby problems, once surfaced, are pushed to higher levels for ultimate resolution. [Ettlie, Stoll, 1990 p.38]

Regardless of where it resides, the Production Engineering function is necessary for successful design improvement and Change Management. This is so in a number of respects. Production Engineering implies an understanding of processes and the development of axiomatic design guidance. This reduces the assimilation drain by increasing the producibility content of Engineering products, reducing the number of downstream changes required to compete. The existence of Production Engineering builds an expectation that improvement is an ongoing part of business, and managing expectations reduces resistance to change. The industry survey results discussed in the next chapter reflect this.

Production Engineering, as a function, is directly associated with the identification stage of the design change framework and involves proactive efforts to improve. Wheelwright and Clark suggested, with respect to product development, that "creative ideas need to be encouraged and nurtured...Potential ideas can come from anywhere in an organization and from numerous sources beyond...However, rarely do organizations have a systematic way of corralling these ideas. By and large, no one is responsible for their identification, no mechanisms are in place for their evaluation, no resources are available for further investigation, and many ideas wither from inattention." [Wheelwright, Clark, 1995, p.66] The purpose of the Production Engineering function should be to see that this is not so. It should by no means diminish the responsibility of the rest of the organization for design improvement, but should facilitate their ability to do so.

The Production Engineering function's relationship to engineering is very similar to that of an R&D organization in a product development firm. The Production Engineering function is responsible for benchmarking the competition, keeping abreast of the latest production technology, and working with other departments to advocate incorporation of technologies which are deemed beneficial. They are also typically tasked with supporting the Standards group and developing axiomatic design guidance. Each of the roles described in chapter 2.0 must be identifiable in the successful Production Engineering function, regardless of whether that function resides in Production, Planning or Engineering. Issues associated with organization design are prevalent today as shipyards strive to obtain the benefits of Production Engineering without the costs of a separate group.

The costs of having a separate group are associated both with tangible costs like management and overhead as well as intangible costs such as friction and potential disassociation between Design and Production. The benefits of a separate group include visibility, better coordination, consolidation of people with particularly good Production Engineering and problem solving skills, and continuity of focus across contracts and departments. The question of organization design is not easily settled, and will be unique to each shipyard. What is clear is that the function is necessary and must be effectively integrated with Production, Planning, Engineering, Purchasing and Contracts in order to achieve its desired result.

Nadler and Tushman propose the "congruence hypothesis" to describe the goal of organization design.

> Each organization as a whole displays a relatively high or low level of congruence. The basic hypothesis of the model is this: Other things being equal, the greater the total degree of congruence, or fit, among the various components, the more effective the organization will be. Put another way, the degree to which the strategy, work, people, structure, and culture are smoothly aligned will determine the organization's ability to compete and succeed. [Nadler and Tushman, 1997, p.34]

To the extent that alignment can be achieved through the informal organization or other means which enhance mutual trust and respect, the formal organization takes on less significance. In the next chapter, shipyard feedback sheds light on how these issues have been handled in practice. The desire to achieve balance between the advantages of a traditional line organization and the need to integrate functions like Production Engineering has led to considerations of alternative team-based approaches consistent with Concurrent Engineering.

Ettlie and Stoll conclude in their book "Managing the Design-Manufacturing Process" that successful manufacturers today exhibit five key integrating actions. These actions include:

- Use of cross functional teams in which all members are trained in design for manufacture methods.
- Manufacturing signs off on design reviews
- Novel organizational structures are used for coordination
- Job rotation is practiced in the engineering functions
- Personnel move between engineering and manufacturing

Concurrent Engineering and Build Strategy development, discussed shortly, represent efforts to integrate Production Engineering as early into the design process as possible. The existence of a Production Engineering function supports the required visibility and continuity for successful consideration of Design for Production at all phases and across all departments. Effective Change Management can insure that improvement proposals identified by, or preferably with Production Engineering as part of a cross functional team, are prioritized and implemented with the least disruption possible.

3.2 CONCURRENT ENGINEERING

Recent attention has turned to the timing associated with producibility related considerations. Early efforts were associated with a design review or "Value Engineering" approach. It has been realized for some time that design decisions which are made in the early stages of development have the greatest impact upon cost. As the number of change proposals increased, it became increasingly evident that a means for reducing the amount of change identified late would need to be put in place.

Furthermore, constraints are added with each design phase that cannot easily be changed. Concurrent Engineering strives to convert design reviewers into active design participants. It is synonymous with Simultaneous Engineering and Integrated Product and Process Development (IPPD). Concurrent Engineering is defined by the Institute of Defense Analysis as "a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support." Cleetus et. al. define it as "the process of forming and supporting multifunctional teams that set product and process parameters early in the design phase." Dean and Unal define it as "getting the right people together at the right time to identify and resolve design problems. Concurrent Engineering is designing for assembly, availability, cost, customer satisfaction, maintainability, manageability, manufacturability, operability, performance, quality, risk, safety, schedule, social acceptability, and all other attributes of the product." This approach is intended to cause the design team to consider all elements of the product, thereby resulting in a lower cost and higher quality end product. This is accomplished through improved communication by every means possible including a combination of collocation as appropriate and leveraging of information technology.

Application of Concurrent Engineering to ship design and construction has been steadily increasing over the last few years as a reaction to the fact that "today the major challenges facing U.S shipbuilders as they plan to enter the world commercial shipbuilding market are how to shorten delivery time, reduce ship prices, and improve the world's perception of U.S shipbuilding quality." [Bennett, Lamb, 1995, p.1] The approach has also become very popular recently as U.S yards find themselves in teaming arrangements together and with combat systems/aerospace companies for a reduced number of military contracts.

Bennett and Lamb report 65% to 90% reductions in the number of engineering changes in manufacturing organizations that employ Concurrent Engineering. This allows the organization to focus valuable resources on higher payoff, higher risk, improvement initiatives. "As CE [Concurrent Engineering] is not a single event but a continuous journey, the final part of the implementation process is continuous improvement of the product and the design process by monitoring and measuring the product design process." [Bennett, Lamb, 1995, p.12]

Concurrent Engineering recognizes that the cost of a product is established early in the design stage, and that the cost to make design changes increases geometrically as the product progresses through the development cycle. [Bennett et. al.] By considering these elements early on, downstream rework associated with design changes can be avoided by anticipating the requirements of downstream designers and users. Concurrent Engineering facilitates Design Change Management primarily by reducing the assimilation drain and improving communication which helps to establish expectations. Design/Build strategies are integral to the approach, in that they define a set of parameters determined to represent low-cost and high-quality solutions to design issues which downstream designers should adhere to. Design/Build Strategy addresses the issue of expectations directly.

3.3 BUILD STRATEGY

"A Build Strategy is an agreed design, engineering, material management, production and testing plan, prepared before work starts, with the aim of identifying and integrating all necessary processes." [Clark, Lamb, 1995, p.1] The notion of the development of a "Build Strategy" has become popular recently in shipbuilding. Winch discusses the development of a "production strategy" as a necessity in a variety of manufacturing industries. "The interdependent relationship between manufacturing strategy and engineering strategy strongly suggests that their development might be best seen as a joint activity...Perhaps the most useful way of thinking is in terms of the production strategy as a component to the business' financial, human resource, marketing, and technology strategies." [Winch, 1994, p.45]

A&P Appledore is credited with developing the formal Build Strategy process for shipbuilding in the 1970's. [Clark, Lamb, 1995, p.2] It may be better to refer to a Design/Build Strategy to more accurately reflect the interdependence of Design and Production and the purpose of the document. The objective is to provide in a single document a description of how the ship is to be produced and the design features that are anticipated to facilitate those production methods. Just as critical as the document is the process by which it is developed, which is hand-in-hand with Concurrent Engineering.

Clark and Lamb identify a number of aims of Build Strategy development. These include:

- Applying a shipyard's overall shipbuilding policy to a contract
- Establishing a process for ensuring that design development takes full account of production requirements
- Systematically introducing Production Engineering principles that reduce ship work content and cycle time
- Identifying interim products and creating a product-oriented approach to engineering and planning of the ship
- Determining resource and skill requirements and overall facility loading
- Identifying shortfalls in capacity in terms of facilities, manpower and skills
- Creating parameters for programming and detail planning of engineering
- Providing the basis on which any eventual production of the product may be organized including procurement dates for "long lead" material items
- Ensuring all departments contribute to the strategy
- Identifying and resolving problems before work on the contract begins
- Ensuring communication, cooperation, collaboration and consistency between the various technical and production functions

Based upon the theory and lessons learned presented in Chapter 2.0, it is clear that Build Strategy development also provides an opportunity to manage change by managing expectations. This is being explored by at least one of the shipyards that participated in this research. Other important aims which should be added to the list above include:

- Establishing targets and goals linked to the shipyard's strategic plan
- Identifying any design or production features which are contrary to past practice or expectations, or features which are targeted for improvement
- Identifying standards which must be revised or developed
- Establishing a Change Management plan, including targets for each ship in a series contract, and guidelines for design improvement throughout the design cycle
- Establishing expectations and schedules for ongoing improvement efforts to address these targets

It has been suggested that prerequisites for a Build Strategy include a Business Plan, a Shipbuilding Policy and a Ship Definition Policy. These provide the basis for beginning a Build Strategy. The Business Plan "sets out the shipyard's ambitions for a period of years and describes how the shipyard aims to attain them...[Shipbuilding Policy] defines the product mix which the shipyard intends to build plus the optimum organization and procedures which will allow it to produce ships efficiently...[and] will also include methods for breaking the ships in the product mix into standard interim products...Ship Definition Policy specifies the format and content that the engineering information will take in order to support the manner in which the ships will be built." [Clark, Lamb, 1995, p.2] Clark and Lamb suggest that the Shipbuilding Policy is aimed primarily at design rationalization and standardization to stimulate the effects of series production. This is associated with the discussion of Mass Customization and Organizational Learning in Chapter 2.0. The Business Plan and Shipbuilding Policy are consistent with the conclusions and recommendations of Chapter 2.0 regarding strategic planning. Identification of the product mix and interim products is also a critical step in design improvement. In Chapter 5.0 it is shown that the identification stage of the design change framework utilizes the Strategic Plan, which encompasses the elements of both the Business Plan and Shipbuilding Policy, as input.

Build Strategy development is therefore consistent with design improvement and Design Change Management. The application of a Build Strategy will be facilitated by a Change Management plan. Effective Change Management is supported by the existence of the Build Strategy.

> Because shipbuilding is dynamic, there needs to be a constant program of product and process development. Also the standards to be applied will change over time with product type, facilities, and technology development...To link the current policy with a future policy, there should be a series of projects for change which are incorporated into an overall action plan to improve productivity. [Clark, Lamb, 1995, p.3]

3.4 STANDARDIZATION

Standardization is a key element of this overall scheme. It has a direct impact upon Change Management by reducing variety and providing designers with uniform guidelines. A change can be implemented by changing a standard rather than changing many details in drawings. Standards act to stabilize processes, represent and communicate agreements, and facilitate managing expectations. All of these were shown to be key ingredients for managing change in the previous chapter. The results of the industry survey, discussed in the next chapter, indicate that standardization is critical to the success of design improvement activities.

There are a wide variety of levels, or tiers, of standardization including:

- Guidance, Requirements and Specifications
- Benchmarks
- Processes
- Baseline designs/engineering
- Interim and end-products

The benefits of standardization programs are numerous and documented in many industries such as the automotive, electronics, aerospace and shipbuilding industries. Some of those benefits which are directly associated with managing design improvement include the following. [Tedesco, 1994, p.20]

- Reductions in design time
- Reductions in changes due to errors in judgment
- Increases in the time available for work requiring special handling, such as elective design changes
- Reductions in changes which could have been avoided with improved communication between engineers, draftsmen, production, etc.
- Reductions in the work content associated with redesign efforts
- Encourages and focuses design improvement

Standardization facilitates Change Management by increasing the level of understanding and stability associated with products and processes.

> In order to be improved, a process must be understood in detail, which in turn means that variability and interdependence in the separate activities and methods used to combine people, machines, material and information have to be known and controlled. [Berger, Working Paper 4, 1996, p.4]

> Stable processes are of the essence of viable, productive manufacturing...Predictability is not possible without the inherent orderliness of stable processes...Achieving stability of processes is difficult. In shipbuilding it is especially difficult. Despite this, stable

> processes are essential to worldwide competitiveness. [Storch, A&P Appledore, Lamb, 1995, p.76]

Some have argued that standardization inhibits innovation, but the majority of researchers in the area of Design for Production area agree that standardization actually encourages innovation with respect to design/production integration. Standards should be viewed as agreements which are subject to change as the need arises, rather than as rigid or constraining. Standardization facilitates Design Change Management by providing focus and enhancing communication. Standardization is capable of balancing stability and innovation through the application of Change Management.

> In fact, kaizen [improvement] is described as inseparable from maintaining standards, since this relationship is argued to be one of the very foundations for claiming that small ongoing improvements can and do accumulate to make a significant contribution to overall performance. [Berger, 1996, p.15]

> Only team proposals that are evaluated, assessed and finally approved by management are implemented. These replace the existing standardized methods and thus become the new standard methods to be used until further approved changes are implemented. In this way all the benefits of standardization are achieved without the problems. Everything is a candidate for change, but nothing is allowed to be changed arbitrarily... [Storch et. al., 1995, p.79]

> The reasons for highlighting standards can be traced to three general characteristics which are claimed to follow with the standardization of operating procedures;
>
> 1. Individual authorization and responsibility
> 2. Enhanced learning through the transmittal, accumulation and deployment of experience from one individual to another, between individuals and the organization and from one part of the organization to another
> 3. Discipline [Berger, Working Paper 4, 1996, p.6]

Standardization and design change are actually completely consistent with one another. Standardization permits design improvement activities to be effective, and Design Change Management practices permit the full range of standardization benefits to be achieved.

3.5 SYNOPSIS

Most of the available research has focused upon the utility of Concurrent Engineering and Build Strategy development to prevent or eliminate design changes before the implementation phases. Both Concurrent Engineering and Design/Build Strategy development seek to reduce the number of downstream changes by insuring that informed decisions are made earlier on. They seek to eliminate a number of the changes resulting from "design reviews" by making those that would review the design (downstream designers, planning and production) part of the development process at an earlier stage.

This research focuses on the fact that it is unrealistic to presume that Concurrent Engineering, Build Strategies and Standardization will eliminate the desire to continually improve. These are intended to reduce the need for changes which should and can be anticipated earlier in the design process. They do not eliminate the possibility for change later in the contract as the result of additional, unforeseen opportunities or the realization that performance gaps widen over time. The scale, complexity, and long design cycle time of ship design projects, in conjunction with the intricate interdependency of design decisions, suggest that opportunities for improvement will always present themselves at a variety of stages throughout the design cycle. These tools, enhanced to maximize the opportunity to manage expectations, provide a foundation for managing change but do not eliminate the need for an effective Change Management plan.

These activities reduce the assimilation drain, allowing the organization to focus on greater opportunities later on. They are compatible with, and complemented by, an effective Change Management approach. "Because shipbuilding is dynamic, there needs to be a constant program of product and process development. Also, the standards to be applied will change over time with product type, facilities, and technology development." [Clark, Lamb, 1995, p.4] "Planning is important and necessary. It's just not sufficient. Some organizations spend more time planning than executing and have gorgeous, elegant plans but fall down in the execution." [Carr et. al., 1996, p.191] A Change Management plan is required to provide the design organization with the flexibility and adaptability necessary to be able to react to these situations and opportunities, both technically and organizationally. A Change Management system is also needed to insure that acquired knowledge is integrated into future design decisions and build strategies.

In the next chapter the results of an industry survey are presented which support the conclusion that the entire suite of Design for Competitiveness methods are required to facilitate Design Change Management. In Chapter 5.0 the means by which strategic planning can be linked to the process of identifying improvement proposals is discussed.

4.0 ANALYSIS OF INDUSTRY ATTITUDES AND PRACTICES REGARDING DESIGN CHANGE MANAGEMENT

In the preceding Chapters, the theory and foundations of Design Change Management were discussed. The conclusions drawn so far were based in large part on an extensive review of the literature and the author's experiences involving design improvement at a major U.S. shipyard. In this Chapter, the results of an analysis of a broader range of industry feedback are used to:

- Validate the conclusions drawn so far
  - Demonstrate that change management is a critical competitive ability
  - Demonstrate that a decision analysis model for use in prioritization is essential
- Provide additional insight
  - Further develop the elements of the design change framework
  - Facilitate the development of an evaluation decision model

The selection of benchmarking questionnaire subjects includes both U.S. and foreign shipyards. The survey group included four U.S. shipyards, of which three provided detailed responses to the questionnaire. In addition, a Japanese shipyard provided a detailed response. Additional insight was gathered from an aerospace firm and the construction industry. A copy of the survey questionnaire is provided in Appendix A. The shipyards involved in this research all characterized themselves as sellers of capacity rather than sellers of products. Other basic characteristics of the shipyards are illustrated in table 4.0.

4.1 APPROACH TO BENCHMARKING

There are four categories of benchmarking that are widely recognized. The following definitions are adapted from "Benchmarking Global Manufacturing" [Miller, Meyer, Nakane, 1992, p.19]:

1. Product Benchmarking

   Long standing process of carefully examining or "tearing down" another manufacturer's product. This does not require cooperation from the subject.

2. Functional or Process Benchmarking

   Focus of comparison is on functional process such as order entry, assembly, testing, product development, setup, etc. Requires cooperation from the subject.

	RECENT MARKETS	RECENT CHANGES	COMMERCIAL VS. MILITARY	UNITS/YR	UNDERSTANDING OF GOALS	BASIC DESIGN CYCLE	DETAIL DESIGN CYCLE	PRODUCTION CYCLE	EXPERIENCE LEVEL COMMENT
:al	Naval Aux., has significant prior tanker experience and containership experience	Emphasis of developing commercial designs and work	Currently 100% military non-combatent with efforts underway to obtain commercial work	2 newbuilds	Ranges from top and most middle management only to understanding by all	18 to 24 months	15 to 19 months	18 months commercial, 54 months Naval Aux.	Numbers have been reduced in engineering, but average skill level risen. Skill mix in engineering now more consistent with commercial requirements. Skill level in Produc and Engineering varies sign. with tl number of personnel at any time.
:al	Mix of military non-combatent and commercial. All sizes and types of vessels. Barges, Ro/Ro's, Tankers	Became more proactive regarding the international and commercial market. Significant moves towards teaming arrangements.	85% military non-combatent, contract managed by seperate groups with the same construction management	2 to 7 depending on complexity	Top and most middle management	Unavailable and varies significnatly depending on product	Unavailable and varies significnatly depending on product	Unavailable and varies significnatly depending on product	Have not seen appreciable changes experience levels. They have inves recently in cross-training.
al	Destroyers, some industrial modules	Reduced defense budget, increased competition both foreign and domestic, some increased foreign demand.	99% military, majority combatents	2 newbuilds	Ranges from every manager and supervisor to understanding by all	Unavailable	Unavailable	Unavailable	CAD experience has increased dramatically in Engineering. Team based design has resulted in broad experience for most designers. Tea based design/production has broa skills of production workers. $$$ incentives to learn new skills have worked.
	Wide range of military (combatent and non-combatent) as well as some commercial	Entry in commercial market	90% military	Unavailable	Unavailable	Unavailable	Unavailable	Unavailable	Unavailable
al	LNG, LPG, Submarine, VLCC, High Speed Ferries, Pure Car Carriers, Ro/Ro's, Containerships	Greater emphasis on more sophisticated ships	Any military work is done at a different affiliated Yard	7 to 8 newbuilds	Understanding by all	5 to 6 months	10 to 14 months	10 to 25 months (higher for LNG incl. LNG tanks)	Experience level in engineering is 2 years. Regularly rotate people betw initial design and detail design grou Experience level in production is 24 years. Regularly rotate personnel in production, predominently manage and engineers.

Table 4.0 - Yard Characteristics

3. Best Practices Benchmarking

Similar to functional benchmarking, but with a subtle difference in focus. This approach focuses less on the "nuts and bolts" of a procedure, and more on the attitudes and management behaviors associated with a process.

4. Strategic Benchmarking

Strategic benchmarking is focused on the strategic intent of the subject. It is based on the proposition that one must first consider how a competitor defines success before understanding the secrets of that success. Strategic benchmarking is not focused on a particular process, but examines what is important to the subject. Understanding the strategic intent helps to identify those features which may be important to use functional or best practices benchmarking to study.

This research utilizes strategic, functional, and best practices benchmarking in an effort to supplement and validate the conclusions drawn. Strategic benchmarking looks first at the ends which companies consider important. Functional and best practices benchmarking examine the means to these ends. The precision and "shelf life" of the information obtained varies as one moves from strategic to functional benchmarking. This is illustrated in Figure 4.0.

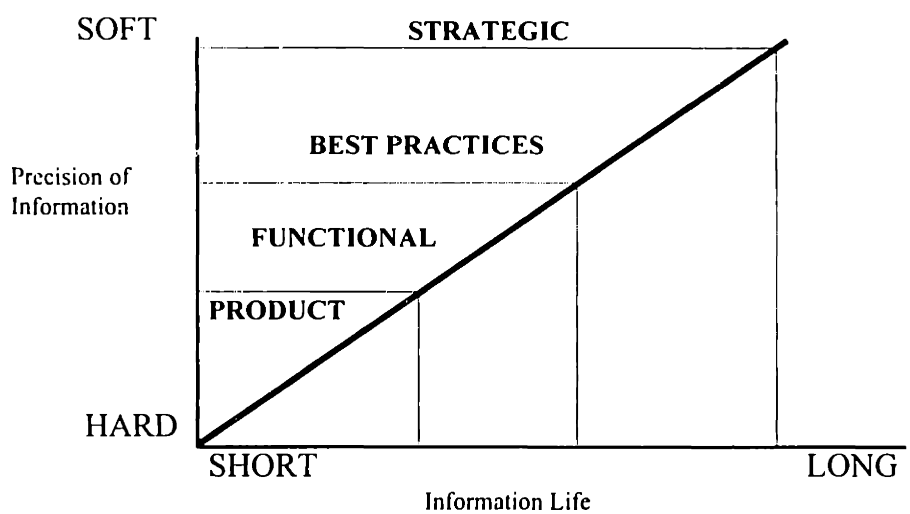


FIGURE 4.0 - PRECISION AND DURABILITY OF INFORMATION [ADAPTED FROM MILLER ET. AL.]

Strategic benchmarking is used to determine the importance given to change management as a goal and the success of the industry in achieving effective change management. Change management as a competitive ability is placed in context relative to other competitive abilities. Strategic benchmarking validates the proposition that Design Change Management is a significant competitive ability in shipbuilding which will continue to be of concern in the future. The attitudes and management practices that support Design Change Management are revealed through best practices benchmarking.

The processes, procedures and tools that support successful Design Change Management are examined through functional benchmarking.

The benchmarking questionnaire used in this research has been structured into the following sections.

- Section A - Overview and Instructions
- Section B - Participant Identification
- Section C - Strengths and Importance of Abilities
- Section D - Critical Needs
- Section E - Change Management Goals
- Section F - Available Procedures
- Section G - Design Change Management Framework
- Section H - Case Studies
- Section I - Characterization of the Company

The role of the questionnaire data as it relates to developing a decision model, together with the previously discussed literature review, is illustrated in Figure 4.1. In addition to assisting the development of a decision analysis model, the feedback obtained has provided greater insight into the procedural context for managing design change. The remainder of this Chapter is generally organized to follow the pattern of the questionnaire.

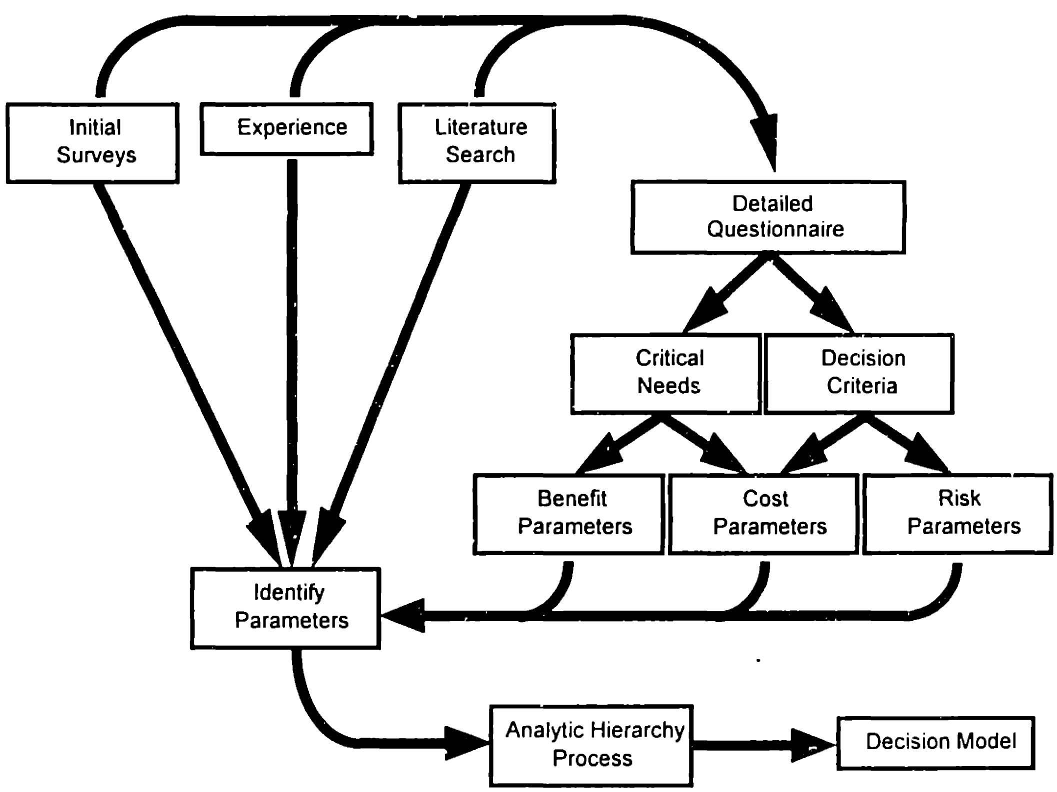


FIGURE 4.1 - ROLE OF SURVEY

4.2 STRENGTHS AND IMPORTANCE OF ABILITIES

One of the primary messages of Chapter 2.0 was that "the essence of an effective manufacturing strategy is the development of those competitive capabilities that will best position the firm for sustainable competitive advantage." [Miller et. al., 1992, p.8] The purpose of this section is to identify and demonstrate the importance of managing design change relative to other competitive abilities. The data obtained in this section also illustrates imbalances between the importance of various capabilities and the strength a company thinks it has relative to these capabilities. Where an imbalance exists, an organization is failing to address areas of critical strategic importance.

The data collected is similar to the strategic benchmarking data reported in the book "Benchmarking Global Manufacturing". The study itself was titled "The Manufacturing Futures Survey", and was conducted by Boston University. The data from this study suggests that while the ability to quickly incorporate design changes is an important competitive capability, manufacturing industries are relatively weak in this area. Table 4.1 illustrates some of the 1990 strategic benchmarking data collected by The Manufacturing Futures Survey for the machinery sector. The abilities are listed in order of decreasing importance and decreasing strength. This survey indicated that an imbalance exists between the importance and strength with regard to the ability to make rapid changes in design and the ability to profit in price competitive markets. While these were considered to be important, industry strength in these abilities was less than that which would be suggested by their importance.

IMPORTANCE	STRENGTH
Provide reliable/durable products	Provide reliable/durable products
Offer consistently low defect rates	Provide high performance products/amenities
Make dependable delivery promises	Offer consistently low defect rates
Provide effective after sales service	Provide effective after sales service
Provide high performance products/amenities	Make dependable delivery promises
Customize products to customer needs	Provide product support effectively
Provide product support effectively	Customize products to customer needs
Make rapid changes in design	Broad distribution
Make fast deliveries	Make rapid product mix changes
Introduce new products quickly	Offer broad product line
Profit in price competitive market	Provide fast deliveries
Offer broad product line	Make rapid volume changes
Make rapid product mix changes	Introduce new products quickly
Make rapid volume changes	Make rapid changes in design
Broad distribution	Profit in price-competitive market

TABLE 4.1 - IMBALANCE OF COMPETITIVE ABILITIES

As will be shown shortly, the shipyard data collected in the course of this research demonstrates that the same imbalance exists in shipbuilding. This portion of the questionnaire, while by no means identical, was modeled after the Manufacturing Futures Survey. For a number of abilities, shipyard personnel were asked to assign a value from 1 (unimportant) to 10 (very important). In Figure 4.2, the results are illustrated with respect to the average of the responses for all the shipyards. While most of the abilities were shown to be important, the results indicate that capabilities associated with identifying and incorporating improvements are considered to be among the more critical, with a rating above 9. This result tends to validate the importance of this research and the conclusions drawn earlier from a review of the literature. Capabilities associated with price and schedule were judged to be most important, illustrating that these are basic needs which must be met to compete.

The results from each of the shipyards individually tend to agree with this conclusion. The average standard deviation of the shipyard results with respect to the importance of each ability is 0.81. This is indicative of the spread of the responses with respect to each ability and is concerned with the importance rating assigned. The value, less than 10% of the range of the scales used (one rate point), indicates that average results are fairly representative of importance as viewed by all the yards. While individual results are not identical with respect to each capability examined, they tend to verify the importance of identifying and incorporating design improvements.

In addition to data regarding the judged importance of abilities, data was collected regarding the strength which shipyards deemed themselves to have with respect to the abilities. While the majority of the capabilities were judged to be important, the data with respect to the strength of abilities shows considerably more variation. Shipyards are not evenly capable with respect to all the abilities even though the majority of them are important. This is illustrated in Figure 4.3 which provides the average results for all the shipyards. The variability of the individual results with respect to strength is wider as would be expected, with an average standard deviation of 1.13. While the ability to identify and incorporate cost or cycle time saving design changes was considered important, shipyards judged themselves to be weak in this area. The results also show confusion on the part of engineering departments with respect to the amount of information which must be conveyed in engineering products. A paradox exists in that it is both important to minimize and maximize the amount of information conveyed, and shipyards consider themselves to be good at neither. The real emphasis perhaps should be on conveying the right information in the right places. This is an issue which shipyards are currently wrestling with in conjunction with the use of information technology. In addition, shipbuilders do not give themselves high marks with respect to budget and schedule which were judged to be the most important capabilities.

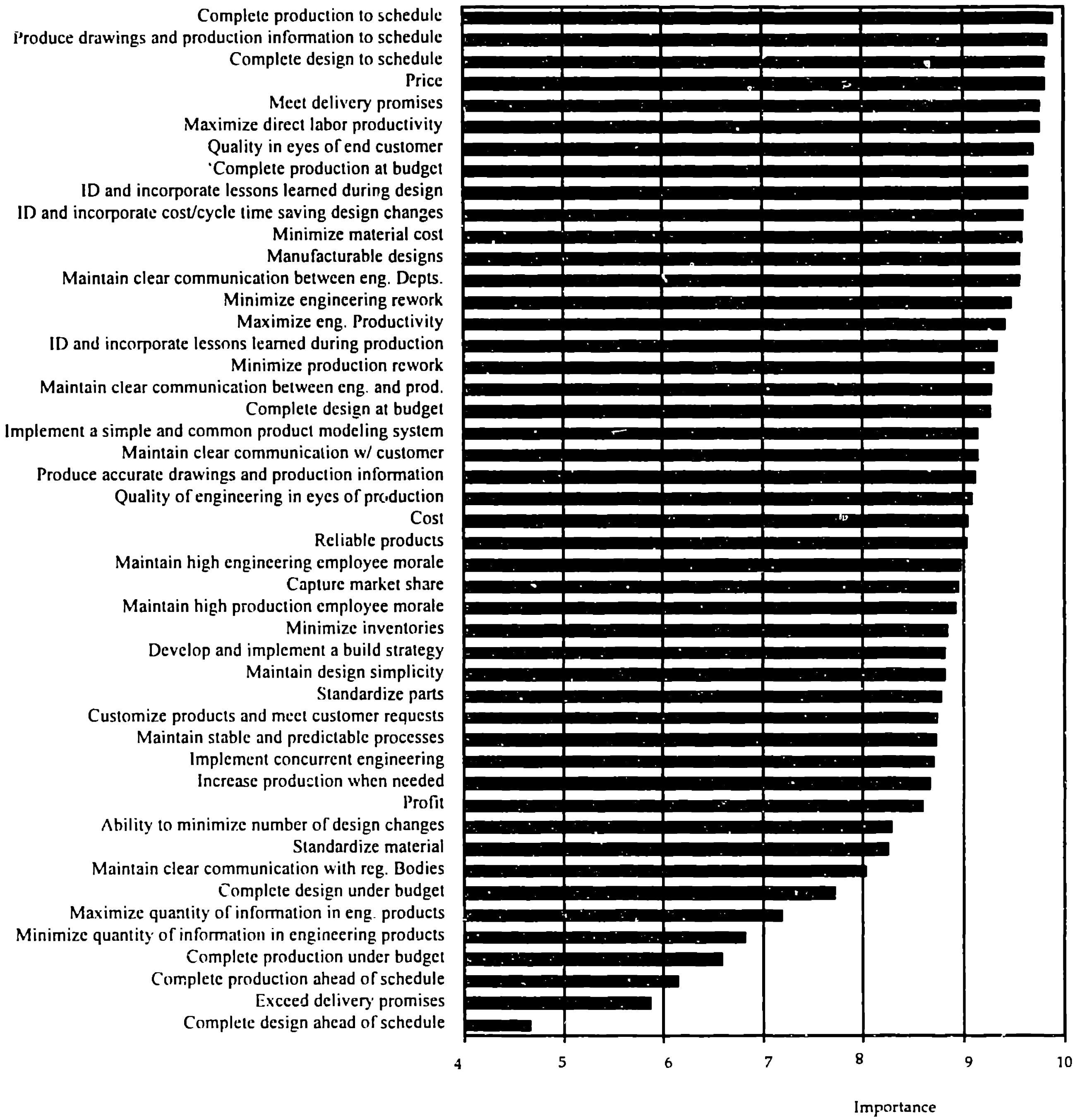


Figure 4.2 Importance of Abilities

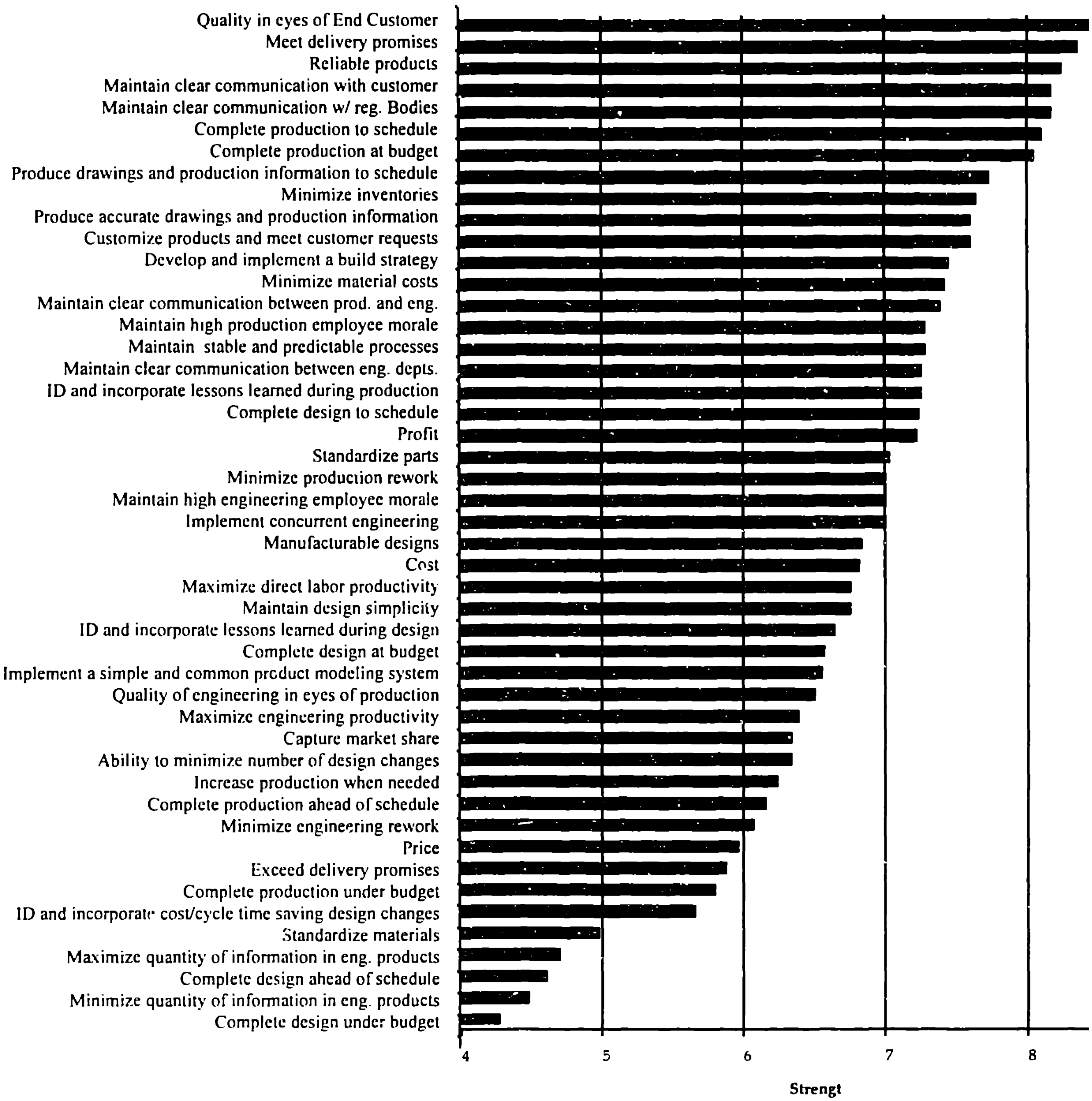


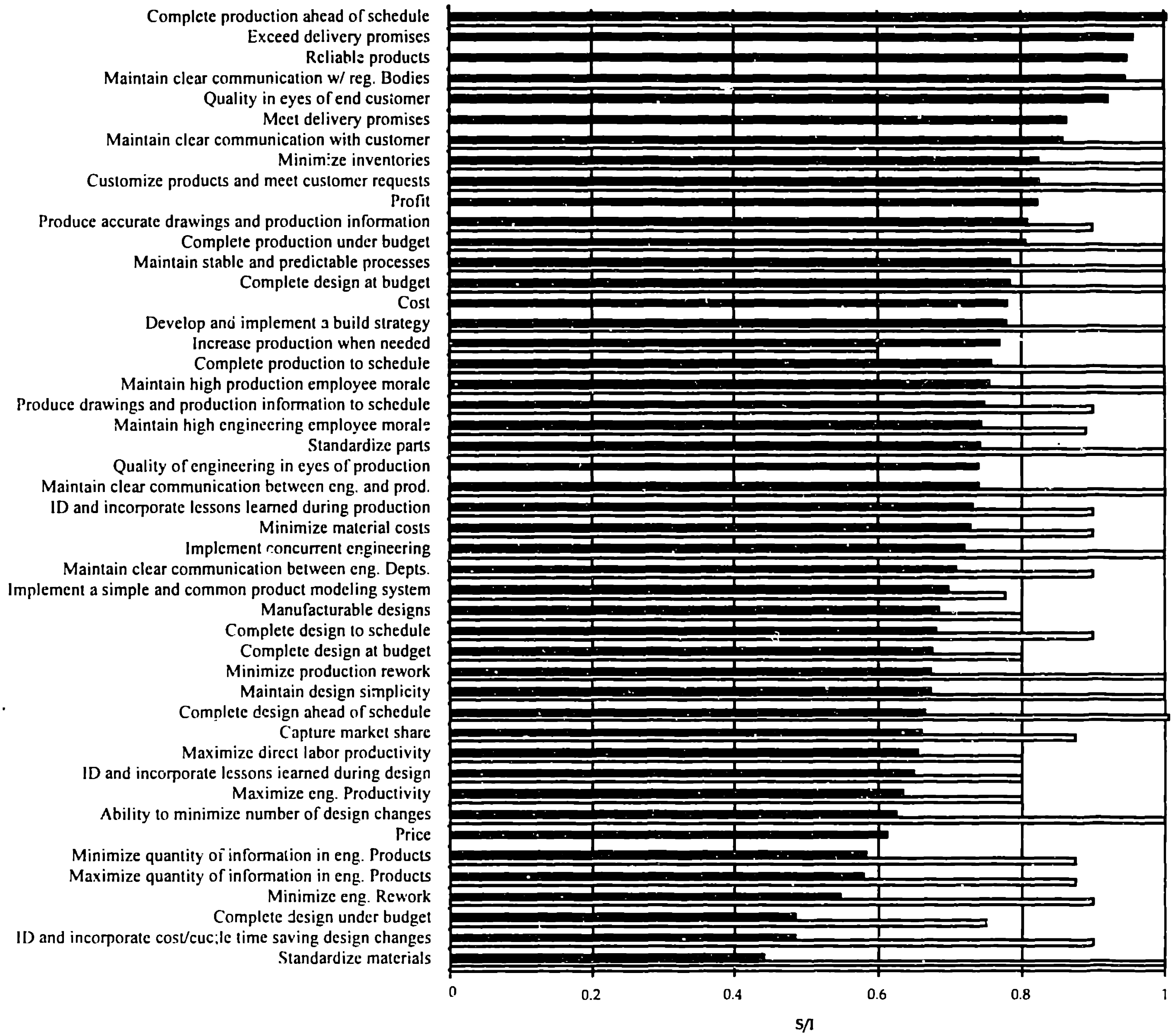
FIGURE 4.3 - STRENGTH OF ABILITIES

Strength should be examined in conjunction with importance. What is critical is achieving strength in areas which are competitively important. For this reason, additional insight might be gained from reviewing the ratio of the strength and importance ratings rather than looking at each in isolation. Such an S/I index might be considered to be a proxy for the level of technological and organizational balance, considered to be a necessity for success. "It is widely recognized however that an even level of technology is important..." [Birmingham, Hall, Kattan, 1997, p.4]

It is interesting to examine the average results for the U.S. shipyards as compared to the results for the Japanese shipyard, which is considered to be world class. This comparison helps to demonstrate the validity of the notion that balance, or S/I results closer to 1.0, are associated with success. The average S/I value for the U.S. shipyards is 0.73 while that of the Japanese shipyard is 1.0. The average standard deviation of the U.S. shipyards' S/I values is 0.09. As Figure 4.4 illustrates, the averaged results for the U.S. shipyards involved in this study do not exhibit balance. Few capabilities are at least as strong as they are important ($S/I \geq 1.0$).

The following list identifies abilities for which S/I is below 0.7 for the U.S. yards (in increasing order).

- Standardize materials
- ID and incorporate cost/cycle time saving design changes
- Complete design under budget
- Minimize engineering rework
- Maximize quantity of information in Eng. products
- Minimize quantity of information in Eng. products
- Price
- Ability to minimize number of design changes
- Maximize Eng. productivity
- ID and incorporate lessons learned during design
- Maximize direct labor productivity
- Capture market share
- Complete design ahead of schedule
- Minimize production rework
- Maintain design simplicity
- Complete design at budget
- Complete design to schedule
- Manufacturable Designs
- Implement a simple and common product modeling system



Complete production ahead of schedule
Exceed delivery promises
Reliable products
Maintain clear communication w/ reg. Bodies
Quality in eyes of end customer
Meet delivery promises
Maintain clear communication with customer
Minimize inventories
Customize products and meet customer requests
Profit
Produce accurate drawings and production information
Complete production under budget
Maintain stable and predictable processes
Complete design at budget
Cost
Develop and implement a build strategy
Increase production when needed
Complete production to schedule
Maintain high production employee morale
Produce drawings and production information to schedule
Maintain high engineering employee morale
Standardize parts
Quality of engineering in eyes of production
Maintain clear communication between eng. and prod.
ID and incorporate lessons learned during production
Minimize material costs
Implement concurrent engineering
Maintain clear communication between eng. Depts.
Implement a simple and common product modeling system
Manufacturable designs
Complete design to schedule
Complete design at budget
Minimize production rework
Maintain design simplicity
Complete design ahead of schedule
Capture market share
Maximize direct labor productivity
ID and incorporate lessons learned during design
Maximize eng. Productivity
Ability to minimize number of design changes
Price
Minimize quantity of information in eng. Products
Maximize quantity of information in eng. Products
Minimize eng. Rework
Complete design under budget
ID and incorporate cost/cycle time saving design changes
Standardize materials
0
0.2
0.4
0.6
0.8
1
S/I

It is clear that capabilities associated with managing design improvement, such as identifying and incorporating changes, are lagging. In addition, capabilities associated with price and productivity are out of balance. Furthermore, the ability to develop manufacturable and simple designs is also out of balance. The conclusion drawn earlier regarding confusion with respect to the appropriate information content for engineering products is supported by the S/I index results.

Data was also collected regarding the improvement which shipyards judge they have had relative to abilities in the past two years, and where they believe they will see improvement in the next two years. Two U.S. shipyards provided this data rather than three. Figure 4.5 illustrates the average results for the U.S. shipyards and the Japanese shipyard with respect to recent improvement. It is apparent that the respondents from the Japanese shipyard considered recent improvement to be relatively low in the majority of the areas, with the exception of the development of a simple and common product modeling system, where they judged their improvement to be on the order of 150%. The U.S. shipyards, on the other hand, judged their improvement to be significant in a variety of areas.

This may be evidence of a more focused strategic planning process being used at the Japanese shipyard as discussed in Chapter 2.0 which limits efforts to those areas deemed most important. In fact, when the importance and strength ratings of the Japanese shipyard are reviewed, we find that the ability to develop and utilize a simple and common product modeling system is judged to be important, but not very strong with an S/I value of 0.78. This ability is one of only three with S/I values below 0.8 as listed below.

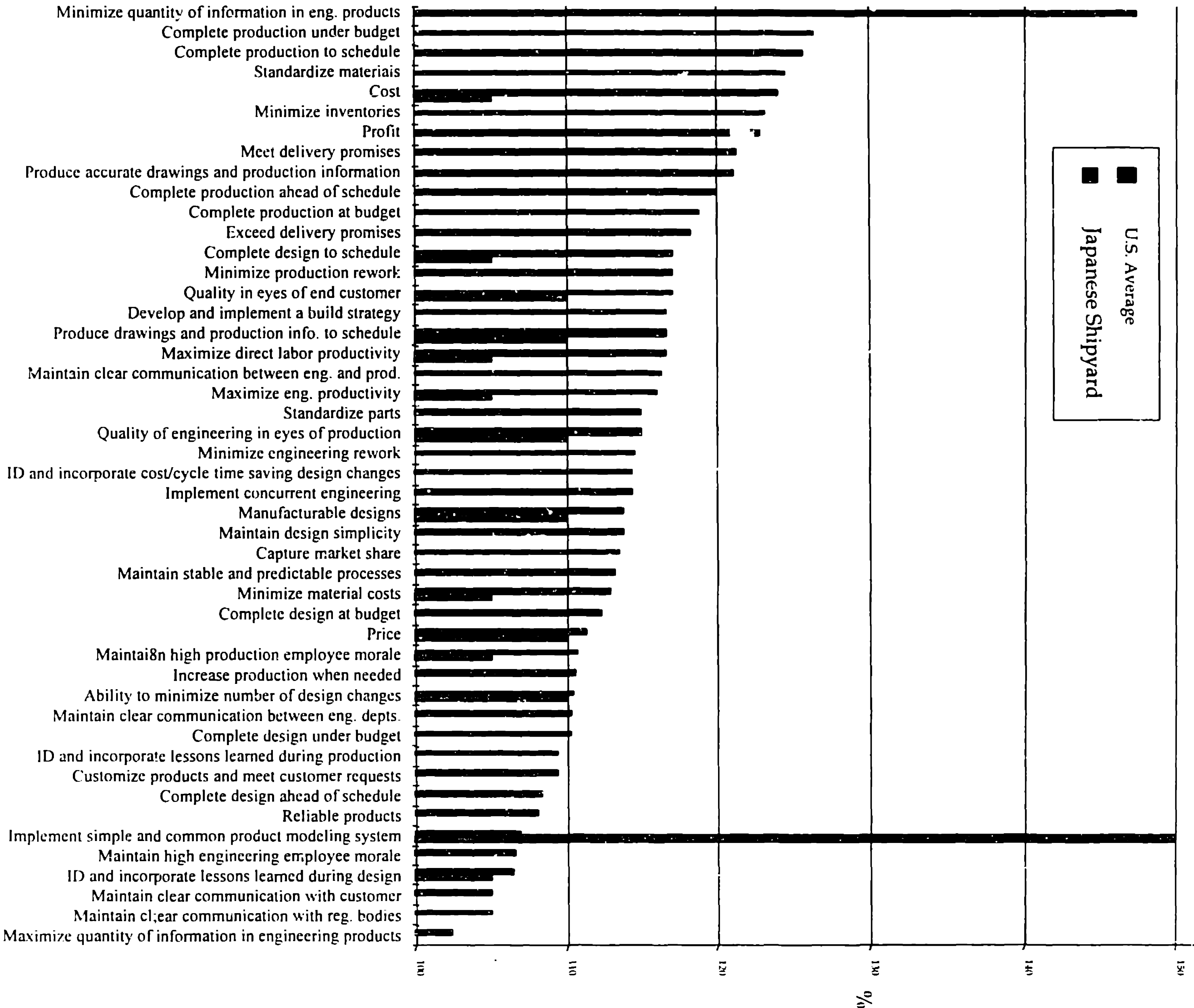
- Increase production when needed (I = 10, S/I = 0.6)
- Complete design under budget (I = 8, S/I = 0.75)
- Implement a simple and common product modeling system (I = 9, S/I = 0.78)

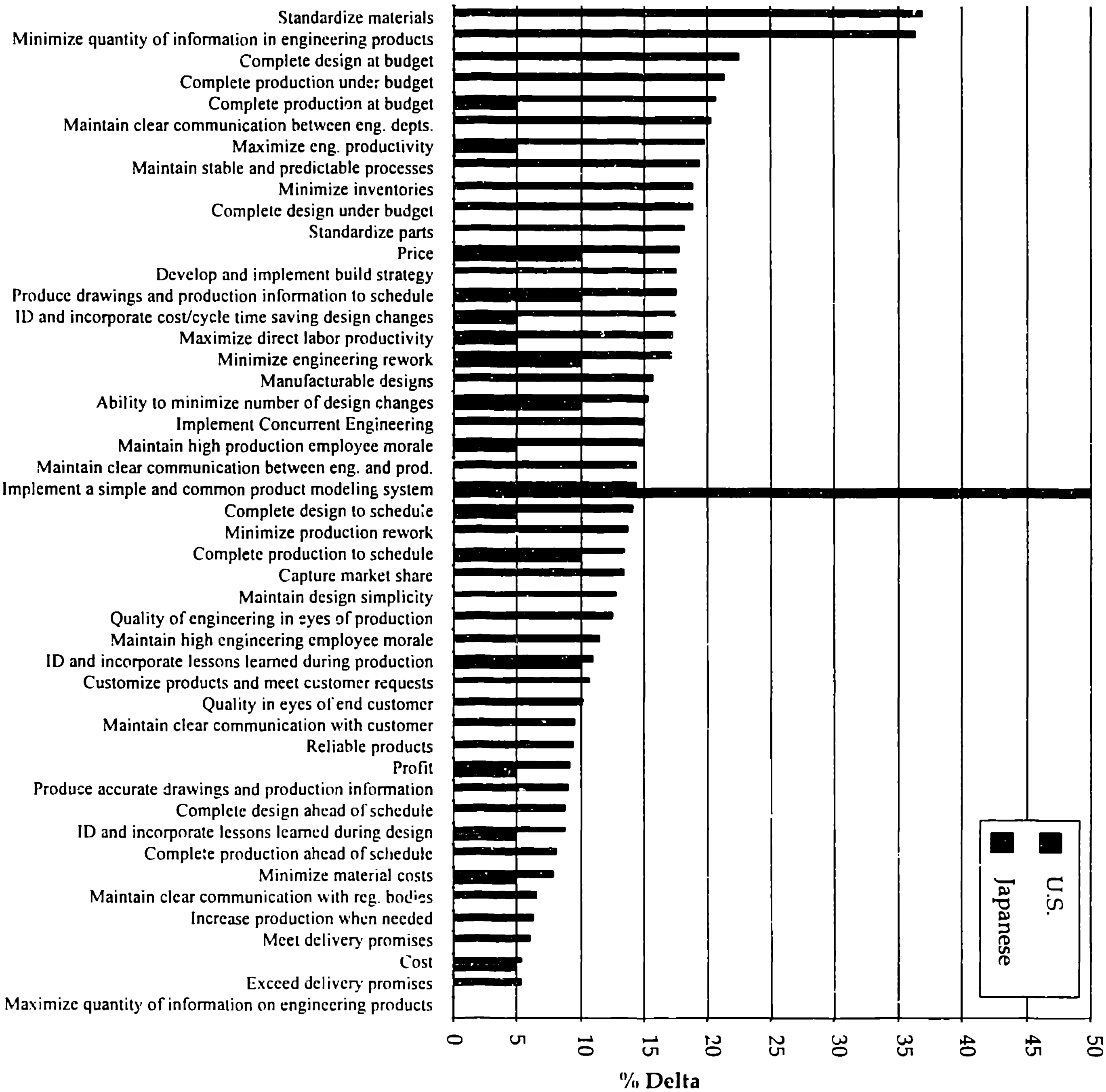
The U.S. shipyards' S/I values show that improvement is required in a wider variety of areas in order to achieve balance. The broad range of abilities for which the U.S. shipyards judge themselves to have recently improved significantly may be evidence of their efforts to address this broad imbalance. Based on the recent activity and training observed with respect to Hoshin and strategic planning at U.S. shipyards, it is also likely that the U.S. shipyards have not been utilizing as focused an approach in the past. It may also be possible that the U.S. shipyards overemphasize their improvement as compared to the Japanese shipyard.

The average standard deviation for these values is 10.6, which is reasonable given the scale. The following abilities, in increasing order, were judged to have been most improved ($\geq$ 110%) in the period from 1995 to 1997 by the U.S. shipyards. A significant result is that abilities associated with managing design improvement have been significantly improved in the past two years, demonstrating that the subject of this research is an area of concern in industry. The greatest strides have been in "basic need" abilities associated with schedule, budget, cost, standardization and production information format.

- Complete design under budget
- Maintain clear communication between Eng. depts.
- Ability to minimize number of design changes
- Increase production when needed
- Maintain high production employee morale
- Price
- Complete design at budget
- Minimize material costs
- Maintain stable and predictable processes
- Capture market share
- Maintain design simplicity
- Manufacturable Designs
- ID and incorporate cost/cycle time saving design changes
- Implement Concurrent Engineering
- Minimize engineering rework
- Quality of Engineering in eyes of Production
- Standardize parts
- Maximize Eng. productivity
- Maintain clear communication between Eng. & prod.
- Maximize direct labor productivity
- Produce drawings and production information to schedule
- Develop and implement a Build Strategy
- Minimize production rework
- Complete design to schedule
- Quality in eyes of End Customer
- Exceed delivery promises
- Complete production at budget
- Complete production ahead of schedule
- Produce accurate drawings and production information
- Meet delivery promises
- Profit
- Minimize inventories
- Cost
- Standardize materials
- Complete production to schedule
- Complete production under budget
- Minimize quantity of information in Eng. products

The anticipated focus for future improvements is illustrated in Figure 4.6. Again, a more focused effort is evidenced in the responses from the Japanese shipyard. In fact, implementation of an improved product modeling system appears to be the single most important focus for the Japanese shipyard, with modest improvements had and anticipated in other areas. The results for the U.S. shipyards demonstrates that basic abilities continue to be the most important focus, but that the rate of improvement is anticipated to increase with respect to abilities associated with managing design improvement.


Minimize quantity of information in eng. products
Complete production under budget
Complete production to schedule
Standardize materiais
Cost
Minimize inventories
Profit
Meet delivery promises
Produce accurate drawings and production information
Complete production ahead of schedule
Complete production at budget
Exceed delivery promises
Complete design to schedule
Minimize production rework
Quality in eyes of end customer
Develop and implement a build strategy
Produce drawings and production info. to schedule
Maximize direct labor productivity
Maintain clear communication between eng. and prod.
Maximize eng. productivity
Standardize parts
Quality of engineering in eyes of production
Minimize engineering rework
ID and incorporate cost/cycle time saving design changes
Implement concurrent engineering
Manufacturable designs
Maintain design simplicity
Capture market share
Maintain stable and predictable processes
Minimize material costs
Complete design at budget
Price
Maintai8n high production employee morale
Increase production when needed
Ability to minimize number of design changes
Maintain clear communication between eng. depts.
Complete design under budget
ID and incorporate lessons learned during production
Customize products and meet customer requests
Complete design ahead of schedule
Reliable products
Implement simple and common product modeling system
Maintain high engineering employee morale
ID and incorporate lessons learned during design
Maintain clear communication with customer
Maintain cl;ear communication with reg. bodies
Maximize quantity of information in engineering products
U.S. Average
Japanese Shipyard
100
110
120
130
140
150
%


Standardize materials
Minimize quantity of information in engineering products
Complete design at budget
Complete production under budget
Complete production at budget
Maintain clear communication between eng. depts.
Maximize eng. productivity
Maintain stable and predictable processes
Minimize inventories
Complete design under budget
Standardize parts
Price
Develop and implement build strategy
Produce drawings and production information to schedule
ID and incorporate cost/cycle time saving design changes
Maximize direct labor productivity
Minimize engineering rework
Manufacturable designs
Ability to minimize number of design changes
Implement Concurrent Engineering
Maintain high production employee morale
Maintain clear communication between eng. and prod.
Implement a simple and common product modeling system
Complete design to schedule
Minimize production rework
Complete production to schedule
Capture market share
Maintain design simplicity
Quality of engineering in eyes of production
Maintain high engineering employee morale
ID and incorporate lessons learned during production
Customize products and meet customer requests
Quality in eyes of end customer
Maintain clear communication with customer
Reliable products
Profit
Produce accurate drawings and production information
Complete design ahead of schedule
ID and incorporate lessons learned during design
Complete production ahead of schedule
Minimize material costs
Maintain clear communication with reg. bodies
Increase production when needed
Meet delivery promises
Cost
Exceed delivery promises
Maximize quantity of information on engineering products
0
5
10
15
20
25
30
35
40
45
50
% Delta
U.S.
Japanese

4.3 CRITICAL NEEDS

Having verified that the ability to effectively manage design change is of strategic importance, the next section of the survey seeks to identify specific attributes of management practices which contribute to the success or failure of change management. This section represents a form of best practices benchmarking, since it concentrates on management attitudes and management focus rather than on step-by-step procedures. The shipyards were asked to rate the importance of factors identified in the preceding Chapters. The average results (three U.S. and one Japanese shipyard) are illustrated in Figure 4.7. The average standard deviation for these results is 2.1, which represents approximately 20% of the scale. This significant variability illustrates that shipyards have differing views regarding the ratings. For example, one of the U.S. shipyards indicated that all of the items were equally important with a rating of ten.

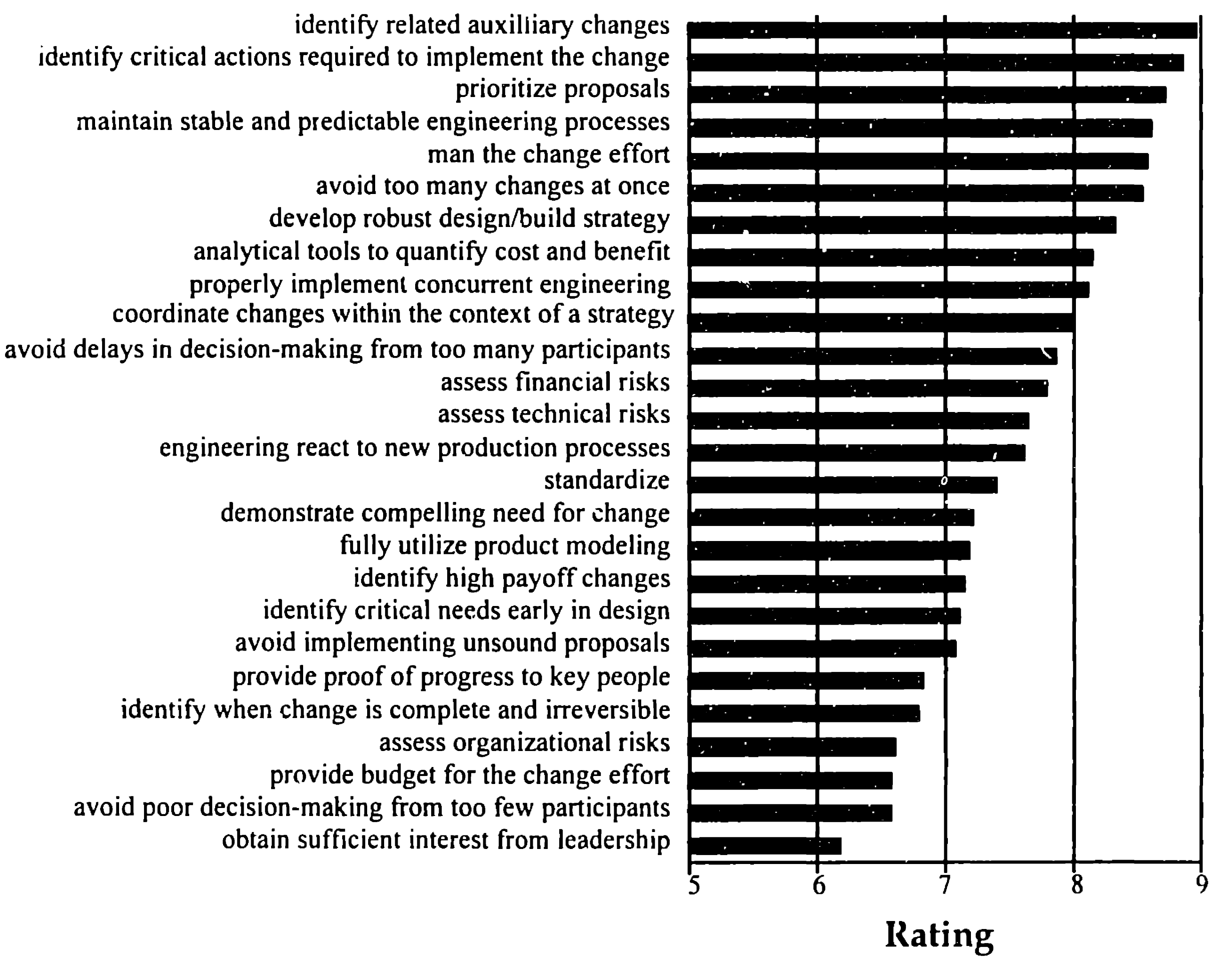


FIGURE 4.7 - CRITICAL NEEDS

All of the factors identified are considered to contribute to success by all of the shipyards. A significant result is that activities associated with planning, decisionmaking, prioritizing, stability, and manpower are considered to be most important. This supports the emphasis given in this research (in Chapter 6.0) to developing a decision analysis model for use in the evaluating, prioritizing, and decisionmaking phases of the design change framework. The results also validate the conclusions drawn in earlier Chapters related to the necessity for stability, coordination, Concurrent Engineering, and Build Strategy development.

4.4 CHANGE MANAGEMENT GOALS

As was explained in the introduction to this research, Design Change Management has a number of objectives. In Section E of the questionnaire, the subject is asked to rate the importance of various goals. This section continues the use of best practices benchmarking and allows processes and procedures to be placed in the context of the objectives considered to be important. The following figure illustrates the average results, indicating that all of the goals are considered to be important on a nearly equal basis. The average standard deviation of these results is 1.1.

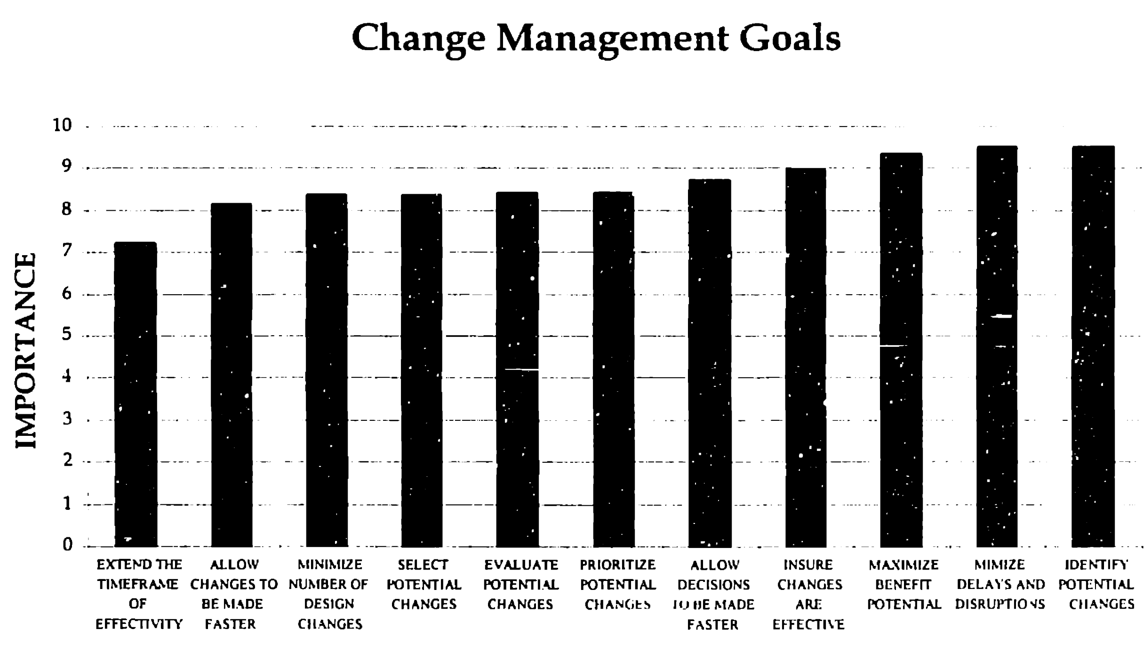


FIGURE 4.8 - GOALS

4.5 AVAILABLE PROCEDURES

This section identifies the procedures which are in place for managing different types of design changes at the organizations examined. The subjects are asked to rate the relative strength of their procedures. By identifying areas of strength and weakness, best practices can be identified and research focus further defined and validated. The results demonstrate that processes and procedures associated with elective change are weak while those associated with mandatory changes are relatively strong. This provides further validation of the importance of the research focus on design improvement resulting from elective change. The averaged results, with an average standard deviation of 1.4, for the four shipyards are illustrated below.

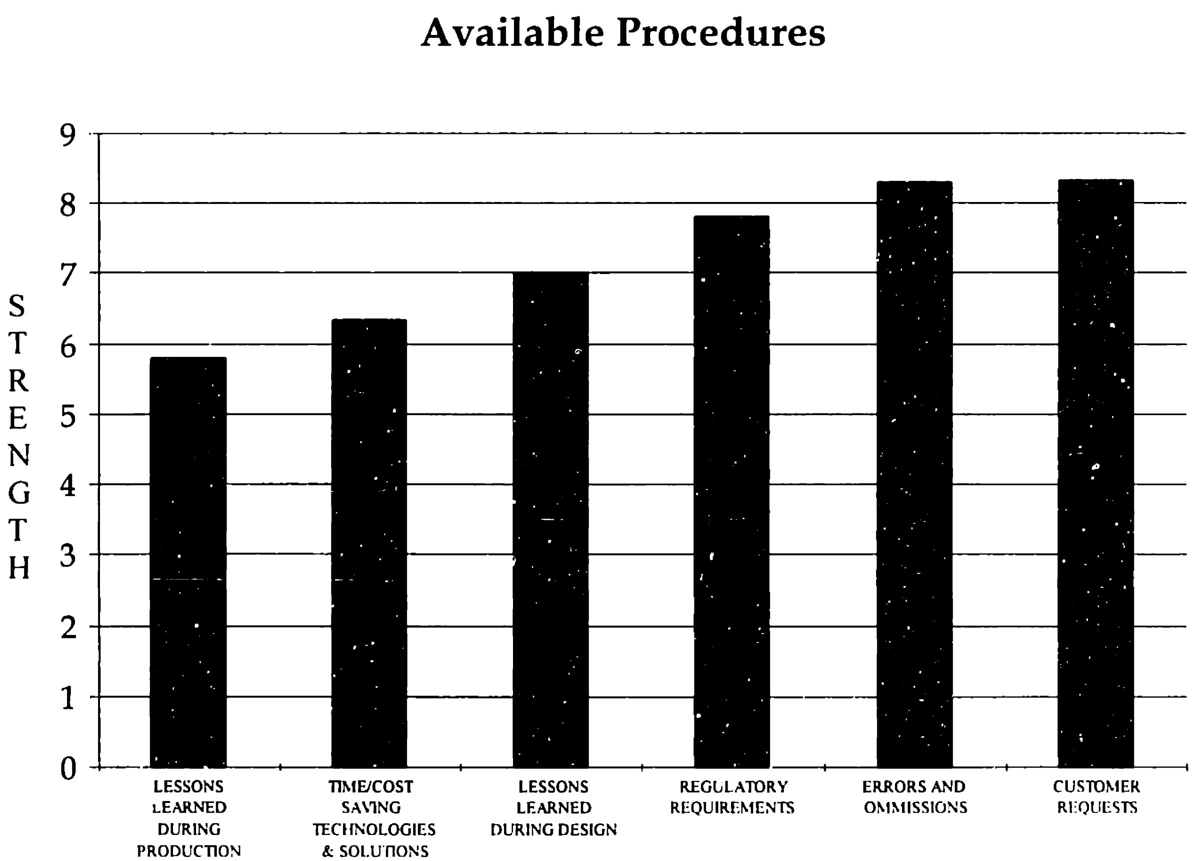


FIGURE 4.9 - AVAILABLE PROCEDURES

4.6 DESIGN CHANGE MANAGEMENT FRAMEWORK

This section seeks to utilize functional benchmarking to identify the "nuts and bolts" of different companies' procedures and practices associated with managing design change. A variety of questions were asked which sought to gain a greater understanding of the processes and procedures in place at the shipyards for managing design change. The shipyards were also asked to rate a variety of decisionmaking criteria. Decisionmaking criteria will be discussed first, followed by a review of each shipyard.

Figure 4.10 illustrates the average ratings with respect to decisionmaking criteria. The average standard deviation is 1.35. This variation reflects differing attitudes regarding benefit, cost, and risk.

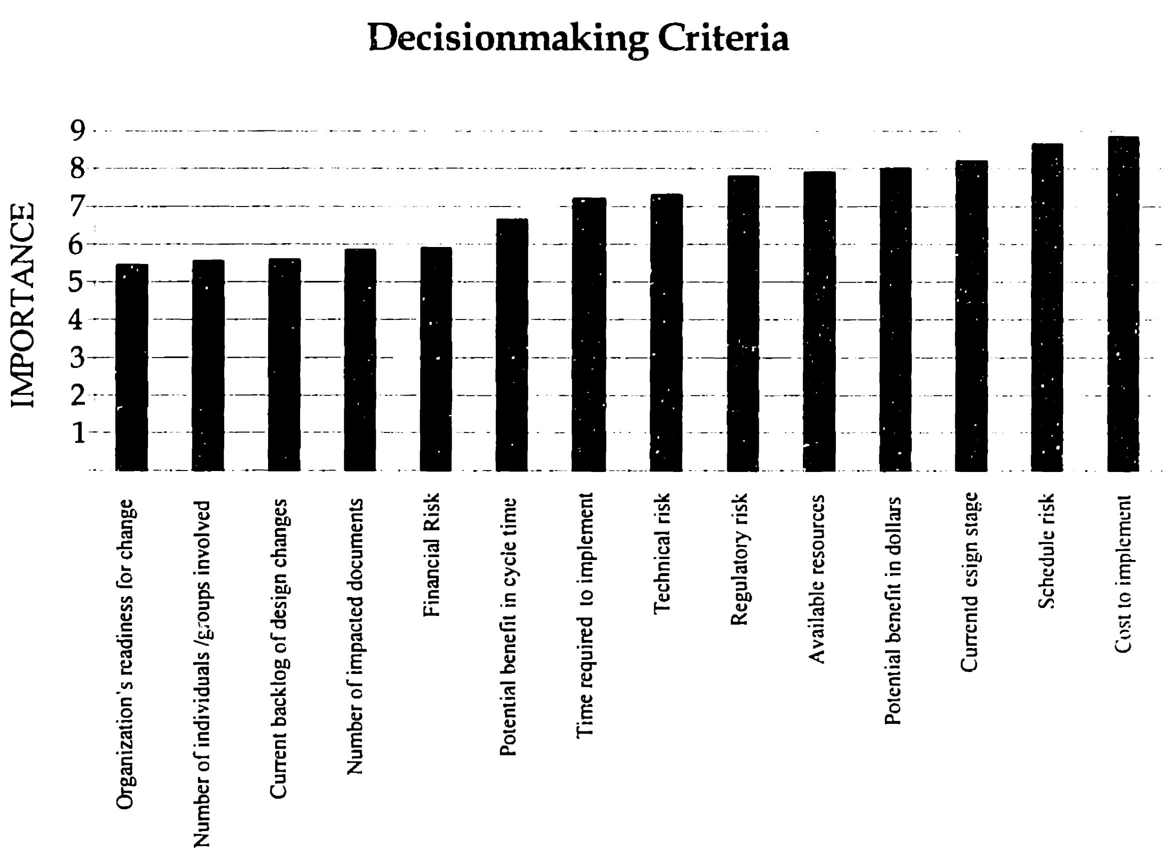


FIGURE 4.10 - CRITERIA RATINGS

4.6.1 Procedures at U.S. Shipyard A

A broad cross section of respondents from shipyard A participated in this research and an in depth examination of their processes and procedures was possible. Figure 4.11

illustrates their average feedback with respect to decisionmaking criteria. Based upon these results, it appears that this shipyard is an opportunity seeker which favors benefits over costs or risks as a decision criteria. It also favors cycle time reduction over a more narrow view of cost reduction. The individual responses show variation from one another (n = 9, s = 2.4), indicating that it is necessary to establish a policy and consensus within the yard.

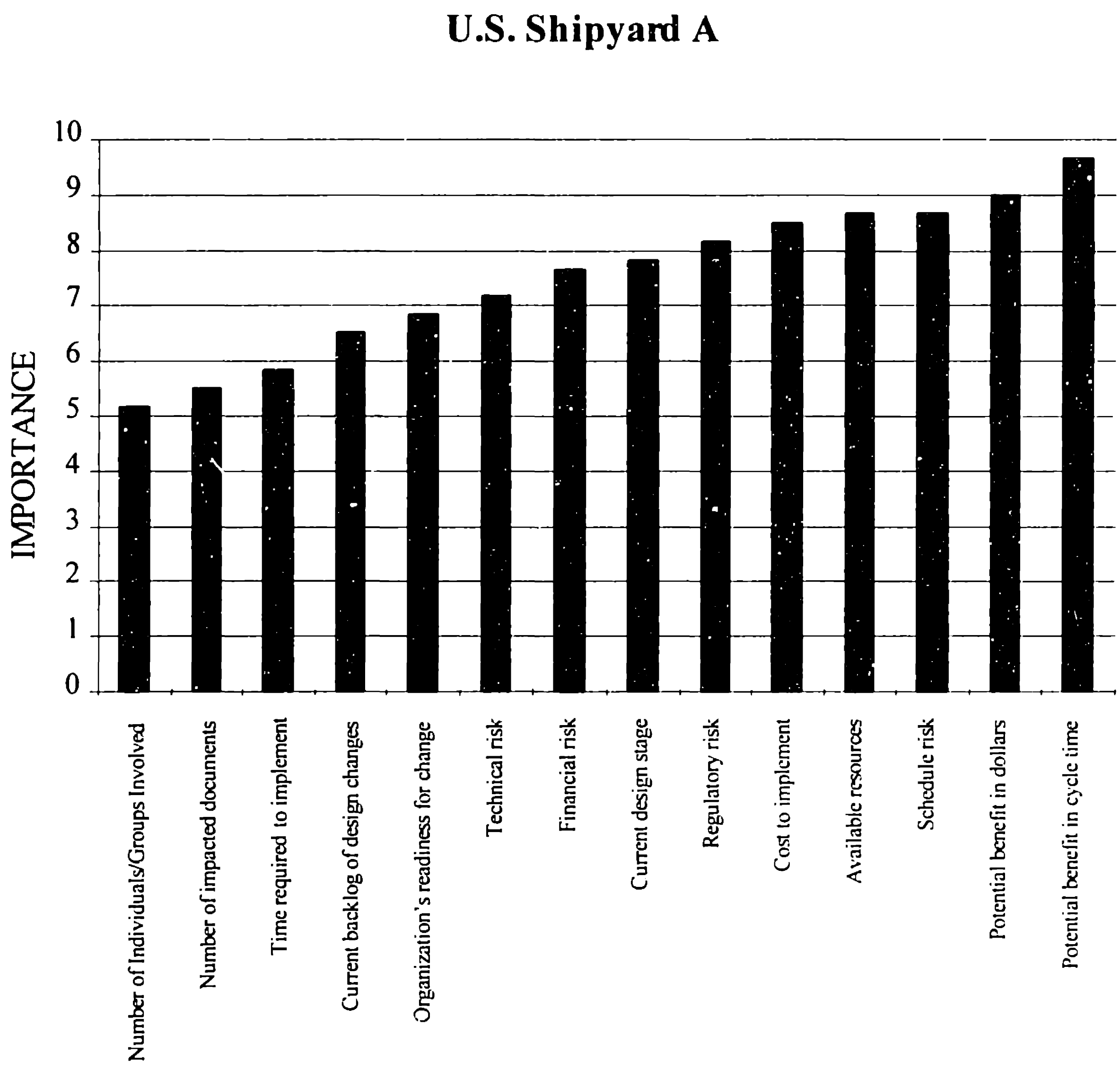


FIGURE 4.11 - U.S. SHIPYARD A CRITERIA RATINGS

4.6.1.1 Production Engineering at Shipyard A

At this shipyard, there is an active Production Engineering department, consistent with the opportunity-seeking attitude reflected above. This group identifies and coordinates time and cost saving technology, and lessons learned during production. This shipyard has recently undergone a reorganization, and for some time it was not clear if there would be an independent Production Engineering department that would report to Planning or Engineering. Ultimately, it was kept independent and reports to Planning rather than Engineering. Production Engineering, which is relatively small, has been collocated with the Design departments along with Detail Planning. This collocation is a response to many of the problems associated with organizational design that were discussed in Chapter 3.0. Responsibility is shared between Production Engineering, Production and Engineering/Design for elective design improvement.

This shipyard has utilized a variety of tools or "enablers" to facilitate design change. These methods change depending on the program stage. During concept design, the mechanism for identifying and incorporating design improvements is the Build Strategy. Production Engineering is responsible for coordinating the Build Strategy, which involves Planning, Production, Engineering and Program Management as well as the Customer. The Build Strategy identifies the design and production schedule as well as unique production approaches and the corresponding action required in Engineering and Design to support those features. More recently, effort has been made to more closely relate the Build Strategy to measurable goals and objectives and to identify future goals as suggested in Chapters 2.0 and 3.0.

During Detail Design, weekly discussions between Engineering and Production have been ongoing. Design supervision is required to participate in "production walk-throughs" with senior yard management including the President and Vice-Presidents. These involve presentations by Production management/supervision at each workstation regarding their efficiencies, progress towards achieving goals, and problems which have occurred that week. In addition, production has an opportunity to create high visibility in front of senior management for any engineering action they have requested or require. There are designated points of contact, typically liaison personnel or design supervisors in the Design departments for changes required for each block or interim product. The Project Engineer assigned to a contract also serves as a point of contact for correcting errors when cross trade issues are involved as well as communication with the Customer. These communication channels often result in the identification and high visibility for errors or issues associated with the content and format of engineering products rather than elective design changes for the purposes of reducing cost or cycle time. Occasionally the weekly meetings or walk-throughs result in the identification of improvements.

In general, changes for the purposes of reducing costs and cycle time have been identified through Production Engineering. The mechanism for identifying and acting on these changes has evolved in recent years. Changes have been identified both through value analysis of engineering products as well as lessons learned during production. At this shipyard, recent contracts now in production have made extensive use of value analysis. Production Engineering reviewed most design products for potential improvements and held weekly meetings with Engineering to discuss these issues. Production interacted with Production Engineering to identify typical problem areas and to explore where the greatest gains could be made. This review process resulted in the identification of numerous changes and significant engineering rework, but also resulted in improved production efficiencies. This represented a difficult period of adjustment for

Engineering, during which attitudes towards engineering quality and relationships with Production changed significantly. During this period, the relationship between Production Engineering and Engineering/Design was often strained. Numerous changes were identified which were implemented through a variety of means, very often "forced" through significant "politicking" and "championing". This approach may well have been the only means available then to rapidly introduce required changes due to the culture that existed at the time. As will be discussed later with respect to implementation strategies, coercive methods are often necessary when an organization is in poor shape or key stakeholders do not support change and there is little time. Such an approach has a significant cost which must be offset by a compelling need.

The approach had a destabilizing effect in Engineering, which struggled to maintain schedule while participating in the process. The relationship necessarily evolved over time in a manner consistent with the conclusions drawn in Chapter 2.0. The compelling need for change was emphasized and supported by upper management which permitted Production Engineering to have extraordinary influence over Design early in the evolution. Successes built momentum and support throughout the organization and Engineering became more participative. Destabilization and schedule difficulties within Engineering due to the "assimilation drain" permitted Engineering management to successfully negotiate a reduction in the number of changes which could be "forced through the system" at any given time in recognition of the limited "assimilation point budget" which the organization has. In addition, the need to focus has resulted in an emphasis on prioritization, planning and Concurrent Engineering as evidenced by recent training in Hoshin Planning. More recently, the emphasis has shifted from value analysis as the principal mechanism for identifying design improvement towards a rigorous Build Strategy process coupled with a lessons learned program. An Industrial Engineering department has been added which is more closely aligned with production for the purposes of facilitating improvement of production processes. A dedicated Standards group interacts closely with Production Engineering, but reports to a different Vice-President. This shipyard makes good use of job rotation and close relationships are often achieved in that way. For example, the supervisor of the Standards group had previously been in the Production Engineering group. Other examples of designers transferred to Production Engineering and production engineers transferred to Engineering and made supervisors responsible for implementing proposals exist.

Errors are often reported to the designated points of contact in Engineering/Design using "liaison engineering disposition" sheets or "problem identification reports." Engineering changes during design and production are identified through the use of Engineering Change Notices and revised drawings. This shipyard has recently revised its processes and procedures in pursuit of ISO 9001. There are numerous formalized processes associated with change management. Until recently the mechanism for identifying and acting upon lessons learned was ad hoc. A formal process for lessons learned has recently been introduced. Among the processes and procedures identified are:

- Shipyard originated configuration change analysis

- Engineering change notices
- Contract drawing and document maintenance
- Ship specification generation and maintenance
- Deviation and waiver processing
- Engineering change order implementation
- Standards issue and change procedure
- Lessons learned

Of these, the shipyard-originated configuration change analysis procedure, the standards issue and change procedure, and the lessons learned procedure are directly associated with elective change. The remaining processes and procedures constitute a traditional configuration management process which may be referenced and utilized by these procedures.

The configuration change analysis procedure was developed to cover changes including requests by Production, design improvements from within Engineering, equipment or material changes suggested by Materials/Purchasing, proposals from planning and manufacturing improvements from Production Engineering. It is primarily concerned with the mechanism for communicating desired changes to Engineering and the means for evaluation of those changes by Engineering in situations when additional engineering effort will be required. If less than 200 additional hours are required, negotiation with supervisors and division managers suffice. This procedure often applies to changes identified by Production Engineering, working in concert with Production and Planning, to address production targets and goals in anticipation of performance gaps or improved methods. It is often the result of proactive thinking and improved processes rather than production experience, which is addressed by the lessons learned procedure discussed shortly.

Suggested design changes are submitted to Engineering supervisors using a design improvement submission form. The procedure is primarily intended for suggestions prior to drawing issue for the impacted hulls (more than three months in advance). Design Engineering is responsible for conducting a preliminary evaluation to determine feasibility, followed by a more detailed investigation to determine if they concur that "if the initiative met expectations, it would result in a clear reduction in cycle time and/or overall costs across the remaining ships in the class." The Design supervisor(s) responsible for the impacted drawings are responsible for this evaluation, which they forward and discuss with the division manager. The division manager is responsible for further discussing the proposal with the primary point of contact, typically the originator of the proposal. If the division manager concurs that the proposal is feasible, and more than 200 engineering m/h are required, the Design Engineering Change Group conducts a detailed analysis. The results of the analysis are a recommendation by the change group to the contract Program Manager, who makes a final decision regarding the change. If the program manager chooses to approve the change, the program manager is responsible for distributing budget to the impacted engineering division. The analysis by the change group includes consideration of positive and negative impacts within Engineering in the following areas:

- Identification of Engineering disciplines impacted
- Extent of product model modifications required
- Modifications to manufacturing plans, fabrication plans, vent sketches and pipe spool sketches required
- Bill of material changes
- Recommendation for timing of implementation (unit, block, zone or hull)
- Impact upon existing standards and new standards required
- Changes to specification or other contract documents
- Changes to basic (system) design required which may require approval, including piping and ventilation calculations
- Impacts to purchasing schedules/costs
- With the assistance of Production and Production Engineering, determine cycle time and labor cost reductions
- Determine expectations for cost recovery

A significant feature of the process is the authority of the Program Manager to authorize an engineering change, and responsibility for providing budget residing with the program. If no budget is available to distribute, the Program Manager must either defer the change or negotiate with production or senior management to transfer budget from another area of the yard or management reserve. Another significant feature of the procedure is the establishment of a time fence of three months lead-time to drawing issue for any proposed changes. Thus, this process is not intended for drawing changes, but for changes in the sense of the word used in Chapter 2.0. A "change" in this process is anything contrary to Engineering's expectations regarding how they would proceed. Note also that this process concentrates on impact to Engineering, and makes no effort to prioritize changes or test their agreement with strategic intent or specified goals and objectives. This process is continually evolving, and these shortcomings are currently the focus of improvement.

4.6.1.2 Standardization at Shipyard A

There is a dedicated Standards group at this shipyard with a supervisor assigned to manage and coordinate all activities. The supervisor reports to the director of Design and the Engineering Vice-President. New standards are developed via requests from Engineering departments, Production departments, Production Engineering, management or customer requests. The group is primarily tasked with coordinating activities, while content is solicited largely from the appropriate groups. A leader is assigned within this group to coordinate activities associated with a particular standard. It is the supervisor's responsibility to keep standards current and "ensure that it supports any processes associated with its subject." This is accomplished through delegation to leaders within the group. The procedure recognizes that "as external standards, regulations and internal processes develop and improve, it becomes necessary to modify standards." This supports the conclusion of Chapters 2.0 and 3.0 that standards are an effective means for focusing and communicating design improvement.

The supervisor establishes priorities for development and revision of standards and determines the scope of activity for each, ranging from correcting known errors identified by internal customers to total revision or development of new standards. The prioritization process has evolved over time from a "squeaky wheel gets the grease" approach to, more recently, an effort to integrate prioritization with shipyard strategic planning and the needs of foreseen product types. The Standards group interacts with Marketing, Advanced Programs and upper management on an ongoing basis. This is entirely consistent with the conclusions drawn in Chapter 2.0. The leader coordinates activities for a particular standard as assigned by the supervisor. The procedure lists a number of sources of input which the leader is tasked to consider. This shipyard's emphasis of standards development as a mechanism for design improvement is clear from this list which includes Design for Manufacture and Assembly (DFMA) as a consideration. Proposals are issued to stakeholder groups for review through a standard review board process. The leader is responsible for coordinating at least one meeting to discuss the standard and obtain feedback. Conflicts are resolved through consensus, although the Standards group develops the final proposal based upon feedback. Approval is through signature by the Standards Supervisor, the Director of Design and/or Vice-President of Engineering and any stakeholder groups which the supervisor identifies.

4.6.1.3 Lessons Learned Program at Shipyard A

The lessons learned procedure is broader in perspective than the change procedure discussed earlier, and may involve coordination with multiple departments. While the previously discussed procedure is concerned with the process of Engineering evaluation and approval, this procedure is concerned with the entire organization. Another difference is that this procedure is established for proposals which are identified as a result of actual experiences in production rather than value analysis or other motivations such as identification of perceived performance gaps or new technology and production processes. It is concerned with the process required to submit, evaluate, plan and implement a lesson learned. A lesson learned is defined in this procedure "as an opportunity to make an improvement based upon discovery of a product, process or condition that did not support efficient design, fabrication, assembly, or erection." This may be the result of the identification in the field of a better approach, or the realization that targets are not being met even though the design "works".

A lessons learned recommendation is one that is motivated by a desire to do better and will result in a change to the design or bill of material, or to the Build Strategy and schedule. The lessons learned procedure does not apply for error correction, where work in the field cannot proceed or requires re-work due to the existing design. In those cases, the Engineering Change and Liaison Engineering Disposition processes apply. This procedure makes use of a "Lessons Learned Form" for use by originators to identify and communicate a lesson learned to Production Engineering. This form includes any sketches or photographs and as detailed a description as is appropriate. The appropriate liaison engineer is often involved in the process of developing the information associated with a lesson learned and can establish with a design supervisor that a lesson learned recommendation can be accomplished through the Engineering Change Notice and Liaison Engineering Disposition sheet process without further evaluation. This would be the case if the change does not require significant effort and consensus regarding appropriate action is quickly reached. Production Engineering is responsible for maintaining a data base of submitted proposals for each hull (and cross referenced between hulls). Production Engineering personnel will review the proposal with the originator to refine the proposal and screen it against any current established criteria. At the time of this research, the Production Engineering department was working to determine how best to set criteria and screen proposals. After the screening process, Production Engineering will conduct a detailed benefit analysis followed by a cost/schedule analysis for each impacted department. At the time of this research, the benefit analysis was conducted using a combination of engineering economy and goal oriented benefits which were not rigorously quantified. Dissatisfaction was expressed regarding the evaluation process. One respondent in Design commented that they "tend to be 'gut driven'. Even decisions with 'analytical' backup tend to have their basis in conjectural estimates rather than long term statistical data." The shipyard was researching ways to improve the evaluation process and to integrate this analysis with the strategic planning and goal setting process that it was beginning to implement (involving Hoshin planning). The cost/schedule analysis is conducted with the assistance of the departments, and in the case of Engineering would involve the review process described for the previous "shipyard-originated configuration change analysis." At this point a decision is made as to whether to proceed, or to defer (but maintain the proposal) or to drop it. A decision to proceed enters into the planning phase. A decision to defer may result in additional information gathering or a notation to review the proposal again after some condition is met (in which case it is maintained in the database). A decision may be made to drop the proposal, in which case it remains in the data base but is noted as having failed the evaluation with no conditions for re-evaluation.

The planning process for proposals is coordinated by Production Engineering and involves all of the stakeholder departments. An implementation plan is developed intended to address all aspects of the proposal including tasking, responsibilities, schedules, budgets, priorities, monitoring and control functions. The implementation plan will describe the implementation strategy and organization design to be used to take action (traditional line organization vs. a highly projectized approach). Often a hybrid approach is utilized, with a Production Engineer monitoring activities. One Design Engineering respondent commented that "implementation is performed by a hybrid of the teams that do base work, plus the participation of a "tiger team" dedicated to change...Implementation of some changes can vary from (a) little participation (or none) by the "tiger team" to (b) formation of a separate additional "tiger team" dedicated to a specific change." They also commented that the strategy would depend on if the change was sweeping across base teams or focused with a high impact on budget and schedule. Approvals are obtained by stakeholder department management. Budget is made available through budget transfer from the departments being positively impacted or from management reserve as negotiated by the Labor Budgeting department, Program

Management and the involved department managers. Budget was not seen as the significant roadblock. One respondent commented that "budget may or may not be available. If not, the proposal may be implemented via an expected overrun. Resource availability is the problem." This was echoed by other respondents within Design. Thus, manpower and "assimilation drain" as discussed in Chapter 2.0 were greater roadblocks to success suggesting the need to carefully prioritize proposals.

4.6.1.4 Roadblocks and Recommendations at Shipyard A

It was apparent that a method for prioritizing proposals was required, as the number of proposals was growing significantly. The shipyard was beginning to review alternative approaches to prioritize proposals relative to a strategic policy, both for lessons learned and proactive proposals. For example, when asked what roadblocks exist which hamper the process, one senior level Production Engineer responded "Volume of required changes, conflicting priorities, and resource availability." A senior level individual in Design commented that there has been "...too much initiative for change and constant turmoil." These comments further validate the conclusions drawn in Chapter 2.0 and the attention given in this research to developing a decision analysis tool for evaluating and prioritizing proposals. In addition, while proposals are beginning to be captured for later use in a database, one respondent commented that they were "...not always effectively [captured]. Process needs to be improved." Another commented that they were "...rarely if ever, formally. However, informally, the champion will continue to promote the change in the face of determined opposition." Thus, improvement is necessary and the process remains highly politicized. One respondent commented about past experiences that "...proposals are made to all levels of management to search for approval...careful lobbying for support is guaranteeing success." In the absence of strong upper management participation with strong correlation required between proposals and strategic objectives, it is not clear that this tendency could ever be deterred. These comments are consistent with the conclusions of Chapter 2.0 regarding champions and sponsors, but improvements to the process are necessary to prevent a drawn out decisionmaking process. The shipyard was just beginning to implement a database for tracking and maintaining proposals and develop a more rigorous strategic planning process to address these issues.

It was also evident at this yard that the problems regarding organization design discussed in Chapter 3.0 were experienced. Initially the Production Engineering function was independent of Engineering and Planning and a less structured process was used to "drive" proposals. Currently, the function reports to the Vice-President of Planning and is collocated with Detailed Planning and Design. Feedback suggests that the new approach is superior, in that it results in closer cooperation among the groups and greater alignment with strategic objectives. In addition, changing attitudes and success have fostered an improved relationship. When asked about incentives to participate, the responses at this shipyard ranged from "none" to "corresponding budget increase" to "profit sharing and performance criteria". The introduction of the "production walk throughs", additional upper management attention, and closer cooperation appear to have had a positive impact upon attitudes towards design improvement. Evaluation criteria for personnel include support of the shipyard mission and improvement efforts, but there is no formal reward system in place specifically for design improvement.

4.6.2 Procedures at U.S. Shipyard B

Shipyard B provided a different perspective. At this shipyard, design changes are perceived in the context of configuration management. There is a configuration management process in place which closely resembles Mil-Std-973 and has evolved from government regulations. These changes are generally in response to customer requests or to correct errors. For example, they responded that often "…for commercial work, design changes are handled by the Program Manager or his staff. Changes to commercial contracts are usually of a minor nature and their number is usually very small...No special procedure is followed because the Program Manager is working closely with the customer." Changes for the purpose of improving production performance or quality are handled by the Engineering department. At this yard, concerns regarding risk and cost are more important than potential benefit as illustrated in Figure 4.12.

It is interesting to note that the average S/I index for this yard is 0.78 while that of the previous yard is 0.71, suggesting that the explanation for the differing attitudes is not differing perceptions of their strength with respect to important capabilities. The difference also cannot be explained as being a function of shipyard size. Both of these yards employ roughly the same number of people. The difference appears to be cultural and a function of different attitudes regarding the relative importance of benefit, cost and risk. While shipyard A has invested heavily in recognizable "quality programs" and training in the Deming management method and quality tools, shipyard B never instituted a similar quality program or extensive training. It can also be explained by different perceptions of a compelling need. Those interviewed at shipyard A clearly believed that there was a compelling need to improve performance on existing contracts and in preparation for future contracts. Shipyard B, on the other hand, appeared more satisfied with their present situation and ability to obtain commercial work despite similar perceptions of their strength with respect to abilities. Shipyard B's emphasis was clearly on basic design processes, customer relationship, and major production processes/organization rather than design improvement based upon lessons learned or new/revised interim products and standards. The focus was on shortening the basic design cycle and introducing major new production and design technologies including upgraded steel fabrication areas and new product modeling systems. Shipyard A, on the other hand, was involved in all avenues of improvement activity. At shipyard B there did not appear to be any evidence of a formal lessons learned program or Production Engineering effort. Because access at this yard was more limited, it was not possible to determine if a majority of Detail Design and Production personnel shared these views.

U.S. Shipyard B

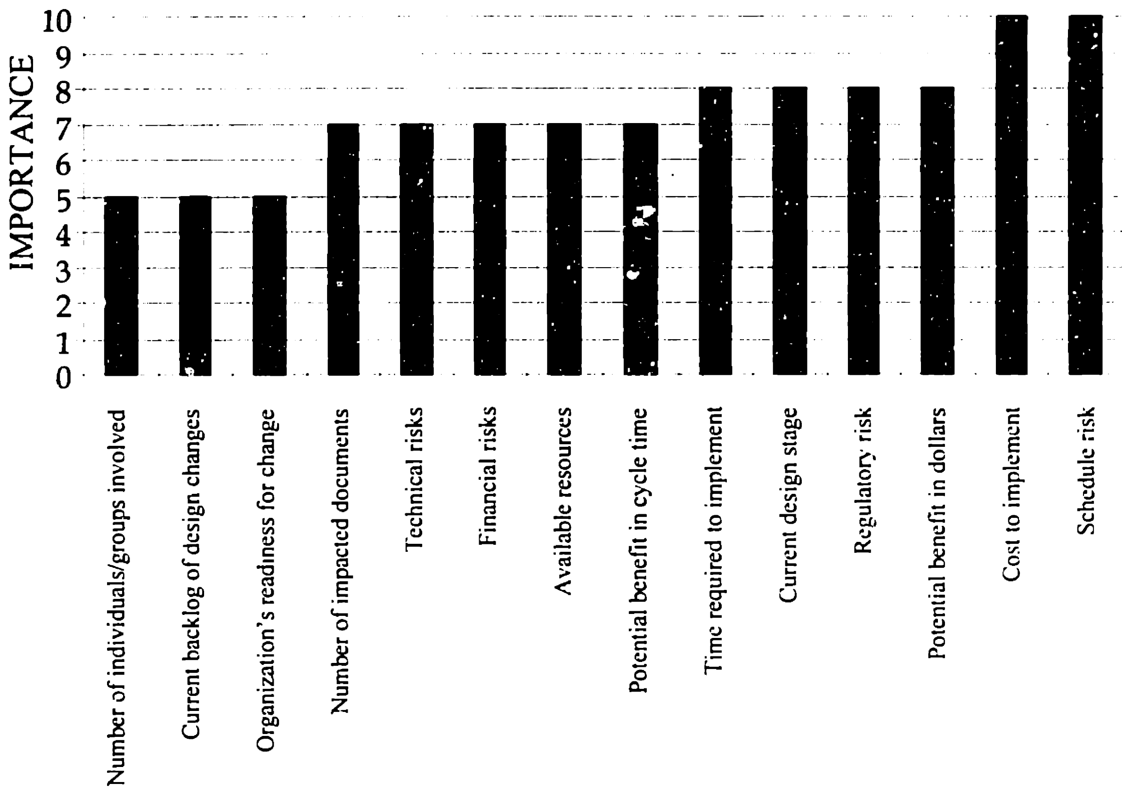


FIGURE 4.12 - U.S. SHIPYARD B CRITERIA RATINGS

This shipyard is undergoing a dramatic shift towards a Concurrent Engineering environment and stresses identifying improvements at the start of a contract with strict control during detail design and production. While shipyard A was seen to be very active in Build Strategy development and had begun to make significant strides in developing a Concurrent Engineering approach to new design development, shipyard B was much more focused on Integrated Product and Process Development (IPPD). Recent contracts at this yard required their adoption of IPPD and an Integrated Product Data Environment (IPDE). It was commented that "a proper design would eliminate changes that would disrupt the production [& engineering] process. It is important to realize that we are transitioning towards an IPPD culture where many [design improvement] situations are dealt with before design completion." There did not appear to be significant interest in ongoing design improvement efforts throughout the design cycle.

Errors and omissions are identified by the functional departments. Customer requests are the responsibility of Program Management. Changes motivated by regulatory requirements are the responsibility of the functional departments.

Responsibility for cost and time saving technologies is shared by all. Lessons learned during production are identified through production engineers who operate within the Engineering department (there is no separate Production Engineering department). Identification utilizes a variety of feedback systems in place at the shipyard. Evaluation is performed through consensus rather than a rigorous procedure. Prioritization is through consensus of management. Decisionmaking is also through management consensus and negotiation. Planning is through the traditional data management and planning system. Implementation relies upon functional department resources and negotiation between departments.

4.6.2.1 Change Management Procedure at Shipyard B

This shipyard made two of their procedures available for review. The first is that for engineering support of contract changes and the second is for the standards system. The change procedure is intended to establish a uniform processing system for review and incorporation of changes and covers all types of changes including error correction, shipyard proposals and customer requests. The procedure relates to how these proposals are handled by Engineering and does not discuss how improvement proposals are identified. The procedure makes limited reference to shipyard-initiated changes and is clearly intended for government contracts. It has evolved from government contracts, and as was mentioned earlier, on commercial contracts this shipyard often streamlines the process or eliminates it. It was suggested that the few changes which may be proposed are settled through a more ad hoc process of consensus of the program management and stakeholder groups.

This procedure assigns responsibility to the Project Administrator (similar to the Project Engineer at other organizations) for oversight of a Configuration Control Group. The group has a supervisor who reports directly to the Project Administrator. The Project Administrator is responsible for routing the proposal and coordinating its review. Each engineering section has a member on the change control board who is responsible for coordinating the analysis and evaluation of proposals within his/her functional area. Ultimately section managers approve the evaluation made by their section. Change proposals are documented with a narrative and any applicable sketches/photographs together with an evaluation of positive and negative impacts. The change control board approves changes through consensus. Budget is assigned through a transfer negotiated by program management in the case of shipyard proposals. The Project Administrator or staff is responsible for maintaining tracking and monitoring of all changes. Impacts considered during evaluation are aimed primarily at assessing the potential disruption of a change and include positive and negative impacts upon:

- Health and Human Engineering Factors
- System Safety
- ILS/LCC Considerations
- Test procedures

- Operation
- Performance
- Weight/Moment
- Dimension/Size
- Appearance
- Cost
- Number of drawings impacted
- Manhours to incorporate in each section
- Number of engineering sections impacted
- Number of concurrent changes
- Density/Complexity of changes
- Number of affected systems
- Impact to manuals
- Impact to material and lead-times
- Schedule impact
- Reworking of accomplished tasks
- Transfer of personnel
- Acceleration required to meet schedules
- Dependencies on analysis and tests

The evaluation forms used by this yard admitted both quantitative and qualitative data. Quantitative ranges for each evaluation criteria were assigned qualitative labels (none, low, average, major and high). Each of these were in turn assigned percentage factors which were utilized in a "disruption formula". This demonstrates a recognition of the difficulty to compare proposals using quantitative data alone and the need to be able to synthesize a judgment where multiple criteria and scales exist.

4.6.2.2 Standardization at Shipyard B

The standards procedure appears to be more conducive to the introduction of productivity-motivated changes, and is similar in several respects to that of shipyard A. The request for a new standard may come from either internal or external sources. Internal requests are made using a request form which is submitted by an employee to his/her supervisor. If the supervisor concurs, the proposal is submitted to the appropriate Engineering section manager. While shipyard A maintained a dedicated Standards group, shipyard B assigned responsibility to engineering sections for maintenance of their standards. These alternative approaches have pros and cons as discussed in Chapter 3.0. This has the benefit of closer communication and utilization of standards within the sections. A potential problem is that cross section standards will be poorly coordinated and utilized.

The Engineering section manager is responsible for approving and prioritizing requests associated with a particular section's standards. Research and analysis is conducted by an assigned individual (cognizant engineer) within each section who is responsible for coordination and assuring that all applicable regulatory body requirements are met. Revised or new standards go through a ten working day review cycle by all identified yard stakeholders, coordinated by the cognizant engineer. Comments are reviewed by the cognizant engineer and meetings are conducted as necessary to resolve conflicts through consensus. All standards must receive final approval by the section manager and the cognizant Production group Vice-President and Engineering Vice-President.

4.6.3 Procedures at U.S. Shipyard C

Shipyard C appears to be an opportunity seeker based upon the survey response they provided. Unlike shipyards A and B, this yard is predominantly involved in combatant work. Like shipyard A, there is an active Production Engineering function. This is reflected in their prioritization of benefits, costs and risks as evaluation criteria. Figure 4.13 illustrates their response.

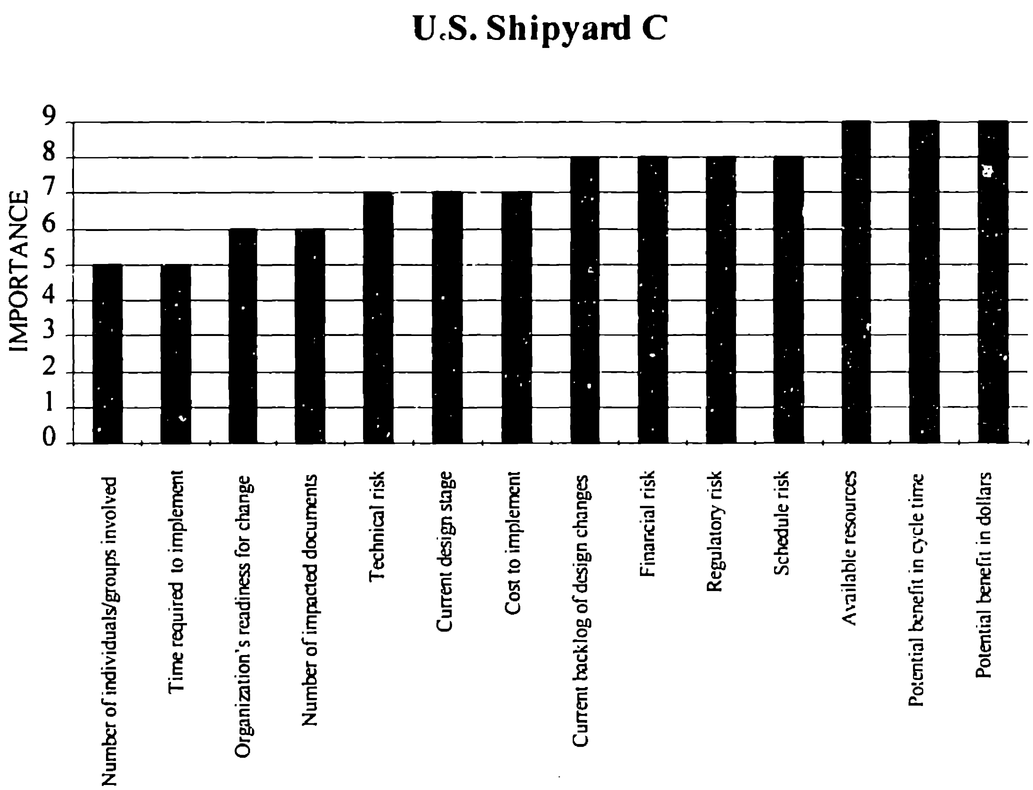


FIGURE 4.13 - U.S. SHIPYARD C CRITERIA RATINGS

Access to processes and procedures was not available, but the following was learned through survey comments and interview. This shipyard facilitates design improvement in a number of ways. They make extensive use of a review process, both pre and post construction, that involves Design, Planning and Production. This review process is similar to value engineering. Design is also involved in production walkthroughs which often result in the identification of proposals. Documenting and communicating proposals is somewhat ad hoc, ranging from immediate consensus through discussions between affected parties to corporate level presentations when significant expenditures are required. They make an effort to encourage decisions to be made at the lowest possible level. A cost/benefit analysis is generally done but can be "extremely informal and between a designer and a mechanic or very high level. The focus is on a company based best answer." Budget is made available from Production funds or Design budget underruns. Upper management is involved "extensively. CEO has weekly meetings." It was commented that responsiveness to production requests "is the expectation of their [engineering] job function and therefore linked to performance reviews."

They commented that "resources in Planning, Design and Engineering are the most significant roadblocks. Management attention is a distant second." This comment reinforces the feedback from the other shipyards and the conclusions drawn so far. Prioritization is important to assure that only those proposals which are most aligned with strategic objectives are acted upon. A sensitivity to the state of the organizations involved, or their current "assimilation drain" and overall "assimilation budget" is required.

4.6.4 Procedures at U.S. Shipyard D

This shipyard did not provide a detailed survey response, but a site visit and interviews were conducted. The results of this interview reinforce the lessons learned at the other shipyards and also reinforce the conclusions drawn in Chapter 2.0. This shipyard is involved in both military and commercial work. Like shipyard A, this yard has been involved in the quality improvement movement for quite some time, at least ten years. They developed a Quality Improvement training program in 1989, and a revised program again in 1993. In January of 1996 they implemented an initiative aimed at reducing their costs and cycle time by 50%. This shipyard's most recent efforts have been to re-engineer their processes and products. Their recent initiative was motivated by the downsizing of the US Navy and their subsequent desire to enter the international commercial market. Some problems with their previous quality improvement programs which they hoped to avoid and differences between the new program and the previous ones included:

- Previous programs did not result in an integrated effort which was traceable to an overall strategy.
- Previous programs resulted in a flurry of disconnected projects and initiatives.
- Previous programs were aimed at incremental, continuous improvement. New program was aimed at breakthrough, discontinuous or completely "re-engineered" improvement.

- The new program followed the business process re-engineering model of improvement.
- The new program focused the application of prior TQM training within an improved strategic and organizational framework.
- The new program emphasized stabilization of processes and re-organization prior to re-engineering of processes and products.

The shipyard has followed a multi-pronged approach which attempted to balance:

- Process improvement
- Product improvement
- Capital investment and facilities
- Technology transfer
- Organizational change

Examples would include investment in a new steel factory, robotic process lanes and new CAD/CAM systems.

In support of their initiative, they organized to facilitate process and product re-engineering. They created a new executive position, VP of Strategy and Process Innovation. Reporting to this VP were seven directors of process innovation in the following areas.

- Engineering/Design
- Steel
- Outfitting
- Manufacturing Engineering
- Planning/Scheduling
- Information Systems
- Production Engineering

Full-time employees (37) were distributed throughout these groups. These would form the core team. In addition, for each initiative identified, employees from throughout the yard were brought on board to participate. The full time individuals reporting to the directors were in turn team leaders for the initiatives. Each group initially focused on processes. Each group was assigned a hired consultant (the consultants were from the same organization) whose sole purpose was to educate the group regarding process re-engineering and benchmarking. Each group followed the same basic steps, which are consistent with the change management framework introduced in this research:

- Identify core processes which are cost or cycle time drivers (Engineering focused on 8 major processes)
- Document the existing process
- Make sure that they were following a standard and predictable process (Stabilization)
- Benchmark best practices
- Identify the desired process and/or objectives (Gap analysis)

- Re-engineer processes or products to support objectives

They began their recent efforts with what they called the "quick wins" team. The objective was to identify "low hanging fruit", and achieve early savings that would build commitment and momentum. This is consistent with the conclusions drawn in Chapter 2.0. The VP of Process Innovation was responsible for insuring that each group (i.e. all the directors) were working in concert against an overall strategy which was a flowdown from a corporate strategy. The groups worked together and jointly visited best practices and technology transfer. They did not have the same processes across product lines. They recognized that a lack of standardization had become a significant problem. A big driver of differences was their specialized military work. They worked to standardize their processes and products concurrently with their other efforts.

This shipyard has historically had a Production Engineering department. In the past this group was largely responsible for detail planning. They worked closely with the engineers after the design was underway to determine how to plan the construction or installation. Their work historically included responsibility for setting up process lanes, and they would work with the engineers if they had suggestions for improving the design. There was a general sense that the group was not working as an integrated part of the overall improvement process, and that the group was not focused strategically. The new Production Engineering group is responsible for developing the Build Strategy and identifying features which are desirable for new contracts, or features that are desirable to be introduced into existing contracts. They are now a more focused group, obtaining input and suggestions from the re-engineering groups discussed above and providing the required support. They evaluate changes based upon positive and negative impacts upon cost, schedule, and risk.

4.6.5 Procedures at a Japanese Shipyard

A Japanese shipyard participated by responding to the survey and providing some detailed information regarding their processes and procedures. This shipyard is representative of "best in class" among the shipyards reviewed in this research. It is involved in commercial shipbuilding including tankers, ro/ro's/passenger/pure car carrier, Containerships and LNG. While having a much higher production rate than the U.S. yards, employment at this yard was less than half that of the U.S. yards. The survey response indicates that this shipyard considers costs and risks to be more significant evaluation criteria than potential benefit.

This shipyard responded that they primarily utilize three means for facilitating design improvement. They provide a mechanism for incorporating improvement at the concept design stage through quality function deployment (Concurrent Engineering and Build Strategy development), during detail design through value analysis, and during all stages of design and production through a lessons learned feedback system.

The lessons learned feedback system in use at this shipyard is coordinated by their quality control department. Their quality control cycle utilizes a database to capture lessons learned and track action. This database catalogs all lessons learned throughout all stages of design and construction. The database includes all types of lessons learned ranging from errors that required correction to suggestions for improvements. Thus a single system is used for all types of motivations. At the initial design phase, the QC department utilizes the database to compile a list of lessons from similar previous hulls. This becomes a starting point for Build Strategy development and Quality Function Deployment activities at concept design. It is also used to develop a checklist for the engineering sections. The QC department also manages activities associated with collecting and disseminating comments during design and construction. A standard form is used to communicate lessons learned regardless of the motivation. Errors and improvements are both considered to be lessons learned proposals. If new technology is identified, construction budget is occasionally transferred to fund its research. The Design department commented that they are always looking for innovations, and that they form committees of employees tasked with benchmarking. A portion of the Design Department's overhead budget is allocated for this purpose. Design and Production management meet frequently to discuss desired improvements and to negotiate appropriate transfers of budget.

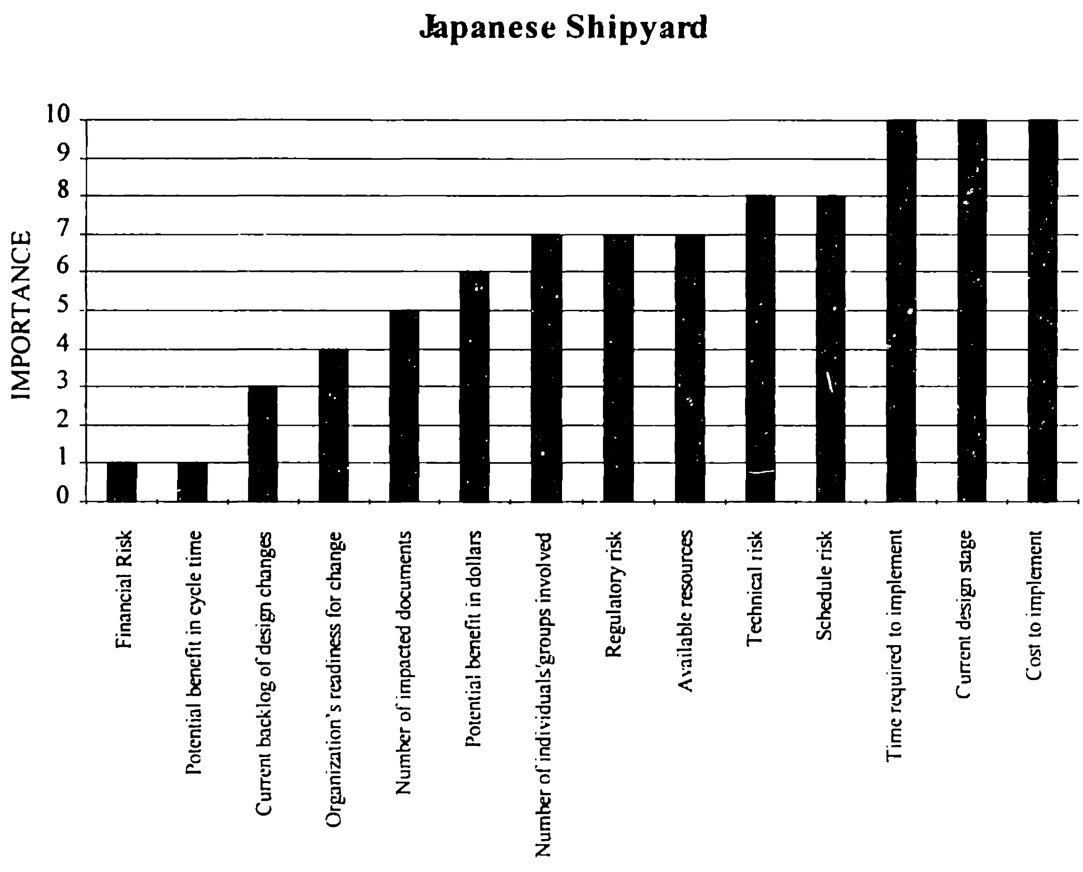


FIGURE 4.14 - JAPANESE SHIPYARD DECISION CRITERIA

Prior to implementation, all departments conduct a cost/benefit analysis. The QC department synthesizes and summarizes the results. QC will coordinate communication between departments to refine the proposal and develop consensus regarding the costs and benefits. Monthly meetings chaired by the President are held to review the status of lessons learned submitted to the various departments. The support of the process by the President insures that all involved follow through on agreements. It also strengthens the process of deploying strategic goals throughout the organization and evaluation of proposals with respect to these goals. All Engineering and Production sections are represented. Decisions as to whether or not to conduct additional research are made at these meetings. Decisionmaking authority is in the hands of the section manager in charge of the impacted design section with respect to prioritizing which ideas should be implemented. In cases where the change is broad, the department manager may make a decision instead. Authorization from upper management is required before implementation can proceed. Implementation usually occurs prior to the construction of a follow or similar hull.

4.7 CASE STUDIES

In this section of the questionnaire, participants were asked to identify examples of design changes which represent both successes and failures in the hopes of identifying factors that contribute to success. Responses to this section of the survey were limited, but several factors were identifiable. A participatory implementation strategy was indicated to be generally more successful than one which was not inclusive of all impacted departments. The following were identified by one or more respondents as factors which are associated with success.

- Proposals are initially identified by Production rather than other departments
- Proposals are aligned with an understood strategy
- Proposals have highly visible support in Production and departments other than the originating department
- Rigorous planning is used to implement the proposal, including consideration of necessary training and inclusion of all impacted departments

4.8 LESSONS FROM AN AEROSPACE COMPANY

In addition to the data gathered regarding shipbuilders, a visit was made to a major U.S. aerospace manufacturer. The similarities between the issues faced by the aerospace firm and shipbuilders were striking, and common issues and concerns exist with respect to:

- Manufacturing/Production Engineering
- Change Management
- Scheduling
- Standards
- Quality Assurance
- Accuracy Control

The company found its market share dwindling in recent years, and it was a high cost producer relative to its competition. They recognized that they would go out of business unless significant measures were taken. Deming training was abandoned due to problems with implementation. They found it difficult to implement this training at the same time as significant downsizing. They also found training in less "soft" approaches such as Design For Manufacture and Assembly (DFMA) to be more successful. Upper management initiated a program similar to that discussed earlier for U.S. Shipyard D. Their efforts were aimed almost exclusively at DFMA. They had an existing product line which had evolved over time and felt that they needed to completely re-engineer their production processes and subsequently their products. Both Engineering and Production personnel have been trained in DFMA and work together on teams to re-engineer specific areas of products. The approach taken utilized a rigorous strategic planning process as described in Chapter 2.0. Marketing set goals for cost reductions based upon market prices, which they had already obligated themselves to. Department budgets were slashed according to an allocation down through the company of those targets. These targets and budget reductions were summarized along with strategic objectives in an overall Aircraft Design and Manufacturing Strategy developed by upper management and department heads. The objective of this strategy was to "develop a teaming approach that identifies cost effective initiatives which significantly reduce assembly, design and supplier costs, decrease spans [cycle times] and improve quality." A significant element of the overall strategy was to establish a policy regarding attitudes towards potential benefits and risk. Senior management made a decision to insist that general managers demonstrate that they are identifying and implementing a majority of higher benefit, higher risk proposals than lower risk, lower benefit proposals. The approach taken was stated to be:

- Divide the product into manageable, yet distinctive elements for which product teams will be assigned
- Assign cross functional product teams starting at the GM level and involve all levels (i.e. mechanics, designers etc.)
- Cross functional teams to be coached at the VP level
- Establish cost, span and quality top level goals
- Develop initiatives which are mutually beneficial to assembly, design and technology, supplier management, and the "customer", and that tie directly to the goals established for each product team

- Perform cost/benefit analysis on each initiative and review with GM product team prior to VP level approval
- Identify 20% of the initiatives that drive 80% of the costs
- Identify NO MORE than five low risk initiatives per product team
- Implement and monitor those initiatives approved and funded
- Rewards and evaluations tied to performance with respect to improvement targets

A significant feature of the approach is the active participation of upper management and the rigorous use of strategic planning. General managers were held accountable for targets which were allocated to particular sections of particular planes that were deemed to be in support of higher level objectives. GM's were tasked with flowing down program level goals and strategies to cross functional product teams to which they were assigned leadership. The cross functional teams collect proposals from all levels of the workforce, including those developed by Industrial Engineering to support new processes. A large sum was budgeted for improvement initiatives. The previously mentioned strategy suggested the total savings which was to be achived throughout the organization. The ratio of the two represented the hurdle rate against which improvement proposals were compared.

All changes to an aircraft design which require significant engineering effort above a standardized cut-off level must be reviewed and approved by a "change board." Prior to reaching the change board, a concept will have been sketched out with an rough cost/benefit analysis and estimates for actions required. A change management organization within the Industrial Engineering department reviews the proposal and develops a change board package based upon input they solicit from the originators and identified stakeholders. Industrial Engineering serves as a support organization. They also identify proposals for which they elicit support from general managers. They assist cross functional teams in prioritizing approved proposals based upon the guidelines of the overall strategy.

The change board package is similar to a typical shipbuilding change order and includes:

- A description of the change
- A cost/benefit analysis
- Sketches and photos
- A completed checklist demonstrating consideration of all impacts
- A request for engineering effort with an estimate of this effort
- A list of impacted documents

Once the package has been prepared, the change board will review the package and prioritize it among other changes and either approve it, request additional information, defer it, or determine it to be unfeasible. The change board meets three times a week and is co-chaired by general managers within Engineering and Production. It therefore represents a consensus based participative approach. If the change management organization in industrial engineering deems a proposal to be urgent, it can request that it go through a more streamlined "rapid change board process." General managers meet monthly with the change management organization and Vice-Presidents to discuss progress and cross team issues.

Once a decision is made, an implementation control group within Industrial Engineering tracks the project, aids the involved parties in identifying all the steps necessary to implement the project, and provides project management as necessary. Progress is tracked in the same database used by the change board.

4.9 LESSONS FROM THE CONSTRUCTION INDUSTRY

The construction industry shares many characteristics with the shipbuilding industry. Among these are a wide variety of similar trades, and long design and construction cycles. They are also facing similar pressures which result in an increased pace of change. "The engineering and construction contracting environment is increasingly competitive and litigious, project schedules and financial parameters are aggressive, and project scopes are complex...Projects thus are more likely to require changes in order to meet business needs or objectives." [CII, 1994, p. 1] The Construction Industry Institute (CII) serves a similar purpose for the construction industry as the National Shipbuilding Research Program (NSRP) does for shipbuilding. The CII has recently published a series of reports and conducted a series of symposia relating the results of research into change management in the construction industry. At the project change management session of the 1996 CII conference it was suggested that CII initiated this effort in response to the following conditions among CII member organizations:

- there was a lack of quantitative data on the impacts of change on project results
- there was a great deal of divergence of opinion about what constitutes a change, how to deal with change, assessment of the effect of change and what happens when change occurs
- information on the effects of change was mostly anecdotal and based on personal experiences - leading to the mind set that change is a deviation, is bad, is to be avoided and should be dealt with only as necessary
- current business environment requires project execution which is faster and with lower costs but with higher expectations for quality and results - all of which require that change be anticipated and systematically managed into the project execution work process

"CII established the Project Change Management Research Team to find solutions to or, preferably, the means of avoiding such problems [of managing change]...The team's research focused on determining the nature and origin of problems related to changes...As a result of its investigation, the research team concluded that it would provide three primary deliverables to industry: (1) a comprehensive view of agreements and changes; (2) a set of recommended best practices for the effective management of change; and (3) a prototype change management system, reflecting the means of implementing the research team findings" [CII, 1994, p. v] The results of their efforts are reviewed here and placed in the context of this research.

A principal finding of their research was verification of the common belief that reduction in productivity is correlated to increased change. The data shows a correlation, particularly with excessive change, but the amount of scatter in the data suggests that many organizations do better at managing change than others. Productivity in their study was measured as a productivity index equal to the ratio of earned work hours (i.e. budgeted) to expended work hours. Statistical fitting of their data indicated that project productivity declined in engineering and construction with the introduction of an increased number of changes. A close examination of the data shows significant scatter, particularly below levels on the order of 25% of scope. This indicates that if change is managed well and is not excessive, productivity need not decline but that there is an increasing risk that it will do so.

CII made 27 specific recommendations regarding project change management best practices. These recommendations reinforce conclusions drawn earlier regarding the importance of Concurrent Engineering, Build Strategy development, evaluation/prioritization methods and capture of proposals for later use. The recommendations are summarized in five principals of effective change management which correlate well to the design change framework introduced earlier in this research:

- Promote a balanced change culture
- Recognize change
- Evaluate change
- Implement change
- Continuously improve from lessons learned

Promoting a balanced change culture requires that "first, a commitment by all parties must be reached to recognize changes and to increase sensitivity to changes as the project progresses from concept to construction. Second, planning for potential changes should be initiated as early in the project as possible. Third, all parties to the project should agree that changes are to be evaluated and agreed upon as quickly as possible." [CII, 1994, p.1] A balanced change culture is one which encourages beneficial change, and prevents detrimental change. CII recommended that:

- Critical project success factors must be documented and communicated to all parties
- Timely and accurate predictions of the cumulative impact of a change are particularly important
- Anticipate change when allocating time and resources to a project (as a contingency budget)
- Recognize and reward those who initiate beneficial change
- A formal value engineering system be utilized
- Require justification for all elective changes
- Maintain accountability for any change being introduced

The importance of the conclusions of Chapters 2.0 and 3.0 are reinforced by CII's research. Earlier in this research it was suggested that change must be associated with expectations, because resistance to change occurs as a result of a deviation from a stakeholder's expectations. CII concluded that change is best defined as "a modification to an agreement between project participants...Because change can be best understood in the context of agreements, a critical skill for project managers is the ability to discern whether an agreement actually exists. By having a change management process in place, a project manager will be able to better understand the complexity of the project and to better communicate with all project participants." [CII, 1994, p.2] Since resistance to change is associated with expectations, but change is best managed in the context of explicit agreements rather than easily misunderstood or hidden expectations, it is critical to convert as many expectations as possible into explicit agreements. As was discussed earlier, Concurrent Engineering, Build Strategy development and standardization provide a mechanism for making these expectations explicit, thereby facilitating the process of change management in downstream phases.

CII concluded that "project organizations should include a balance of innovators and implementors, should promote teamwork and collaboration, and have a disciplined approach to executing projects. Effective change management should be established as a project success factor for organizational, team and individual performance...Effective management of change requires the use of work execution methods that include specific, integrated and systematic steps to recognize, evaluate and implement change." [CII, 1994, p.9] CII concluded that evaluation of changes was of particular importance. Their recommendations are consistent with the conclusions drawn in Chapter 2.0:

- After an elective change is evaluated, the immediate focus should be on the decision of whether to implement. This will require a reasonable order of magnitude estimate of the impact of the change and a similar measure of the benefit of the change.
- In order to determine if an elective change should be implemented, economic guidelines should be pre-established to guide the decision makers.
- The decision to proceed should be made as soon as the decisionmaker is assured it will meet the criteria established for elective change.
- Caution must be exercised in making quick judgments in favor of implementing elective change, as secondary effects of making a change in one area can often impact another area.
- Guidelines for change implementation must be clear and consistent with the projects critical success factors.
- Changes should be evaluated against the business drivers and success criteria for the project

4.10 SYNOPSIS

The importance and focus of this research is supported by the survey results which reinforce and validate many of the conclusions drawn in earlier Chapters. Additional insight has also been gained into which aspects of the change management problem are most important and require improved approaches or processes. Among some of the most significant conclusions to be drawn from the industry survey are:

- Change management and design improvement capabilities are considered to be strategically important, but industry strength in this area is low.
- The industry is actively seeking to improve its capabilities in the area of Design Change Management.
- U.S. shipyards exhibit a broad imbalance between the importance of capabilities and their strength relative to those capabilities. A Japanese shipyard representative of best in class exhibits a significantly greater balance (S/I = 1.0).
- U.S. shipyards exhibit a more diverse improvement program while the Japanese yard exhibited more focused improvement efforts.
- The existence of a visible corporate strategy which identifies performance gaps to be addressed with goals and objectives appears to be important to success.
- Activities associated with maintaining stability, prioritizing, planning, and decisionmaking are considered to be most critical to successful change management.
- A mechanism for quickly and effectively evaluating and prioritizing proposals and linking them to business strategy is essential. Decision criteria must be explicit.
- All of the change management goals introduced in Chapter 1.0 are considered to be equally important. These include extending the timeframe of effectivity, allowing changes to be made faster, minimizing the number of design changes, selecting potential design changes, evaluating potential design changes, prioritizing potential changes, allowing decisions to be made faster, insuring changes are effective, maximizing benefit potential, minimizing delays and disruption due to changes and identifying potential changes to reduce costs.
- Most organizations believe their procedures are effective for dealing with mandatory changes, but weak with respect to elective changes.
- Different shipyards have varying perspectives regarding decision criteria and the relative importance of maximizing benefits, minimizing costs, and minimizing risks

associated with change proposals. A shipyard policy and strategy must make guidelines clear.

- An active Production Engineering group appears to be present in those yards which reflect a preference for maximizing benefits over minimizing costs and risks.

- Close relationships and collocation of Production Engineering with Engineering and Planning appear important to success.

- The most significant roadblock to implementing elective change is manpower rather than budget. Change should be anticipated when allocating time and resources to a program.

- Participation and consensus are commonly used and appear correlated to success.

- Conclusions regarding the importance of Concurrent Engineering, Build Strategy development and standardization to change management success are reinforced by industry experience.

In the remaining chapters of this research, each stage of the Design Change Management framework are reviewed. The conclusions drawn so far are addressed in each stage with existing theory or the development of new processes. Based upon the conclusions above and those of the preceding Chapters, particular emphasis will be given to the development of a decision model for evaluating and prioritizing changes within the context of a shipyard strategy or policy.

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5.0 IDENTIFYING DESIGN IMPROVEMENT PROPOSALS

In this chapter the identification stage of the framework is explored in greater detail. As was discussed in previous chapters, a clear linkage between design improvement proposals and shipyard strategy has been lacking in actual practice. The means of identifying design improvement proposals which support strategic goals are explored here. The recommended approach is consistent with what Keeney refers to as "value-focused thinking."

> Values come before alternatives in value-focused thinking. Hence, after a decision problem is recognized, the full specification of values is the next activity. For many decisions, these values should first be qualitatively explored at length and then possibly quantified. The qualitatively articulated values, and any quantitative embellishments, are then directly used in the third activity, the creation of alternatives. The intent is to broaden the range of alternatives considered by eliminating any anchoring on already identified alternatives. [Keeney, 1992, p.50]

The objective is to utilize competitiveness-based improvements. Shipyards should regularly examine the environment to anticipate changes rather than react to them. "Not all decision situations have to be created by outside forces. It is worthwhile to seek out decision situations, situations I refer to as decision opportunities rather than decision problems. Such decision situations do not occur outside your control; they occur because of your control." [Keeney, 1992, p.17] A proactive approach can exert pressure on the market allowing a shipyard to lead rather than follow. Being proactive means examining not only todays gap, but the trends for you and your competition. The identification stage of the design change framework should be aligned with this philosophy and must necessarily start with the target market.

The identification stage of the framework can be considered to be broken into a number of sub-elements consistent with the managed improvement process presented at the conclusion of Chapter 2.0. These sub-elements include:

- Understanding of current and future product mix
- Understanding of competitive environment and pressures
- Analysis of gross performance gap
- Product analysis of product mix
- Competency mapping
- Technology surveys and benchmarking
- Analysis of performance gaps associated with critical capabilities
- Development of objectives and goals
- Identification of improvements to address strategic response (objectives and goals)
- Characterization of proposals and preparation for evaluation phase

Product mix defines the competitive environment

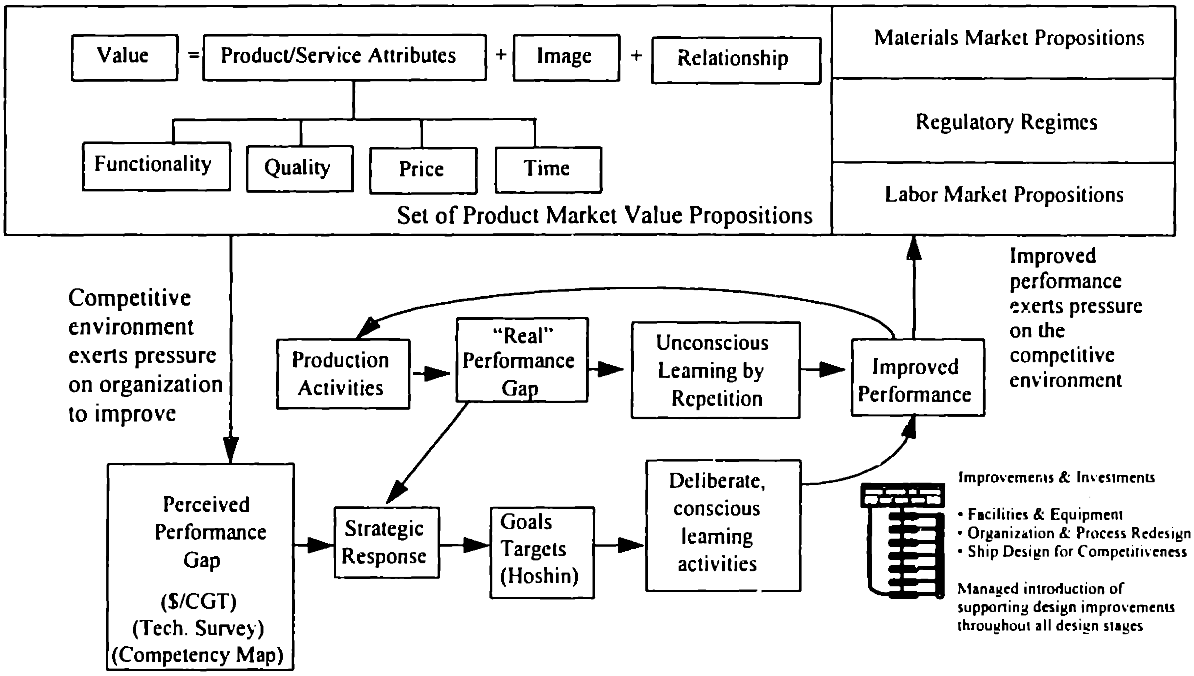

FIGURE 5.1 - MANAGED IMPROVEMENT PROCESS

5.1 PRODUCT MIX AND THE COMPETITIVE ENVIRONMENT

The product mix identifies the competitive environment. As was discussed in Chapter 2.0 and illustrated in Figure 5.1, a significant component of the competitive environment is defined by the product market value proposition. In turn, labor, regulatory and material markets are also a function of the products being considered. Financial markets and potential product volumes are key elements to be considered.

> Shipyards do not operate in isolation. They are subject to forces imposed by the external environment to which they must react. The external environment provides both opportunities and threats, and the nature of the external environment must be understood to enable these to be identified and addressed.
>
> In general, external forces are outside the control of a shipyard. In particular this comment is directed at price, which fluctuates on a commodity basis. It is one of the characteristics of the shipbuilding industry, that very large fluctuations in price have been experienced in the past and it is largely due to this variation that shipbuilding is seen as a difficult and high risk industry.

> In order to survive in this difficult environment a shipyard must adopt a inherent strategy to match the facilities and organization to a targeted market sector. This strategy must be considered very carefully, with decisions made on a rational and scientific basis, and not on intuition. [Stott, 1995, p.13]

Therefore, the first step for making values (goals and objectives) explicit is identifying the products which constitute a particular shipyard's market. The product mix defines the competitive requirements. The conclusions regarding strategic planning in Chapters 2.0 and 4.0 would suggest that goals must be linked to these requirements through the realization of performance gaps. Subsequently, the design/Build Strategy and change management process must support these goals.

There are two possible activities associated with this identification sub-element. The first of these defines an optimal product mix to take advantage of a yard's present distinctive and core competencies. This is closely aligned with the seller of products strategy. The second is to define the distinctive and core competencies which are required to take advantage of future available product mix. This is closely aligned with the seller of capacity strategy. A thorough review of the product mix should result in a better understanding of what has been produced in the recent past and what is being produced today, and what skills associated with these contracts are still strong today. A review of the market will result in an understanding of core opportunities, stretch goal opportunities and those opportunities that are not credible today. Core opportunities are those for which the shipyard has distinctive and core capabilities. Stretch goal opportunities are those for which the shipyard has core capabilities but not many particularly distinctive capabilities. Those opportunities that are not credible are those for which the yard is missing core competencies necessary to compete. The first step is to examine this portfolio and begin to develop a strategy for maximizing the set of core opportunities. What strategic responses are necessary to convert stretch goal opportunities into core opportunities, thus maximizing the potential to win orders?

The main point, as illustrated in figure 5.1, is that different product mixes will likely require different capability mixes. While a broad skill base will be shared among different product mixes, those capabilities which must be distinctive rather than core or routine will differ. Examples include the relative complexity of different ship types, the materials used, the level of outfit vs. steelwork, cycle time pressures, and so on. To establish goals and objectives without first understanding the product market and its pressures is not effective, because it is not likely that the goals and objectives will support any particular set of products well. It may help to improve the shipyard, but not in a focused way which supports competitively winning orders. Market requirements can first be examined at a high level to determine gross performance gaps. This can be followed by a more detailed exploration of the needs of an anticipated product mix.

5.2 ANALYSIS OF THE GROSS PERFORMANCE GAP

Use of the "compensated gross ton" (CGT) as a metric for establishing market requirements and relative shipyard performance has been popularized recently. This serves as a mechanism for establishing high level or gross performance gaps. The history of the metric is provided in NSRP 0434 "Requirements and Assessments for Global Shipbuilding Competitiveness." [Storch et. al., 1995, p.23] The concept of the compensated gross ton has its roots in an agreement between the Association of West European Shipbuilders (AWES) and the Shipbuilders' Association of Japan (SAJ) in 1968. The present concept and mechanics of calculating the CGT were established and adopted in 1984 by the OECD, AWES and SAJ. The compensated gross ton is equivalent to the gross tonnage multiplied by a coefficient established by consensus of the OECD, AWES and SAJ for a variety of ship types. A list of such coefficients has been published. Recently, efforts have been made to develop coefficients for military ships as reported in NSRP 0434. This coefficient is intended to adjust the gross tonnage for complexity. The intent is to allow CGT to be used as a proxy for shipyard output regardless of the ship types. The concept is that this allows a shipyard to be defined in terms of its costs per CGT. Constant cost curves for dollars per CGT can be established by disaggregating the metric into two components, namely cost per employee year and employee years per CGT. [Birmingham, Hall, Kattan, 1997, p.3] A standard practice for calculating costs per employee year has been developed.

> The costs should exclude those for the direct raw materials attributed to specific contracts and concentrate on the added value (i.e. the remainder making up the total operating costs for the company.) This is calculated by summing the following totals:
>
> - wages paid to all employees, including overtime and bonuses,
> - costs for all subcontractors,
> - social costs of employing workers,
> - costs of materials and services to run the business (not chargeable to specific contracts),
> - overhead costs, and
> - cost of supply-and-fit type subcontracted items [Birmingham et. al., 1997, p.2]

The product of these terms is $/CGT and a plot utilizing each term for an axis results in curves of constant $/CGT. Particular shipyards can identify where they lie on such a plot. They can also use this tool to estimate where their competition is located relative to their performance. Finally, different product types will generally have an estimated market $/CGT associated with them. Thus a shipyard can identify, at a very high level, where it is relative to its anticipated products as well as its competition. Many consultancies are busy assisting shipyards with this activity at this time.

Figure 5.2 illustrates how gross performance can be tracked against the $/CGT isolines. In this example, two competing shipyards are shown to exist on the same isoline. One of these is a low cost, low productivity producer able to compete at a given $/CGT level and the other is a high cost, high productivity producer competing at the same $/CGT level. The first relies on its lower costs and would tend to have a higher manning level and/or longer cycle times as exhibited by its emp. yr./CGT and $/emp. yr. The second would be representative of a yard with fewer personnel and a higher degree of automation. The dashed isoline might be considered to represent the $/CGT the market will bear for a given product type. The second solid line might be representative of a third shipyard's $/CGT performance. The positions on this plot relative to the market $/CGT and competition reflect a performance gap at a high level. The tangent to an isoline at the position of a particular shipyard upon it is representative of the break-even strategy or performance gradient, the minimum ratio of emp. yr./CGT to $/emp. yr reduction that must be maintained to move to a lower $/CGT performance. Thus this tool provides a mechanism for exploring high level strategy and performance gaps. A shipyard should have some reservations regarding the results. The first of these is that the coefficients used to convert GT to CGT are based upon consensus and do not necessarily represent the true complexity of a given ship. The second is that this model only addresses the product value proposition, and therefore the competitive environment, in a limited way. The model addresses cost and indirectly time, measures performance as cost and deliberately discounts the materials market.

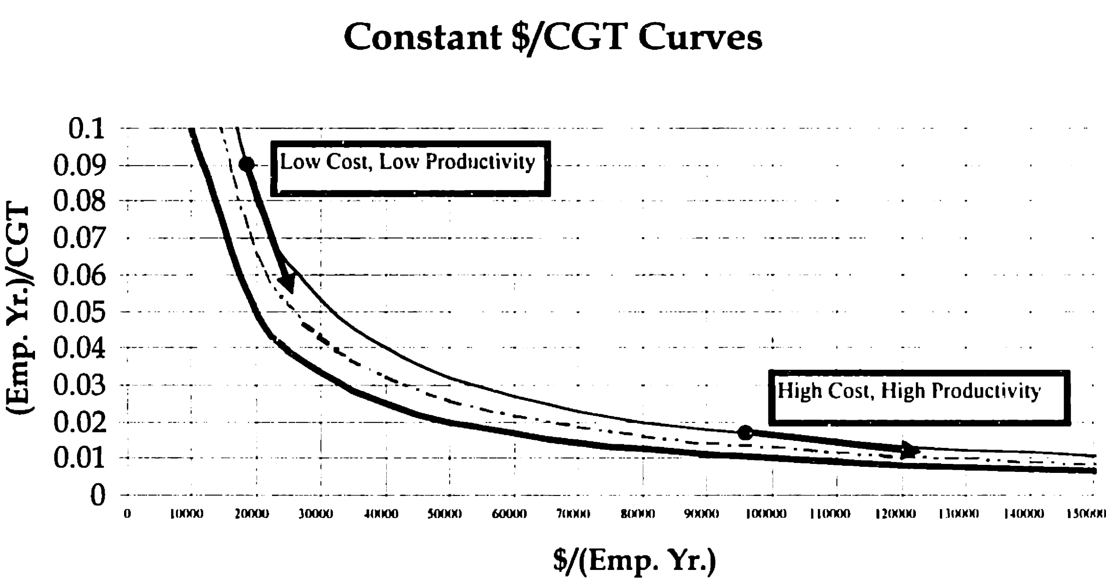

FIGURE 5.2 - $/CGT

Having established at a high level what shipyard performance is relative to competitors and market expectations, and having established the anticipated product mix, a product analysis can provide additional insight into the required strategic responses to address the identified market. A product analysis seeks to identify families of interim products for each of the types of vessels in the product mix and associate processes and capabilities with them. The approach explores how each product type relates to the competitive environment and provides the foundation for developing a competency map. The analysis groups interim products by production stages and processes. The result is a:

- coding of families of interim product types
- hierarchical interim part tree for each interim product family
- identification of processes associated with each interim product type
- additional refinement of the target product mix and identification of commonality

5.3 COMPETENCY MAPPING AND BENCHMARKING

The previous steps identified performance gaps at a detailed level, and subsequently identified interim products and processes associated with a target product mix. The next step is to develop a competency map (as defined by Vollmann, 1996) as described in Chapter 2.0. The competency map links competencies, capabilities, processes and resources back to strategic responses to the competitive environment. The approach is consistent with the utilization of the Analytic Hierarchy Process, to be described in the next chapter. It is also consistent with Keeney's observations regarding "value focused thinking", Ackoff's methods, and Hoshin planning. The competency map will ultimately form the benefits component of the decision model developed in this research.

Having identified the product mix and competitive environment, one needs to examine the elements of that environment and establish what the pressures are, existing or anticipated, to which the organization must respond to compete. The steps taken so far in the identification stage of the framework are all aimed at facilitating this. The answers to that question constitute the high level strategic response of the shipyard. The competency map provides a means of structuring the deployment of that response throughout the organization. Figure 5.3 provides an example of how the competency map is structured with respect to one of the elements of the competitive environment. Product analysis, and benchmarking (both internal and external) as discussed in Chapter 4.0 and several recently published technology surveys, contribute to the identification of capabilities, processes, and resources required to support a given set of strategic responses associated with an environment defined by a particular product mix. In the language of Keeney, the competency map forms a "fundamental objectives hierarchy", while the subsequent identification of alternative proposals forms the associated "means-ends hierarchy." [Keeney, 1992] A shipyard can use the concept of the competency map and go as low in the map as required to set meaningful and measurable targets and goals which can then be acted upon.

A shipyard could develop a single competency map if there is sufficient commonality between ships in the product mix. Multiple connected hierarchies could be developed in cases where the ships require different responses. The hierarchical representation structures the problem in such a way as to visibly link proposals to the shipyard's competitive strategy. It also permits structured decision analysis to be performed through pair-wise comparisons of elements of the hierarchy, including prioritization of the products in the mix at the top of the hierarchy. The analytic hierarchy process, described in Chapter 6.0, can be used to prioritize and synthesize the ship type hierarchies based upon marketing priorities. Competencies, capabilities, processes and resources can be pair-wise compared and prioritized based on internal and external benchmarking and the definition of performance gaps. Metrics such as the S/I index discussed in Chapter 4.0 could be used for this prioritization. Finally, the hierarchy permits lower level maps to be developed from higher level ones facilitating discussions related to specific departments and groups, and the targets and goals required to support elements of the map.

After developing an initial competency map, technology surveys or benchmarking can be used to refine the hierarchy and establish specific objectives and goals. Surveys serve to identify performance gaps. These gaps can be internal with respect to expectations and can be based upon expert judgment and actuals with respect to importance and strength of capabilities as was the case in the survey conducted as part of this research. Surveys can also be external with respect to the competition, seeking to establish relative strength for the elements of the competency map. This activity helps to classify capabilities and processes as distinct, core or routine as described in Chapter 2.0. A flurry of recent activity by a number of consultancies and shipyards has resulted in a standard template for a technology survey (discussed in NSRP 0453) which can serve as a starting point. Ultimately the objective is to obtain information that relates directly to elements of the competency map.

When analyzing performance gaps it is critical to look at not only the intensity of the gap, but the anticipated trend and the importance of the parameter. This is illustrated in Figure 5.3. One could prioritize based upon the ratio of strength, or intensity of the gap, to importance to the competitive environment. By examining the trends, it should be obvious that improvement will be required continuously since the competition is also improving.

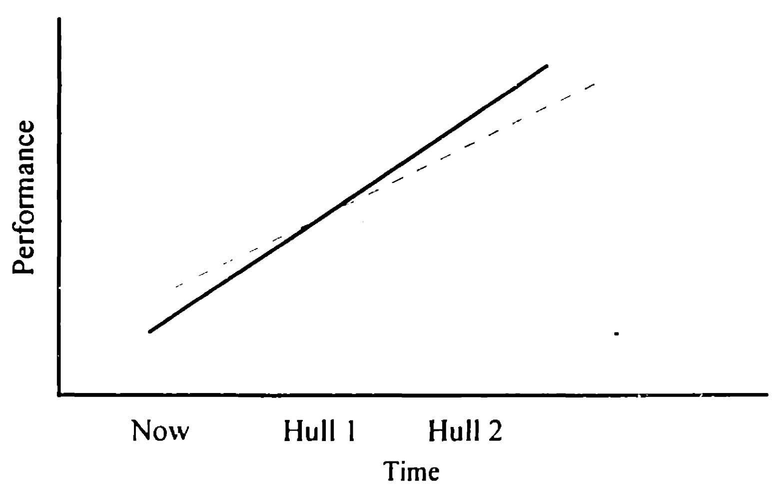

FIGURE 5.3 - PERFORMANCE GAP TREND

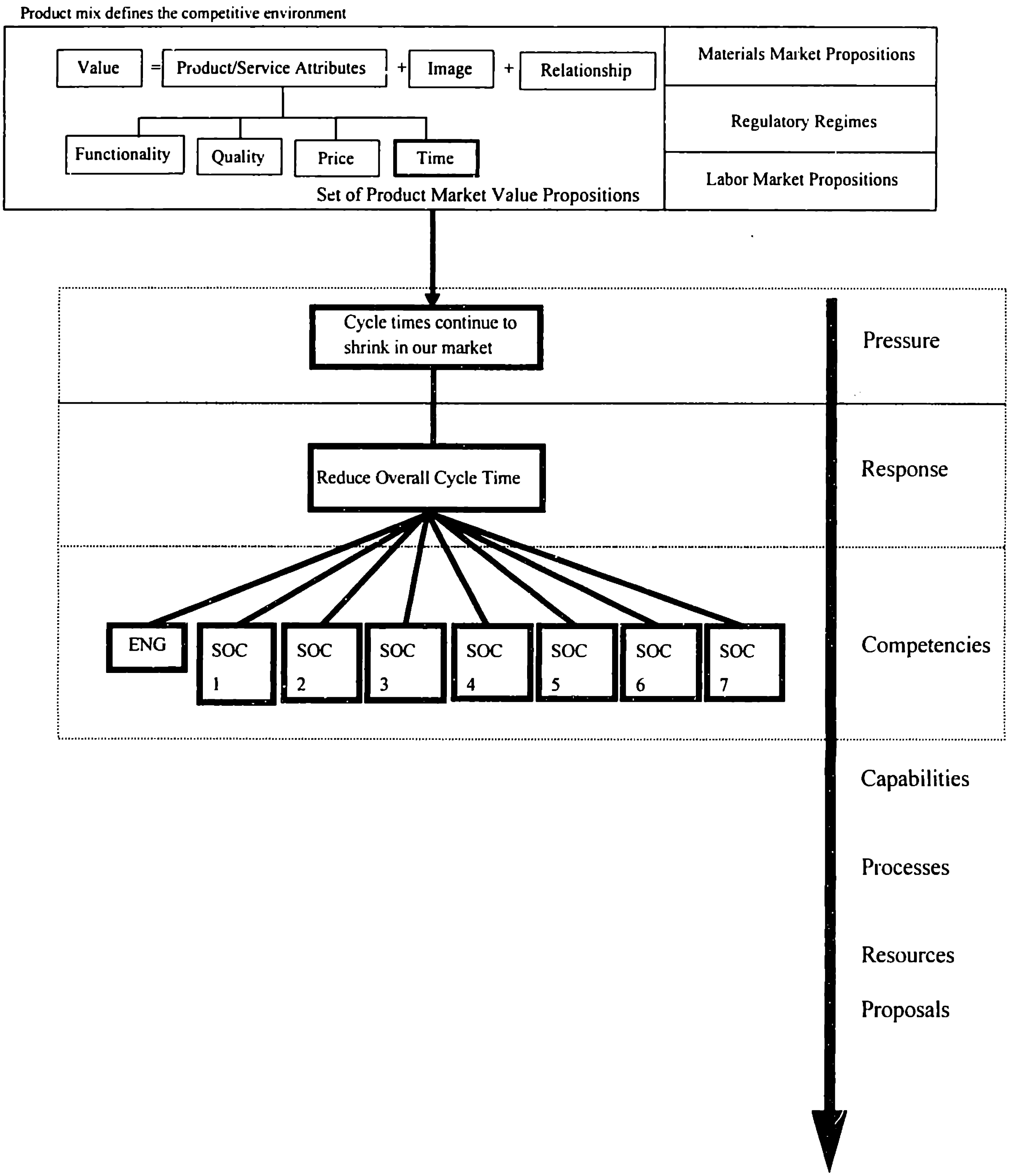

Figure 5.4 - Competency Map

To set goals, targets and measures one must define a set of attributes or metrics. Keeney defines three types of attributes. These include natural, constructed and proxy attributes. Natural attributes are in general use with common interpretation, such as man-hours for a given process. Constructed attributes are developed specifically for a given context and may combine multiple natural attributes. Constructed attributes generally associate a verbal descriptor with a quantitative scale. An example would be the five technology levels of the technology survey of NSRP 0453 or the organizational readiness scale of McCarthy presented in Chapter 2.0. A proxy attribute is used when a parameter of interest cannot easily be measured. An example might be man-hours of production rework as a proxy for engineering quality. Shiba suggests that stretch goals should be challenging but persuasive. They should be associated with dates or hulls and a measurement schedule and plan should be developed to enable tracking and corrective action. As will be discussed in Chapter 6.0, it is also important to set thresholds or a shipyard policy regarding what constitutes reasonable or feasible proposals to be considered. This is required to set up a screening process for limiting detailed and time consuming evaluation to only those proposals that are feasible and non-inferior.

Consideration of measurable goals, objectives and thresholds will also help to refine and improve the competency map. A multitude of brainstorming and creativity-enhancing techniques exist for expanding and improving the hierarchy in a group setting that may include division managers or department supervisors for example. Keeney suggests that fundamental objectives, and therefore their associated goals, should be:

- Essential
- Controllable
- Complete
- Measurable
- Operational
- Decomposable
- Nonredundant
- Concise
- Understandable

Having established elements of the hierarchy and goals, one can finally begin identifying or creating design improvement proposals which support success within a given competitive environment. As was discussed in Chapter 3.0, at the concept design stage the identified fundamental objectives and goals should be made integral to the design/Build Strategy. In follow on design/production phases proposals should be reviewed to contribute to the goals specified in the design/Build Strategy according to a schedule also made explicit in the design/Build Strategy. This is necessary to manage expectations, a key component to managing change as discussed in Chapter 2.0.

The process of actually creating alternatives is associated with the Production Engineering function as described in Chapter 3.0. In Chapter 4.0 the existence of a

Production Engineering function was suggested to be best practice. Sources for proposals include lessons learned during design such as through value analysis, lessons learned during production, and ongoing research associated with time/cost saving technologies.

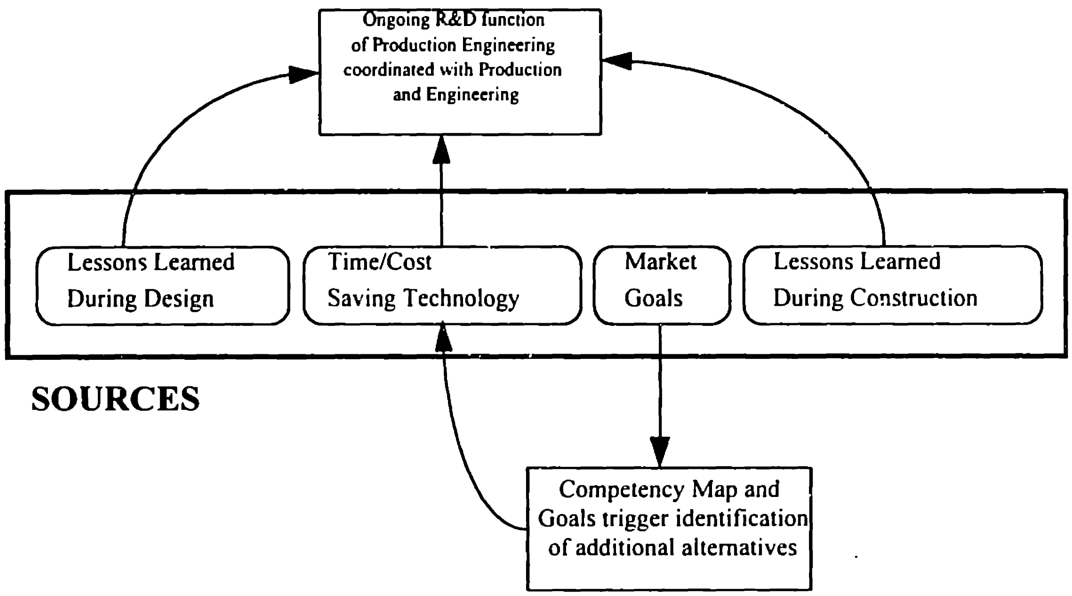

FIGURE 5.5 - CREATION OF ALTERNATIVES

The structure of the hierarchy assists in counteracting cognitive biases, anchoring, and constrained thinking. Keeney recommends a number of ways that cognitive roadblocks can be mitigated so that existing alternative proposals can be reviewed and improved. These recommendations support the conclusions of Chapter 2.0 and the industry survey that a participative approach is preferable and that facilitators with core competencies in creative thinking and problem solving who are outside the "daily grind" are valuable.

- Brainstorm supporting proposals for each goal
- Brainstorm proposals for pairs of goals (and so on)
- Examine how alternatives might change if attributes/metrics used change
- Examine how alternatives might change if goals/thresholds were varied
- Explore common properties of good alternatives
- Use generic categories for alternatives (such as "structural details" and "pipe joints")
- Remove constraints on resources, timelines, or risk
- Encourage long term thinking - what learning opportunities are important
- Examine consequences and improve performance for all stakeholders
- Obtain participation of stakeholders associated with elements of the hierarchy
- Avoid tendency to anchor in past practices

5.4 SYNOPSIS

The identification procedure described in this chapter has been developed based upon lessons learned from the industry survey and the literature. In Chapter 2.0 the history of the quality movement was reviewed and it was demonstrated that recent attention has been focused on mechanisms to align improvement activities with strategic objectives. The industry survey presented in Chapter 4.0 supported that conclusion. The proposed identification approach described in this chapter addresses this issue.

The input to the identification stage is competitive pressure manifested as perceived or actual performance gaps. The output is a set of design improvement proposals focused upon strategic responses to the competitive pressures. The identification stage of the design change framework consists of a number of sub-elements aimed at first making the competitive environment explicit, followed by establishing objectives and goals, followed by identifying alternative proposals that support those goals. The theory and practice of value focused thinking and other methods aimed at eliminating or reducing cognitive biases are used to insure that a broad range of proposals is considered and to improve their performance relative to the identified goals. The output of the identification stage signals entry to the evaluation stage, which is the topic of the next chapter.

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6.0 ALTERNATIVE METHODS FOR EVALUATING AND PRIORITIZING PROPOSALS

It was previously illustrated in this research that initiatives to reduce production costs and cycle time by implementing design changes have had notoriously mixed results. Clearly, change proposals have not been managed well. "To manage well, you need both to make good decisions and to implement them efficiently. You are not managing well if you make bad decisions that you implement well or if you make good decisions that you implement badly." [Adizes, 1992, p.7] In this chapter and the next, the focus is on quality decision-making and the development of appropriate decisionmaking tools. A 1989 Ship Design for Producibility Workshop concluded that "...in most of the past Navy efforts, there was no systematic approach to review, no means of judging cost/effectiveness, and no decision criteria as a basis for selecting producibility concepts. The approach of treating producibility in an unstructured, subjective manner is inefficient, and less than fully effective." [Keane, Fireman, 1992]

The quality of management is a function of the quality of decisionmaking and the efficiency of implementation. Quality decisionmaking is in turn a function of its effectivity and its efficiency. The effectivity of a decision is reflected by the degree to which it furthers the goals of the organization. "The quality of a decision should be evaluated in light of the impact it has on the system for which it was made." [Adizes, 1992, p.14] Equal emphasis must be placed on the decision alternatives and the values or objectives which will be used to evaluate these alternatives. "The relative desirability of consequences is a concept based on values. Hence, the fundamental notion in decisionmaking should be values, not alternatives." [Keeney, 1992, p.3] In this chapter we are concerned with the means by which quality decisions can be made with respect to design change proposals, and how these proposals can most efficiently and effectively be evaluated with respect to their impact on the multiple values and objectives of the organization as a whole. Values, or strategic objectives, must be reflected through the evaluation criteria and the weights associated with these criteria. An effective decision analysis tool is one which recognizes that "what is missing in most decisionmaking methodologies is a philosophical approach and methodological help to understand and articulate values" and to align decisions with these core strategic values. [Keeney, 1992, p.8] It would be desirable for the decision model to structure the problem such as to facilitate the identification of core values and objectives, and therefore suggest additional alternatives which may not have been obvious. In Chapter 5.0 the identification of proposals utilizing value focused thinking was discussed. A competency map and hierarchical representation was used to develop strategic goals and objectives. In this chapter these goals and objectives form the basis for a decision analysis model for evaluating and prioritizing the proposals.

With respect to decisionmaking, efficiency refers to the ease of use of the decisionmaking methodology and the speed with which decisions can be made. It is hoped that the model developed in this chapter will recognize and address the fact that "there is a considerable gap between Operations Researchers and managers. The OR people provide management with sophisticated but difficult to use instruments, managers expect streamlined and easy to use tools to support their project selection process." [Fahrni & Spatig, 1990, p.155]

6.1 CONTEXT

In this chapter a decision model is developed as a tool for the evaluation, prioritization, and decisionmaking phases of the design change framework that was presented earlier in this research (see Figure 6.0). This model is developed through an extensive review of the literature regarding evaluation techniques, an analysis of feedback obtained through the industry survey and lessons learned from supporting theory in the literature. This material forms the basis for identifying an appropriate model form and its associated evaluation criteria and parameters.

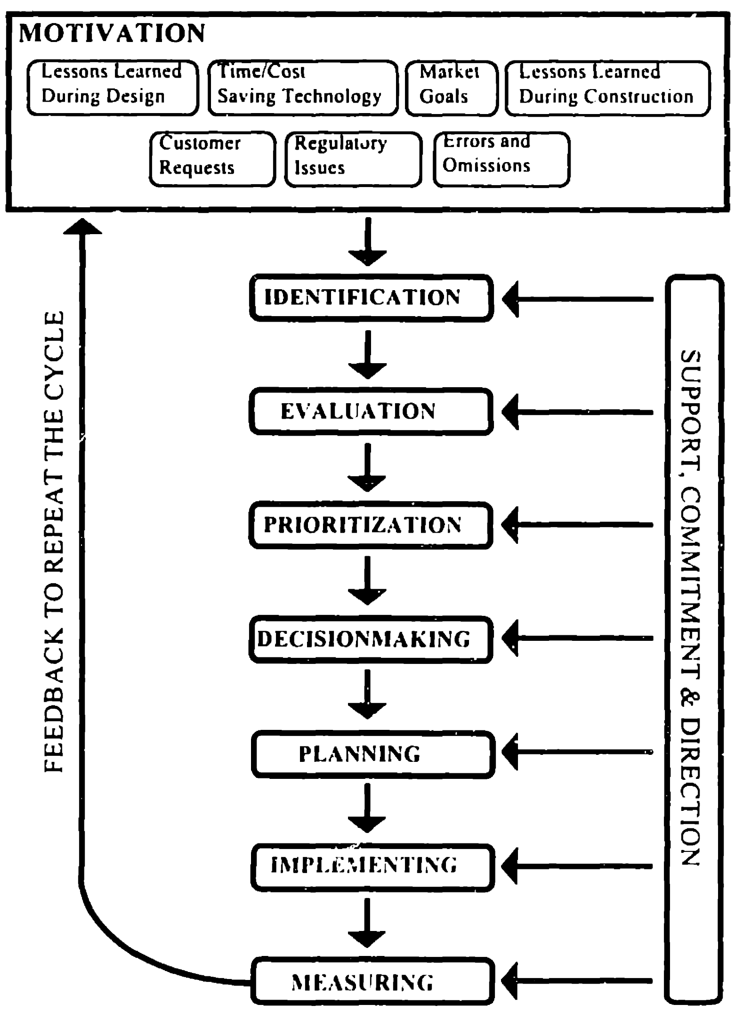

FIGURE 6.0 - DESIGN CHANGE FRAMEWORK

The results of the industry survey demonstrated that evaluation and prioritization of proposals are key elements of concern when managing change. For this reason, any study of Design Change Management must necessarily examine alternative evaluation approaches and decision model forms. Research conducted as part of this study at a number of shipyards suggests that the evaluation techniques used in practice are generally limited to traditional engineering economy and simple checklists or scoring models. These findings are similar to the results of empirical studies conducted by numerous researchers in the fields of decision science and operations research. "Their findings suggest that conceptually simple models such as checklists and scoring approaches are widely used, while more sophisticated modeling techniques, e.g. mathematical programming, have so far had little impact." [Fahrni, Spatig; 1990, p.156] Interviews of personnel at a number of shipyards also suggested that the evaluations were often considered suspect and that there was a general sense that the results did not always reflect a high level, integrative shipyard strategy. In this chapter, a broad range of tools available for evaluating proposals are presented along with their axioms and assumptions. These tools are subsequently critiqued for the purpose of pointing out the strengths and weaknesses inherent in each.

Every approach presented will be shown to have a number of shortcomings, some more numerous than others, and for this reason it is necessary in any decision modeling problem to identify the best approach for the problem at hand. After the tools are presented, the special needs of prioritizing change proposals are discussed and these tools are placed in the context of these needs to determine which approach or approaches are best suited for this problem. Finally, a decision model for evaluating and prioritizing design change proposals is suggested.

6.2 ALTERNATIVE EVALUATION TECHNIQUES AND DECISIONMAKING MODELS

Decision making models can be categorized as either continuous or discrete. Discrete models are those which seek to evaluate a number of specific identifiable alternatives. Continuous models optimize a solution subject to constraints when there are an infinite number of feasible solutions. In managing design change proposals, we are interested in discrete models used to evaluate a set of discrete proposals.

The tools presented will fall into two broad categories, those that evaluate over a single attribute and those that evaluate over multiple attributes. Single attribute evaluation techniques include the general classes of Engineering Economy, so-called "Primitive" Models, Formal Decision Analysis, and Decision Analysis with Utility Theory. Multiple attribute evaluation techniques include the so-called "Elementary" Methods, Multi-Attribute Utility Theory, and Priority Theory (or the Analytic Hierarchy Process). Of particular interest are the multi-attribute models, as any evaluation of design changes must consider a variety of parameters. In the discussion of the multiple attribute tools will be issues associated with independence and dependence among the model parameters.

6.2.1 Single Attribute Analysis

6.2.1.1 Engineering Economy Criteria

Traditionally, the techniques used to evaluate change proposals fall into a class of analysis known as Engineering Economy. Engineering Economy is concerned with evaluating the economic merit of projects by examining projected cash flows. Application of engineering economy criteria is conceptually simple, but very difficult in practice. A principal problem with evaluating alternatives using traditional Engineering Economy is that these approaches ignore issues associated with uncertainty and risk. They also fail to adequately account for intangible costs, intangible benefits, and differences in the scales of the alternatives themselves, their benefits or their costs.

As mentioned, they fail to address more than one criterion, or attribute, in a single evaluation. The data collected through the benchmarking questionnaire demonstrates that a variety of criteria are important to shipbuilders when evaluating design change proposals as was illustrated in Chapter 4.0.

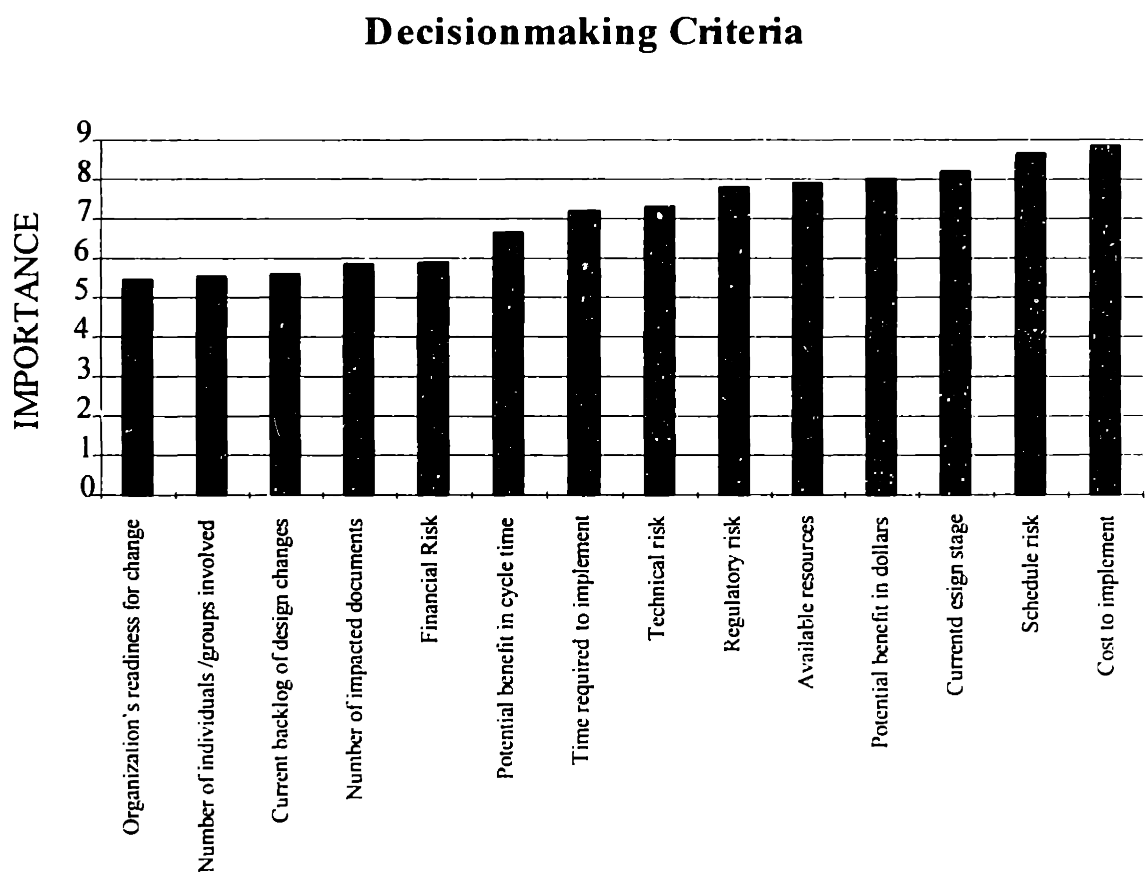

FIGURE 6.1 - MULTIPLE CRITERIA

Economic evaluations are difficult to perform in practice for a number of reasons. One of the significant difficulties with economic evaluation is that evaluating and projecting true costs and benefits can be very difficult for anything but the simplest of real world problems. The more uncertainty that is associated with a scenario and industry, or the longer the project life cycle, the greater this difficulty. Even if the project life is brief, assessing benefits and costs in detail can be difficult if the environment is complex and those performing the evaluation cannot realistically assess factors across the entire organization within a decision-maker's window of opportunity. The traditional techniques of Engineering Economy assume that all costs and benefits can be quantified in a tangible way, that they are quantified to the same scale (dollars), and that this scale is also a directly linear measure of value. It should be noted that all of the engineering economy criteria will generally result in different rankings for the same alternatives. For all these reasons, decisions presented as based on purely economic evaluations of alternatives are often suspect. This is why they are rarely relied on in practice. A decision-maker will use the information provided by those performing an economic evaluation, and then couple that information with numerous other internalized criteria to make a go/no-go decision. These single attribute techniques are presented here first because they are common, and second because they are utilized as part of more rigorous approaches.

Traditional engineering economic approaches to evaluating proposals include Net Present Value, Benefit/Cost ratio, Internal Rate of Return, Cost-Effectiveness Ratio and Payback Period. All of these are concerned with evaluating discounted cash flows and providing a basis of comparison between alternative projects and some minimum standard. Cash flows are discounted for the time value of money using an appropriate discount rate. Determining what discount rate is appropriate is one of the difficulties associated with these types of analysis. It is not a trivial problem, as the choice of discount rate will have a dramatic impact on the evaluation. The twin facts that the choice of discount rate is a matter of judgment and can have rather enormous economic and technical implications make this selection highly controversial. [de Neufville, 1990, p.223] It is beyond the scope of this research to examine the selection of discount rates in detail. For the sake of continued discussion, the discount rate that is appropriate is the one which represents the rate of return that would be exceeded by all the investments that the company would make before it ran out of budget to invest. It is a rate higher than the interest it would receive by lending its money. The minimum standard to which alternatives are compared utilizing various criteria is established by making assumptions regarding all the alternatives that have previously been available for investment, and the alternatives that are expected to exist in the future, and what their measures of merit would be on average with any particular criteria.

The Net Present Value (NPV) of a project is the difference between the discounted benefits and costs assigned to the project by the evaluator. Anything with an NPV greater than zero represents an alternative which has a higher return than the discount rate. A project with an NPV equal to zero would still be profitable, but not as profitable as those projects which formed the basis for establishing the discount rate. As a lone criteria for go/no-go decisions for proposed projects, the NPV does not provide sufficient practical information to make decisions. For example, the NPV criteria does not indicate the amount of effort (or investment) required to achieve the NPV. Two projects may have identical NPV's while one of them requires significantly less investment (project A), making it more attractive. This is because investing in the more expensive alternative (project B) has a hidden opportunity cost. This opportunity cost exists because by investing in project B, one is losing the benefits that could be achieved by investing in project A instead and then further investing the difference in their "real" costs. In order to make the NPV criteria effective, one needs to count these opportunity costs as part of the cost assigned in the NPV calculation. Opportunity costs are even more elusive to the evaluator in industry than the "real" costs are, which themselves are difficult to identify. In addition, NPV provides no information to the evaluator regarding the life of the project, and the timing of the returns. Thus NPV is typically a good evaluation criterion only when alternatives are similar in levels of investment, difficulty, and timing.

Benefit-Cost Ratio (BCR) analysis utilizes the ratio of the discounted benefits to the discounted costs as a criterion to establish that an alternative is attractive and also to provide an indication of the relative levels of investment required on a normalized basis. Alternatives with a benefit-cost ratio greater than one are attractive because the benefits exceed the costs, and the ratio provides an indication of the benefits achieved per unit of investment. As a lone criterion for decision-making, the BCR provides a greater range of information than the NPV in a single unit of measure and is therefore more easily applied to ranking of alternatives. Even so, the BCR is still problematic. The BCR does not provide an indication of the total expected profit, nor the total required investment. Thus, while it provides more information than the NPV, it is still not appropriate as a lone criterion. Given two projects with the same initial investment, BCR shows bias towards projects with low recurring costs even in situations where the total NPV is higher for the project with recurring costs and the net each year is higher for the project with recurring costs. BCR has been manipulated through semantics to address this problem. For example, there is controversy regarding the assignment of "dis-benefits" instead of costs.

The strict definition of BCR would require the total discounted benefits to be divided by total discounted costs. It has been argued that the recurring costs should be counted as "dis-benefits", since they are immediately covered by the benefits in the same period, and subtracted from the benefits rather than added to the costs. There is ambiguity in this type of assessment, neither approach necessarily resulting in an optimal solution. Once again, unless alternatives require similar investments over similar timelines, BCR does not offer clear direction. A criterion related to BCR is the Cost-Effectiveness Ratio (CER). This is a similar criterion which assesses benefits in units other than dollars, typically physical units of measure. It is intended to simplify analyses which involve units that are difficult to quantify as dollars. It still requires that all benefits be measured according to the same units. It represents a very different type of analysis, since the benefits and costs are not convertible. Thus, there is no way to tell if the costs were "worthwhile". The costs cannot be compared directly to the benefits. Typical applications would be to safety, cycle time reduction, and quality improvement where a single measure of merit other than dollars is of interest, and it has already been decided that a certain level of investment is to be made in one or several alternatives. CER will suggest the best alternative provided one is committed to investing. It cannot tell you if investing is appropriate in the first place.

A fourth criterion which is often employed is the Internal Rate of Return (IRR). The IRR is the discount rate for which the NPV of a particular investment would be zero. The IRR represents the "return on investment", and is a readily understandable measure of merit. The IRR also has the significant advantage that it does not require the determination of a discount rate. Recall from the earlier discussion that determination of the appropriate discount rate is a matter of judgment often plagued with controversy, and the results of NPV and BCR are very sensitive to the discount rate chosen. A major problem with the IRR is that it can be ambiguous. A single alternative can easily have more than one IRR! This often happens when a project has significant "closure costs". In these cases, some low IRR results in an NPV of zero since the closure costs are not discounted greatly and tend to balance the benefits. At some high IRR, there will exist an NPV of zero since the closure costs are discounted greatly, but so are the benefits over time and therefore balanced by the initial investment.

The final traditional engineering economy criterion to be discussed here is the Payback Period (PP). The payback period represents the time it takes for the undiscounted annual benefits to equal the initial investment assuming that the benefits are in equal yearly installments. Thus, this criterion seeks to compare alternatives with respect to the time dimension while the other criteria were interested in overall benefits. The PP can be considered to be a criterion that is related to risk. In general the further into the future one needs to project to obtain benefits, the greater the risk. The PP is related to the BCR in that it is inversely proportional to the BCR. Thus a high BCR implies a short PP. While of interest as a criterion, it does not serve well as a lone criterion since it implies nothing regarding total net benefits or optimal solutions. A ranking of alternatives by payback period does not provide a decision-maker with the information required to decide what to invest in, but can be used to eliminate alternatives which may be undesirably risky because it takes too long to recover the investment.

As was mentioned earlier, all the criteria discussed so far result in different rankings. All can be easily manipulated as they are sensitive to matters of judgment such as the discount rate and semantics regarding costs and benefits. Thus, while emphasizing quantitative analysis, they can still be quite subjective. Each is concerned with a different aspect of evaluating the alternatives. All are of interest to the evaluator, and so no single criterion can be relied on in isolation. Only one of the criteria discussed, the CER, can handle intangibles, and it has limited application. Typically, more than one type of evaluation must be done together with sensitivity analysis. Sensitivity analysis is required because the real world is uncertain. Engineering Economy criteria are deterministic and depend on the assumptions made. Sensitivity analysis is required to evaluate these assumptions and address risk. A decision-maker utilizes that information and processes it based on internalized criteria in conjunction with other criteria that are not addressed above. Early efforts to address risk and uncertainty resulted in a group of techniques collectively referred to as "primitive" decision analysis methods.

6.2.1.2 "Primitive" Models

There are a number of approaches to evaluation that are often referred to as "primitive" models. [de Neufville, 1990, p.298] They are referred to as "primitive" because they are generally considered to be inferior to formal decision analysis involving decision trees and probability assessment by practitioners of Utility Theory. These decision tools include the Laplace criterion, the Maximin/Maximax criteria, and the Regret criterion. These tools seek to improve upon engineering economy criteria by utilizing engineering economy criteria within an additional structure known as a "pay-off matrix". This helps to structure the problem and evaluate alternatives under uncertain conditions, or various "states of nature" that might exist. The problem becomes one of evaluating the alternatives based on an engineering economy criteria assuming that each state of nature exists.

In the Laplace approach, a pay-off matrix is constructed consisting of one axis defining the alternatives to be evaluated and another axis defining the "states of nature" or uncertain conditions that may exist that alter the value of the alternatives. This model assumes that each state of nature is equally likely, and that the best alternative is the one with the highest expected value. The Laplace model is often criticized by the decision analysis community as being arbitrary because the rankings are altered by the introduction of "trivial" or "irrelevant" alternative states of nature. This criticism is unfortunate, because while the Laplace criterion is problematic in a number of ways, each example cited by texts and papers regarding this particular flaw has not appeared fair to the author of this research. Typically, the additional states of nature are not really trivial. They provide additional information about the problem which should rightly alter the rank. For example, the addition of duplicate states of nature with different titles (in other words, different states of nature which result in payoffs for each alternative identical to those of another state of nature) will alter the rankings. This appears reasonable rather than a flaw, as the presence of an additional state of nature should alter the expected value of each alternative if it really is a different state of nature. Its addition represents new information about the environment and means that the original structure of the problem was wrong. The update to the rankings is analogous to the revision of probabilities using Bayes Theorem or likelihood ratios when new information about a problem exists. If it is actually a duplicate state of nature, it should not be listed in the problem twice. A related decision making approach is referred to as the "Hurwicz's Principal." [Carter, 1992, p.61] This approach defines two states of nature, one representing the best outcome and a second representing the worst. The decision-maker weights the two states of nature to reflect a level of aversion to risk. For example, the outcome of the best state of nature may be assigned a weight of 80%, with the worst a weight of 20%. The score is then the sum of the weighted outcomes of the states of nature. The drawbacks of the Laplace and Hurwicz criteria are that they assume each state of nature to be equally likely (which is rarely true), and that they only evaluate a single attribute of the alternatives (rarely useful in practice).

The Maximin and Maximax criteria are related. The former seeks to maximize minimum benefit, the latter seeks to maximize the maximum benefit. One appeals to those who are risk adverse, the other appeals to those who are more optimistic. These criteria utilize the same pay-off matrix as the Laplace criterion, but evaluate only against a single entry for each alternative. These criteria make no assumptions about probabilities and seek out alternatives based solely on the minima or maxima of the outcomes. The Regret criterion is related to the maximin and maximax. This criterion seeks to minimize the maximum delta between the benefit attributed to any alternative at any state of nature and the "best" alternative for that particular state of nature. This criterion is particularly criticized in the decision analysis literature. One source of this criticism is that the evaluation of any particular alternative is dependent on the other alternatives. This is not a fair criticism since the approach is defined as seeking to minimize a value which is dependent on the alternatives. While it might be argued that this is not a rational way to make a decision, the model is consistent with its objectives when it alters the rank based on changes to the alternatives. In addition, it is criticized because the evaluation can be made to look intransitive. For example when pairs are evaluated by themselves, A can be preferred to B, B to C and C to A. This criticism is not valid because it is never appropriate under this model to evaluate pairs alone. One must perform the evaluation across the entire set since regret is defined across the entire set, and under these circumstances there is no intransitivity. As long as the entire set is considered in the evaluation, transitivity will hold. As was the case with the Laplace criterion, the problem with this criterion is not that the rankings are arbitrary (within the context of the assumptions made) but instead that they are not of particular interest or believed to express the preferences of "logical" people. Like the Laplace criterion, these approaches would not appear to be particularly useful since they evaluate against a single attribute of the alternatives and ignore the actual likelihood of the outcomes.

6.2.1.3 Formal Decision Analysis

While the primitive models structure a problem as a pay-off matrix, formal decision analysis structures a problem as a decision tree. A key distinction between the decision tree and the pay-off matrix is that the decision tree can identify the outcomes of situations over multiple periods. Another distinction between formal decision analysis and the primitive models is that probabilities are assigned to alternative outcomes and utilized in assessing optimal choices (in the case of a single period of a decision tree) and an overall optimal strategy (in the case of multiple periods of a decision tree). The primitive models do not utilize probabilities, instead assuming that all of the outcomes are equally likely.

The decision tree is made up of decision nodes and chance nodes. Chance nodes are followed by branches which represent possible states of nature or outcomes. Decision nodes are followed by branches representing alternative decisions. Generally, one starts with a decision node, followed by alternative branches, followed by a series of chance nodes at the end of each branch, followed by branches representing the possible outcomes, which subsequently might be followed by additional periods of decisions or chances and outcomes. The outcomes are measured quantitatively, often in terms of engineering economy criteria. The objective of the formal decision analysis routine is to identify all the possible choices that can be made and the probabilities of all the potential outcomes of each. By doing so, one can calculate the expected value of each decision based on the possible outcomes of the decision and the probability of those outcomes. When more than one independent probabilistic parameter influences the outcome, joint probabilities may be used as long as outcomes for combinations of the parameters of interest can be determined. By calculating the expected values using integration rather than summation, probability distributions can be utilized.

The difficulty with formal decision analysis is that in addition to economic evaluation, one must assess the probabilities of events. It is this which makes the "primitive" models attractive to so many people, who wish to address risk without the added complexity of assessing probabilities. Identifying alternative states and assigning probabilities to these states is not a trivial problem. One must first identify the periods that are to be considered, then the alternative decisions to be made in each period, and finally the mutually exclusive and collectively exhaustive alternative states of nature that lead to outcomes from each decision. Probabilities of each outcome must be assessed. The outcomes themselves must be assessed under a common scale and used in the calculation, together with the probabilities, to determine the expected value of each possible decision.

In theory, if the probabilities can be readily and reasonably estimated, formal decision analysis should offer a ranking of alternative courses of action which is superior to that offered by the primitive models in a number of ways. First, the approach forces the analyst to structure the problem in such a way as to demand careful consideration of all the alternatives. Second, the choice is based on the most likely outcome rather than merely "hedging one's bets". This approach presumes that a decision-maker values the most likely outcome and is not just interested in minimizing the risk, which may not always be true. In reality, decisionmakers exhibit varying preferences for benefit, cost and risk as was discussed in Chapter 2.0 and demonstrated in Chapter 4.0. Formal decision analysis allows a number of influential parameters to be considered through the use of joint probabilities. Finally, this approach is well suited to problems which involve multiple decision opportunities and the formation of a strategy rather than a single decision point.

6.2.1.4 Utility Theory

So far, all the models presented require criteria to be measurable on a single common tangible scale, such as dollars. This is not always desirable, since not all important attributes can be measured on the same scale or easily converted from one scale to another. Examples would be cost and comfort in the evaluation of an automobile. Both have value, but comfort is not easily converted to a scale of dollars. The tools presented also assume that this tangible scale is directly and linearly related to the value of the alternative as perceived by the decision-maker. It is well known that non-linear relationships often exist which alter the "value" of a physical or tangible unit. One dollar does not always have the same value to a decision-maker. Diminishing marginal utility is one example of a situation in which there is a non-linear relationship. Value is a function of the circumstances. Utility theory seeks to establish a common scale which measures value in "utiles" for all attributes that are of interest. Utility theory also allows one scale, such as dollars, to be mapped into this scale of utiles with non-linear relationships accounted for through the creation of a Utility Function. This scale is then used in conjunction with probabilities through formal decision analysis to determine the expected utility of decisions.

In determining the utility function, several key axioms must be satisfied. The first simply states that for every possible pair of consequences of interest, the decision-maker will prefer one to the other or be indifferent between them. The second axiom insists on transitivity of preferences. That is to say that for three alternatives A, B and C if A is preferred to B and B to C then A must be preferred to C. This axiom is one of the more difficult ones to satisfy, as it requires consistency of preferences which is not always true in real life. The third axiom assumes monotonicity of the utility function. This implies that more of a good thing is better, which is also not always true in practice. For some situations more of a good thing can become bad. A fourth related axiom suggests that a higher probability of a benefit is better than a lower probability. A fifth axiom related to utility theory is that probabilities exist and can be quantified for each alternative outcome. The substitution or independence axiom of utility theory states that if a person places equal value on two possible outcomes, then these can be substituted for each other in any choice involving uncertain outcomes without changing that choice. This assumes that a person's preferences are linear with probability. Research has shown that this is generally not the case and that people exhibit non-linear preferences with respect to probability, especially in situations where an additional small unit of probability can be "purchased" to provide a "sure thing". This is known as the "certainty effect." These axioms, which appear rational and reasonable but do not always describe the real behavior of decision-makers, are "normative." They seek to describe how the best decision should be selected even though people do not always operate that way. In deciding to use utility theory, one is expressing a belief that rational people should behave as the axioms describe, and that the fact that they don't is a function of the idiosynchracies of decision-makers rather than shortcomings of the axioms.

> The essential practical questions raised by the controversy are: do we assume that the substitution axiom is so obviously rational that any behavior contrary to it is a mistake, however well informed and intelligent the person may be? If so we should somehow disregard some of the person's stated preferences, and substitute ones we deem correct. (This can be taken as being presumptuous, if not arrogant.) Or do we suppose that the axiom is sometimes deficient for some subtle reason and reject it - and consequently the utility function which depends upon this axiom - when people express contrary preferences? Logic by itself does not resolve this question. [de Neufville, 1990, p.366]

> No matter how intransitivities exist, we must recognize that they exist, and we can take only little comfort in the thought that they are an anathema to most of what constitutes theory in the behavioral sciences today...We may say that we are only concerned with behavior which is transitive, adding hopefully that we believe this need not always be a vacuous study. Or we may contend that the transitive description is often a 'close' approximation to reality. Or we may limit our interest to 'normative' or 'idealized' behavior in the hope that such studies will have a metatheoretic impact on more realistic studies. In order to get on, we shall be flexible and accept all of these as possible defenses, and add to them the traditional mathematician's hedge: transitive relations are far more mathematically tractable than intransitive ones. [Luce, Raiffa, 1957, p.25]

In many circumstances, the axioms appear to produce reasonable results. There are also many circumstances under which this is not the case, and the discussion of these is reserved for later when the Analytic Hierarchy Process (AHP) is introduced. As was mentioned early on, the choice of a decision making model is by no means obvious or trivial which is why this excursus has been undertaken in the first place.

The axioms allow the utility of an uncertain outcome to be stated as the product of the utility of the outcome if it were certain and the probability of the real outcome. The value of a risky scenario is then the expected value, or sum of the products of all the outcomes utilities and their associated probabilities. Therefore utility can be directly substituted within the structure of formal decision analysis.

The remaining question is how to measure utility and what such measurements mean. Utility is measured on a cardinal scale known as the ordered metric. Utility is a number on an ordered metric scale measuring the attractiveness of a consequence, or the state of satisfaction of a consequence. Zero on the scale is simply a reference point which could easily be some other number. This is analogous to temperature scales. Ordered metric scales and ratios of ordered metric scales have no inherent meaning. This is in contrast to the ratio scale which is discussed later as it relates to the Analytic Hierarchy Process. The ordered metric, and therefore utility, scale is defined by two arbitrary points. These are generally defined as zero representing the worst outcome (generally expressed as $U(X_*) = 0$) and one representing the best outcome ($U(X^*) = 1$).

Utility functions are developed by questioning decision-makers about their preferences for lotteries. The approach to this questioning could take two forms. One approach is related to certainty equivalents, the other to lottery equivalents. The certainty equivalent approach relates the utility of the certainty of obtaining an outcome with a lottery of obtaining the best and worst outcomes with some probability. This approach, while popular, has been shown to be faulty. Empirical evidence shows that measurements determined using different probabilities provide different results. This has been associated with the certainty effect described earlier. [de Neufville, 1990, p.381] The method also has been shown to propagate errors, since the results of one iteration of questioning are used to establish the next iteration. The lottery equivalent approach was developed to avoid these problems and is now recognized as the preferred method. This approach makes no reference to a sure thing, therefore avoiding distortions related to certainty effects. It also makes a series of independent assessments, none of which rely on the results of the first. In this approach, two lotteries are compared rather than a lottery and a certainty. A lottery consisting of a 50/50 probability of some outcome X_i and the best outcome X^* is set equivalent to another lottery of the best and worst outcomes with probability P_e. This is generally expressed as

$$(X_i, 0.50; X^*) \sim (X^*, P_e; X_*)$$

X_i is increased incrementally and the decision-maker is questioned regarding the appropriate probability P_e by gradually bracketing P_e until it is agreed to. Pairs of X_i and P_e will then define the utility function.

Construction of a utility function is not easy in practice. The psychometric considerations are often overwhelming. Numerous case studies have been reported with generally the same results. Professor Jonathan Bard of the University of Texas reported in the November 1992 IIE Transactions that "none of the respondents could make sense of the relationship between the posed lotteries and the overall evaluation process. Repeated coaxing was necessary to get them to concentrate on the gambles and to give a deliberate response. Experience seems to show that regardless of an individual's background, unless it includes extensive training in statistics, some amount of frustration is inevitable when trying to deal with low probability events." [Bard, 1992, p.119] While formal decision analysis with utility theory is of interest and represents a greater level of analytical rigor than the other methods described, it may be difficult to use in all situations for the reasons described.

6.2.2 Multi-Attribute Analysis

Multi-attribute analysis tools include the "primitive" or "elementary" Weighted Index criterion, Additive Utility model, Additive Preference Model, Extended Utility Model, Lexicographic Ordering, and Conjunctive/Disjunctive methods. These are labeled "primitive" and "elementary" by practitioners of Multi-Attribute Utility Theory (MAUT), another popular multi-attribute approach. In addition to the methods mentioned so far is the Analytic Hierarchy Process (AHP, sometimes called Priority Theory). The discussion regarding these type of analyses is of key importance, as the ultimate objective of this Chapter is to develop a tool for evaluating change proposals which incorporates a variety of parameters.

6.2.2.1 Elementary Models

Lexicographic Ordering is a simplistic approach that implies that all but the most important attribute (most heavily weighted) of a decision-making problem are insignificant except for the case of breaking ties between alternatives. In essence, it converts a multi-attribute problem into a single attribute problem. In this approach, the attributes are ranked in terms of importance. Next the alternatives are ranked based on the most important attribute. Only in the case of ties are lesser attributes used. This approach does not appear to have a defensibly rational basis unless there are order of magnitude differences in the importance of the most important attribute and the lesser attributes. This approach would also share all the problems associated with the primitive single-attribute evaluation techniques discussed earlier.

Conjunctive and Disjunctive methods seek to eliminate alternatives from consideration based upon minimum standards set against each of the criteria. First one sets a minimum standard against each criterion, or attribute. Second, one culls the list of alternatives based on these criteria. In the disjunctive case, the objective is to keep all alternatives that meet at least one criterion's minimum standard. In the conjunctive case, only those alternatives that meet all the minimum standards are kept. These approaches do not rank alternatives, nor do they define the value or preference for any alternative. They merely quickly reduce a list to those that meet minimum standards, or in other words produce a list of feasible solutions. In addition, there are a number of approaches known as outranking methods and multi-objective optimization methods. The goal of outranking methods is to find all alternatives that dominate other alternatives while they cannot be dominated by any other alternative. [Vargas, 1994, p.19] These are also known as non-inferior solutions (a shorter list than the list of feasible solutions) Alone, these approaches would appear to be of little value. As a screening prior to conducting MAUT or AHP, these approaches are useful as they reduce the list of alternatives to those worth considering based on some set of agreed to standards. Both MAUT and AHP were developed to evaluate and rank a small set of alternatives. With each approach, the amount of effort and data required grows with the complexity of the problem and the number of alternatives. In some cases, the utility function or preference with respect to an attribute is binary, meaning that either the attribute meets a standard or does not and there is no value for intermediary or excessive quantities. By using an elimination routine first, the number of alternatives addressed later by MAUT or AHP can be reduced, and the number of attributes in the model can be reduced by considering only those which do not behave in a binary manner. It also allows the questions posed to be more defined, as the range within which the decision is being made is clear. A preference can be given assuming that all the other attributes meet some minimum standard.

The general concept of the weighted index criterion is that the optimum choice is the one that provides the best weighted average of all the attributes of the problem. [de Neufville, 1990, p.304] These attributes need not be measured on the same scale, but they must each be quantifiable on some scale. One difficulty with this approach is that it does not offer a clear and rational means of establishing the weights for the criteria. This is left to the analyst and may be determined in a variety of ways. In addition, all the components of the weighted index must be normalized to avoid the dominance of characteristics that are evaluated in small units. The means by which these components are normalized alters the ranking of the alternatives. For example, the results could be normalized relative to one of the alternatives, maximum values, minimum values, averages or some other convenient normalizing constant. Thus, the ranking can be easily manipulated and could be considered arbitrary. The AHP is conceptually related, but will be shown to avoid these shortcomings.

The additive utility model is similar to the weighted index model, but evaluates in terms of the weighted sum of the individual utilities as measured by utility functions for different attributes of an alternative. Since utility is measured on an ordered metric scale, that in and of itself has no meaning outside the context of its low point and high point, all the attribute's utility functions can easily be placed on the same scale through a linear transformation which sets the high point and low point at any convenient values. Therefore, dominance of attributes measured in small scales is not an issue and normalization is not required as was the case for the weighted average index. The lack of normalization mitigates the concerns raised earlier regarding arbitrary results. The best alternative would be the one with the highest overall score. This approach assumes that the different attributes can be weighted independently, and leaves the weighting approach to the analyst. A variety of methods for establishing the weights can be found in the literature. Among these are multiple linear and non-linear regression analysis of holistic assessments, direct decomposed tradeoffs (as in the determination of scaling factors for MAUT described later), eigenvector pairwise comparisons as in the AHP, and distribution of 100 importance points among the criteria. Research in the 1980's indicated that on average the methods predicted about equally well. [Schoemaker, Waid, 1982, p.182] Similarly, while it is traditional to use Utility Theory to establish the utility functions for each parameter, the AHP could also be used to develop utility-like functions, known as preference functions. In this case an Additive Preference Model may be considered to exist. The AHP is described in more detail later. A drawback of this approach is that the additive model cannot express the value of any interaction between the different attributes. [de Neufville, 1990, p.397] This is often acceptable, but in many cases the attributes of interest interact in a way which can alter the decision-makers preferences, or utility functions.

One can extend utility theory to cover multiple attributes through the use of an extended utility model in an effort to capture these interactions. "In Principal, the utility over many attributes incorporating all relevant interactions, $U(\mathbf{X})$, can be measured just as the utility for any single characteristic, $U(X_i)$. One could define the utility of two arbitrary reference points and then estimate the utility of all others with respect to them." [de Neufville, 1990, p.399] The basic problem with the extended utility model is that it would require so much data as to make it useless for practical problems. For example, if each of N attributes serving as criteria can be described by a utility function with M data points, then the multi-dimensional utility function will be described by M^N points. The additive model described earlier would have added N curves of M points each for a total of only MxN points by comparison. It is also conceptually difficult for people to understand and provide consistent responses to multi-dimensional comparisons of more than two attributes. An alternative approach is the use of the Keeny-Raiffa Multi-Attribute Utility Theory model.

6.2.2.2 Multi-Attribute Utility Theory (MAUT)

Multi-Attribute Utility Theory, or MAUT, seeks to reduce the number of calculations required to address several attributes as compared to the extended utility model, while at the same time permitting some degree of interaction between the attributes. It will be shown that MAUT is more an extension of the additive utility model than a reduction of the extended utility model. The number of points to be measured in MAUT is linearly related to the number of attributes rather than exponentially related as was the case for the extended utility model. Two assumptions regarding the way a person values the interaction between attributes allow a considerable reduction in the number of calculations that are necessary. [de Neufville, 1990, p.402] These are the assumptions of preferential independence and utility independence. Preferential independence states that the ordinal ranking of preferences over any pair of attributes is independent of the other attributes. Utility independence states that the indifference between a lottery and a certainty equivalent for any attribute does not depend on the levels of the other attributes. [de Neufville, 1990, p.405] While the additive utility model allowed for no interaction between attributes, and the extended utility model allowed for any interaction between attributes at a high computational cost, MAUT allows for interaction of pairs of attributes so long as this interaction is not further preferentially influenced by a third attribute. Note also that the discussion centers on independence of preferences, rather than on functional dependencies. Utility independence is generally satisfied when preferential independence exists. [de Neufville, 1990, p.407] "Situations in which preferential independence does not hold can often be circumvented once detected. This can be done either by eliminating all alternatives with levels of an attribute that fall below a threshold...or by reformatting the problem." [de Neufville, 1990, p.405]

The mechanics of MAUT are described in detail in many texts. The key points are reviewed here for the purposes of making comparisons to the AHP and to provide the required background for the development of a model for evaluating design change proposals. Of particular interest is illustrating the way in which interaction between parameters is addressed.

The multi-attribute utility function $U(\mathbf{X})$ is defined as

$$KU(\mathbf{X}) + 1 = \Pi(Kk_iU(X_i) + 1)$$

where

- $U(\mathbf{X})$ is scaled from 0 to 1 when all x are at their worst and best levels
- $U(X_i)$ are one-dimensional utility functions, similarly scaled for each attribute
- k_i are scaling factors for each attribute
- K is a normalizing parameter

In essence, MAUT is similar to the additive model being the weighted sum of the one-dimensional utilities modified by additional terms to account for the interaction between attributes. For the two attribute case, the multi-attribute utility function can be expressed as

$$U(X_1,X_2) = k_1U(X_1) + k_2U(X_2) + Kk_1k_2U(X_1)U(X_2)$$

which clearly illustrates that the interaction of X_1 and X_2 is reflected through the product in the last term. The individual $U(X_i)$ are measured through the use of lottery equivalents as was described earlier keeping $U(X_{i\bullet}) = 0$ and $U(X_i^*) = 1$. The normalizing factor K is solved for by setting all the $U(X_i)$ to 1, at which time $U(\mathbf{X})$ must also be 1;

$$K + 1 = \Pi(Kk_i + 1)$$

For the two dimensional case;

$$K = (1 - k_1 - k_2)/k_1k_2$$

As was mentioned previously, the MAUT is the additive model with factors to account for interactions. This is seen in the above, as when the sum of the k_i is equal to 1, K is eliminated and the formula for $U(\mathbf{X})$ is identical to the additive model.

A key question is what is represented by the scaling factors k_i, and how are they obtained. "Each k_i is the multi-attribute utility of the best level of its attribute i, when all the other attributes X_j, '$j \neq i$', are at their worst levels." [de Neufville, 1990, p.410] This is a direct interpretation of the MAUT function, since when $U(X_i) = 1.0$, its contribution to $U(\mathbf{X})$ is k_i. The scaling factors are solved for through the use of additional indifference statements such that

$$(X_i^*, X_{j\bullet}) \sim (\mathbf{X}^*, P_i; \mathbf{X}_\bullet) \text{ represents a "corner point"}$$

$$\text{and } k_i = U(X_i^*, X_{j\bullet}) = P_iU(\mathbf{X}^*) + (1-P_i)U(\mathbf{X}_\bullet) = P_i$$

Having established the scaling factors k_i, one calculates the normalizing parameter K as discussed earlier. Once this has been accomplished, they are combined with the individual $U(X_i)$ through the MAUT function to determine the multi-attribute utilities. These multi-attribute utilities can be used in conjunction with formal decision analysis as previously discussed, or used alone as an evaluation tool.

6.2.2.3 The Analytic Hierarchy Process (AHP)

While MAUT is highly normative through its axioms, the Analytic Hierarchy Process is a more descriptive approach to decision modeling which is not as restrictive and in practice is found to be more intuitive and representative of the way decision-makers tackle problems. It provides a structured approach, which utilizes familiar concepts, for dealing with problems which are too large for a decision-maker to address. The Analytic Hierarchy Process, developed by Saaty, "reflects people's tendency toward relative judgments, and the inclination to organize complex goal structures in hierarchical clusters. The method's comparative advantage hence lies in areas too fuzzy, too unstructured, or too political for traditional techniques which require that measurement scales be made explicit." [Schoemaker, Waid, 1982, p.183] "The AHP is based on the innate human ability to use information and experience to estimate relative magnitudes through paired comparisons. These comparisons are used to construct ratio scales on a variety of dimensions both tangible and intangible. Arranging these dimensions in a hierarchic structure or network structure allows a systematic procedure to organize our basic reasoning and intuition by breaking down a problem into its smaller constituent parts." [Saaty, 1994, p.5] While MAUT utilizes ordered metric scales, the AHP is based on ranking alternatives in terms of relative ratio scales.

Utility theory and MAUT assess preferences through the use of statements related to certainty and lottery equivalents, seeking to determine decision-makers indifference between outcomes of certain probabilities. The AHP utilizes three basic Principals to model a decision-making problem making use of a ratio scale rather than probabilistic indifference statements. "The decomposition Principal calls for structuring the hierarchy to capture the basic elements of the problem. The Principal of comparative judgment calls for setting up a matrix to carry out pairwise comparisons of the relative importance of the elements in a level with respect to the elements in the level immediately above it. This matrix is used to generate a ratio scale. Finally the Principal of synthesis of priorities is used to generate the global or composite priority of the elements at the lowest level of the hierarchy." [Harker, Vargas, 1987, p.1384]

The Analytic Hierarchy Process is based on a set of primitive notions and axioms. The first primitive notion relates to the existence of attributes and states that for a finite set A of n elements called alternatives, there is another finite set C of c properties, attributes or criteria with which the elements of A are compared. The second primitive notion is known as the "binary relation." This primitive notion calls the comparison of two objects according to a property a "binary comparison." A set of binary relations are established to describe the outcomes of binary comparisons. These relations are $>_c$ representing "more preferred than with respect to property c" and $\sim_c$ representing "indifferent to according to property c." The third primitive notion is at the heart of the AHP. It assumes the existence of a fundamental scale that all properties can be mapped into. Simply stated, for every pair of alternatives in the set A, a positive real number can be assigned that represents the relative intensity with which an individual perceives a property to be in one element in relation to another element. This primitive notion assumes the existence of the ratio scale, which represents a perception that one element has a greater intensity of an attribute than another. It is this ratio scale and the measurement of intensity of preference that allows intangibles to be measured. "In the paired comparison approach of the AHP one estimates ratios by using a fundamental scale of absolute numbers. In comparing two alternatives with respect to an attribute, one uses the smaller or lesser as the unit for that attribute." [Saaty, 1994, p.69]

Saaty defined four axioms based on these primitive notions. The first is the reciprocal condition. Given any two alternatives, the intensity of preference of A_i over A_j is inversely related to the intensity of preference of A_j over A_i. Thus a matrix of preferences of all A_i,A_j would be reciprocal about the diagonal. The second axiom deals with homogeneity. Paraphrased it states that given a hierarchy H where x is a member of that hierarchy and also a member of a particular level L_k within that hierarchy, all the elements y on the level below, L_{k+1}, which are being compared against x are of a comparable order of magnitude which can be compared using a bounded scale. The third axiom deals with dependency and requires two definitions. Set A is defined as being "outer dependent" on a set C if a fundamental scale (ratio scale) can be defined on A with respect to every $c \in C$. Given that A is outer dependent on C, the elements of A are defined as "inner dependent" with respect to $c \in C$ if for some $a \in A$, A is outer dependent on a. Outer dependence is the dependence of an alternative on an attribute. It is the degree or intensity to which that attribute is present in the alternative. [Saaty, 1991, p.5] Inner dependence, or the dependence of an alternative on another alternative, is the influence, contribution or impact of the second alternative on the first with respect to an attribute they have in common. [Saaty, 1991, p.6] The third axiom states that given a hierarchy H with levels L_1, L_2, ...L_h; L_{k+1} is outer dependent on L_k; L_{k+1} is not inner dependent with respect to all x that are elements of L_k; and L_k is not outer dependent on L_{k+1}. Simply stated, this axiom says that comparisons in a hierarchy structure are possible when a set of elements L_{k+1} is to be compared in terms of an element in the next highest level. [Harker, Vargas, 1987, p.1386] In other words, paired comparisons of the relative intensity of preference of two alternatives are made with respect to elements of the level above, and the intensity of this preference should not be dependent on another element. The basic problem with a hierarchy is to seek understanding at the highest levels from interactions of the various levels of the hierarchy rather than directly from the elements of the levels. [Saaty, 1996 (1), p.13] Two properties of a hierarchy level which have strong overlap should be grouped together as a single more general property for the comparison. [Saaty, 1996 (1), p.29]

> A hierarchy is a particular type of system, which is based on the assumption that the entities...can be grouped into disjoint sets, with the entities of one group influencing the entities of only one other group..., and being influenced by the entities of only one other group. The elements in each group (also called level, cluster, stratum) of the hierarchy are assumed to be independent. If there is dependence among them we study independence and dependence separately and combine the two... [Saaty, 1996 (1), p.11]

When this axiom is violated, hierarchical composition is not appropriate and a "super matrix" network approach is required. This is described in more detail later. It should be noted that while the axiom implies certain types of dependence must be avoided in a hierarchical composition, there is a degree of dependence between alternatives that is inherent to the AHP due to the nature of pairwise comparisons and the normalization that is used in some of the AHP calculations. This is discussed later as it relates to the distributive mode of the AHP. It is often difficult to know when the Principal of hierarchic composition is violated. In practice, one must ensure that the criteria represented are independent or at least sufficiently different, and that these differences can be captured as independent properties in the level. [Saaty, 1996 (1), p.30] It should be noted that inner dependence in the AHP is defined as being relative to an attribute. Two elements are inner dependent relative to an attribute that is part of a higher level.

The fourth axiom is called the axiom of expectations. "Assume that a decision maker has a ranking, arrived at intuitively, of a finite set of alternatives A with respect to prior knowledge of criteria C. He may have expectations about rank order." [Saaty, 1996 (1), p.A-9] The fourth axiom of expectations states that all criteria and alternatives are represented in the hierarchy and assigned priorities compatible with expectations. Essentially it states that the hierarchy must be representative of the problem, and that the criteria used must be appropriate for the alternatives in the hierarchy. This axiom simply states that the hierarchy must be constructed carefully to reflect the behavior one wishes to model.

Pairwise comparisons of all A_i and A_j with respect to a criterion c are symbolized by $Pc(A_i, A_j)$ and result in a reciprocal matrix

$$A = \begin{bmatrix} a_{11}\ a_{12} \dots a_{1n} \\ a_{21}\ a_{22} \dots a_{2n} \\ . \qquad\qquad . \\ a_{n1}\ a_{n2} \dots a_{nn} \end{bmatrix}$$

Psychometric research has determined a 9 point scale useful in converting semantic expressions of relative magnitude to quantities used in a ratio scale. For example, it has been established that people can only respond meaningfully to comparisons involving 7 +/- 2 items in a simultaneous comparison. [Miller, 1956 from Saaty, 1996 (1), p.57] When intangibles are being considered, the scale recommended by Saaty is as shown in Table 6.0.

In a simple hierarchy, a set of criteria C is pairwise compared with respect to contribution to a goal. Alternatives are then pairwise compared with respect to their intensity of preference with respect to the criteria C. This forms a number of matrices as above. The local priorities of alternatives with respect to a criterion are determined through the principal eigenvector of the matrix. Methods for calculating this eigenvector are available in mathematical texts and most spreadsheet programs can perform those operations. Once the elements of each level have been pairwise compared to the elements of the preceding level, with the subsequent matrices and eigenvectors established, it is necessary to synthesize the information to go from local priorities to global priorities and preferences which will rank the alternatives against the goal. This generally involves normalizing the eigenvectors to unity to establish what is known as the priority vector.

A variety of methods exist for synthesizing the judgments depending on whether rank reversal is permissible. Rank reversal occurs under some approaches because the addition or change to an alternative changes the overall prioritization by altering the distribution of weights. In some circumstances this is appropriate and in others it is not. A great debate has raged in the literature for years regarding this subject and it is not the purpose of this research to bring that debate to conclusion. Alternative approaches will be discussed here with some thoughts as to what is appropriate for the problem at hand.

INTENSITY	DEFINITION	EXPLANATION
1	Equal Importance	Two activities contribute equally to the objective
2	Weak	
3	Moderate	Experience and judgment slightly favor one
4	Moderate Plus	
5	Strong	Experience and judgment strongly favor one
6	Strong Plus	
7	Very Strong	An activity is favored very strongly over another
8	Very, Very Strong	
9	Extreme Importance	The evidence favoring one activity over another is of the highest possible order of affirmation

TABLE 6.0 - AHP 9 POINT SCALE

One approach is known as the rank preserving absolute mode. In this approach, alternatives are not pair-wise compared relative to criteria, but are instead directly assigned a value relative to criteria based on a predetermined standard scale. Thus alternatives can be assessed one at a time and the addition or deletion of alternatives does not alter the rank. These scales are referred to as intensity scales that assign relative weights to semantic or objective measures of the attribute relative to each alternative. No pair-wise comparisons are made, and no ratio scales are used except in the determination of the ranking of the criteria themselves. In this case, the overall weight of the i^{th} alternative is supplied by

$$W_i = \sum_{j=1}^{m} w_{ij}x_j$$

where x_j is the weight of the j^{th} criterion as determined by the eigenvector of the matrix of pairwise comparisons between criteria, and w_{ij} is the rating of the i^{th} alternative for the j^{th} criteria as determined through assignment of a value on the intensity scale. Thus the absolute mode is a simple weighted additive model which establishes the weights of the criteria through the pairwise comparison eigenvector approach. This approach requires that the decision-maker be able to establish the intensity scales and directly score the alternatives relative to each criterion. The AHP was developed based on the idea of pair-wise comparisons and the ratio scale as a means of comparing alternatives and evaluating them relative to criteria without necessarily being able to establish a unit of measure for the criteria. In essence the alternatives themselves become the units by which measurements are made. This is illustrated through the distributive and ideal modes. The ideal mode allows rank preservation to be guaranteed while still utilizing relative measurement which does not require the development of an intensity scale.

In standard relative measurement where the alternatives are pairwise compared as discussed earlier, the weight of the i^{th} alternative after normalization is given by the distributive mode calculation as follows.

$$W_i = \sum_{j=1}^{m} w_{ij}(x_j / \sum_{i=1}^{n} w_{ij})$$

where the overall weight of an alternative is subject to change if the number of alternatives changes. "The distributive mode produces preference scores by normalizing the performance scores; it takes the performance score received by each alternative and divides it by the sum of the performance scores of all alternatives under that criterion. This means that with the distributed mode the preference for any given alternative would go up if we reduced the performance score of any other alternative or if we removed other alternatives." [Millet, Saaty, 1996, p.186] Under the distributed mode, one must be careful that the addition of an alternative does not change the decision-maker's attitudes about the problem and reveal additional criteria. Often this is the case, and the addition of these criteria will prevent rank changes. This is the crux of the axiom related to expectations that was discussed earlier.

In addition, when relative measurement is desired but rank reversal is not, the ideal mode of the AHP can be used. Under this mode, "adding a new alternative requires only that it be compared with the highest ranking one. Adding an alternative that ranks lowest on all the criteria would not affect the ranks of the other alternatives. Adding a higher ranking alternative on some criterion would become the ideal and could cause change in the other ranks. However, such an occurrence is admissible." [Saaty, 1994, p.141] The ideal mode determines the preference for an alternative under each criterion by comparing its performance to a fixed benchmark, generally the best available alternative under each criterion. The final weight reflects how close an alternative is to performing "best" on a given criterion. This is represented by

$$W_i = \sum_{j=1}^{m} w_{ij}(x_j / \sum_{i=1}^{n} w_{ij}) / (\max_i w_{ij} // \sum_{i=1}^{n} w_{ij})$$

which simplifies to the un-normalized

$$W_i = \sum_{j=1}^{m} w_{ij} x_j / \max_i w_{ij}$$

The most recent and reasonable guidelines were published in a paper presented at the 1996 International Symposium for the AHP. It is suggested that the distributive mode should be used when the decision-maker is concerned with the extent to which each alternative dominates all other alternatives under the criterion while the ideal mode should be used when the decision-maker is concerned with the extent to which each alternative performs well relative to a fixed benchmark. [Millet, Saaty, 1996, p.186]

These are testable conditions. If the decision-maker indicates that the preference for a top ranked alternative under a given criterion would improve if the performance of any lower ranked alternative was adjusted downward, then the distributive mode is prescribed. Some have suggested that the ideal mode is normative while the distributive mode is descriptive. The absolute mode is not often used in practice any longer since the introduction of the ideal mode. In evaluating alternatives it may often be interesting to explore both the ideal and distributive results.

Since the AHP is more descriptive than normative, it allows for inconstancy in the judgments of the decision-maker. Saaty suggests that an inconsistency of 10% or less is reasonable. The consistency ratio is used to determine if one is below this threshold 10%. The consistency index is defined as $(\lambda_{max}-n)/(n-1)$ where n is the number of activities (columns or rows in a square matrix) and λ_{max} is the principal eigenvalue (calculable as described in numerous texts). The random index is the consistency index of a randomly generated reciprocal matrix from the scale 1 to 9 (or the scale used in the AHP model if different) for the same n. A table of average R.I for a large sample of runs for various n is available in AHP books. The consistency ratio is then the ratio of the two indices and compares the consistency index with what the index would be on average for a consistent (i.e. perfectly reciprocal) matrix.

The steps to apply the AHP presented so far can be summarized as follows.

- Describe the problem, its key characteristics, and define an objective or goal
  - Define and focus the goal as clearly as possible
- Define criteria that influence the behavior of the problem and contribute to the goal
  - Brainstorm criteria or attributes
  - Group like criteria and combine to avoid overlaps where necessary
- Structure a hierarchy avoiding dependency between elements
  - Criteria
  - Sub-Criteria
  - Alternatives
- If alternatives are of widely disparate magnitudes, group into more homogeneous components
- Carefully define the meaning of each criterion
  - determine which can be measured directly and quantifiably
  - determine which must be measured subjectively
  - establish the appropriate metrics
- Test for dependencies (discussed later)
- Develop questions to elicit pairwise comparisons for criteria
- Perform pairwise comparisons for the contribution of the criteria to the goal
- Establish the correct evaluation mode
- Develop questions to elicit pairwise comparisons between sub-elements and alternatives
- Perform the pairwise comparisons
- Use the appropriate calculation mode (ideal or distributive)

- Test for constancy and redefine if necessary
- Perform sensitivity analysis

In developing questions regarding criteria and performing pairwise comparisons, some have found it useful to establish ranges over which alternatives can vary on a given criteria. This provides context for the questions and generally makes it easier for the decision-maker to perform the comparisons. If two "dummy" alternatives are added to the model representing the top of the range for each criteria and the bottom of the range for each criteria, then rank reversal can also be avoided as long as the criteria are difference independent as was described in the discussion regarding utility theory. [Dyer 1990, p.256]

An interesting dynamic extension of the AHP involves mapping a preference trajectory with respect to a variable such as time. This can prove useful in establishing an implementation strategy. An AHP model is developed where the criteria and preferences are dependent on a parameter such as time that is not included in the hierarchy itself. One repeats the AHP analysis for several iterations representing a change in the control variable. An example provided by Saaty illustrates the changing priorities of a person throughout life with regard to socializing, career and family. This extension would be useful in establishing and exploring preferred alternatives where timing is a key variable. Such an approach should also be applicable to utility theory.

It should also be noted that the AHP allows for multiple decision makers. This is critical to a decision model for use in managing change proposals, as it has previously been demonstrated in this research that consensus and participation are features of the process. Multiple decision makers can be admitted in a variety of ways, ranging from deterministic to stochastic. Statistically based approaches may be appropriate when decisionmakers are scattered and represent different interests, the group is large, and unable to discuss the problem at hand. In such situations each decisionmaker may be operating under different assumptions with incomplete information. It may be desirable to examine the results and correlate them to parameters associated with the individuals. On the other hand, "when a small group of individuals work closely together - interacting and influencing each other, the deterministic approach is appropriate. We synthesize the judgments mathematically." [Saaty; 1994, p.201] Synthesis can be made at the level of the judgments themselves, the eigenvectors (priority vectors) associated with each criteria, or the overall synthesized priorities (proposal ranking and weighting). One deterministic approach utilizes multiple decisionmakers as part of the hierarchical structure itself, thereby synthesizing at the level of the judgments. One adds a level to the hierarchy representing the decision-makers and weights them as any other element. Thus, one can distribute "power" among the decision makers disproportionately or equally. This ability to synthesize judgments of multiple decision-makers directly within the model structure sets the AHP apart from MAUT or other approaches. The AHP is descriptive and allows some inconsistency, which is virtually guaranteed in group decision-making. Because MAUT is normative and does not permit inconsistency, it cannot synthesize group decisions. It is simply not possible to construct a valid group utility function that we can apply to collective decision making. [de Neufville, 1990, p.431] The procedure recommended for group decision-making by MAUT practitioners is to model the system, define the non-inferior options, determine individual preferences, explore trade-offs and negotiate toward a collectively satisfactory solution. [de Neufville, 1990, p.446] AHP is well suited for such exploration. When equal significance is given to members of a decisionmaking or survey group, the individual results can be combined using the geometric mean at either the eigenvector or global synthesis level. "When equal importance is given to voters in a group, Aczel and Saaty published a result which incorporated and extended Saaty's derivation of the geometric mean as the proper way for synthesizing the judgments." [Saaty, 1994, p.203] The geometric mean was shown to be superior to the simple average or other aggregation methods because:

- It tended to result in aggregations which more closely modeled known quantities when synthesizing estimates
- It is an identical result to including decisionmakers in a hierarchy with equal weighting
- It satisfies the reciprocal property such that the synthesis of the reciprocal of individual judgments is the same as the reciprocal of the synthesis of the individual judgments
- It satisfies a seperability condition such that the influences of the individual judgments can be isolated
- It satisfies a unanimity, or consensus, condition such that if all individuals give the same judgment X, the synthesized result is also X
- It satisfies a homogeneity condition such that if all individuals weight one alternative X greater than another, the synthesized result will also weight the same alternatives by the same ratio
- It satisfies power conditions such that the synthesis of powers of individual judgments will be identical to the power of the synthesis of the individual judgments. This distinguishes the geometric mean from the simple average and is important to preserve the integrity of the capability to perform operations on a ratio scale.

As mentioned earlier, when there is significant dependency between elements of interest, the supermatrix approach must be used. This approach is described in detail in a number of Saaty's books. In some instances, the supermatrix can be avoided by carefully structuring the problem such that all dependency is between elements of different levels. When this is not the case, the supermatrix approach should be used to capture influence among elements. In this case, a network could be considered to be more representative than an hierarchy.

When the criteria weights depend on the alternatives, and the alternative weights depend on the criteria, we have an example of a hierarchy with feedback. The supermatrix approach could be used in this case since the axiom of independence is violated. It has been shown that this feedback can also be accommodated by performing the AHP analysis twice, once from the bottom up and then from the top down, thereby giving the decision-maker an opportunity to understand what the alternatives are before setting the criteria weights. [Foreman, 1991]

The supermatrix approach is more useful when there is inner dependence between the elements of a level rather than dependence between the levels themselves. "Inner dependence needs common attributes or criteria to determine where there is dependence. The attributes must belong to another component." [Saaty, Takizawa, 1986, p.233] In other words, inner dependence in the AHP is defined as being relative to an attribute. If two elements are suspected of being dependent, but that dependency is not relative to another attribute, it is not significant to the problem as it will not influence the evaluation. To evaluate inner dependencies for a given level relative to an attribute of a higher level, one creates a matrix with activities for each element and identifies within it which elements influence others with respect to an attribute (with an 'x' for example). Such a matrix is created with respect to each attribute in the higher levels.

> The general framework for assessing inner dependence is as follows. Alternatives are dependent according to where there is an 'x'. In that case we can fill out reciprocal pairwise comparison matrices only with respect to those alternatives on which a given alternative depends with respect to a given attribute. Zeros are assigned to the eigenvector weights of the alternatives from which a given alternative is independent...Each eigenvector is then weighted by the independence priorities $A_1(C),...,A_n(C)$ without regard to its dependence on others. The results are composed over the alternatives yielding the final interdependence. [Saaty, Takizawa, 1986, p.233]

The steps in summary are as presented in the paper by Saaty and Takiwaza; "Dependence and Independence: From Linear Hierarchies to Nonlinear Networks":

- determine the criteria weights assuming no dependence (W_1)
- determine the column eigenvectors with respect to each criterion comparing the alternatives as usual assuming no dependence
- Analyze the interdependence of the criteria with respect to the goal using pairwise comparisons forming the matrix W_3
- Deal with dependence among the alternatives or next lower level similarly relative to each criterion or element of the level above
- Synthesize the interdependence priorities of the criteria as $W_c = W_3 X W_1$
- The priorities of the alternatives, W_a ,with respect to each of the criteria are given by synthesizing the column eigenvectors with respect to each criterion with the matrices representing the interdependence of the alternatives with respect to each criterion. Each synthesis (cross product) forms a column of the matrix W_a.
- The overall priorities of the alternatives are yielded through $W_a X W_C$

In practice, independence is often assumed to avoid all the additional computational effort. In general, assuming independence provides a reasonable facsimile model of which decision-makers are typically happy with. This is evidenced by the numerous case studies in the literature which ignore any dependency. It is not always the case that such a model is close enough; dependency should always be checked, and the model carefully formed accordingly.

6.3 Synopsis and Comparison of Methods

The next concern is to establish which approaches are most appropriate for evaluating alternative change proposals, keeping in mind the problems which operations research and decision science have faced in practice as described at the beginning of the Chapter. Several decision science researchers have reviewed alternative methods to determine which are appropriate under given conditions, particularly for the justification of R&D type projects. For example, Fahrni and Spatig have suggested that all the available decision and operations research models are useful to some degree and that what is important is that "one takes into account successively how far the selection parameters can be quantified, how far one project interferes with or depends on completion of another, whether a project has one or more than one objective, and the degree of acceptable risk." [Fahrni, Spatig, 1990, p.155]

A set of key quality characteristics is necessary which describe the needs of decision modeling tools for evaluating design change proposals. The benchmarking questionnaire results and shipyard interviews undertaken suggest that key quality characteristics of a decision system for the purpose at hand include (in no particular order):

- Speed of evaluation
  - ⇒ Of great concern in practical applications.
- Flexibility
  - ⇒ New information or "what if" type questions should be readily and quickly dealt with.
- Ability to structure the problem and facilitate identifying core values and objectives
  - ⇒ The quality of the decision requires alignment with a strategic purpose.
- Ability to structure the problem and facilitate identifying additional alternatives
  - ⇒ The evaluation process should serve not only to choose among given alternatives, but also to spark creativity and innovation which may lead to even better alternatives.
- Intuitive appeal to decision-makers
  - ⇒ The approach must be understandable. The underlying details need not be completely understood as long as the input, output, and relationships are clear. The model should represent as closely as possible the way in which people think about the problem and should seem "natural." The more "natural" the approach, the easier it will be to implement and integrate into the company processes, procedures, and organization.
- Ability to eliminate inferior solutions quickly

⇒ Valuable effort should not be expended collecting data related to an inferior alternative. The decision system must be able to identify alternatives which fail to meet threshold criteria and should no longer be considered or must be modified to eliminate the failure.

- Ability to rank (order) non-inferior solutions
- Ability to weight non-inferior solutions

⇒ In addition to priority ranking alternatives, the model should weight their relative importance or contribution to the company's overall strategy or goal. This allows alternatives to be compared. Without such a weighting, it becomes difficult to make decisions associated with allocating resources.

- Ability to address multiple criteria and objectives
- Ability to address dependency between elements
- Ability to consider quantitative data
- Ability to consider qualitative data
- Ability to synthesize group decisions

⇒ The model needs to be able to incorporate data from a variety of sources. It should also provide a means for allowing a number of people to evaluate the alternatives and then synthesize their judgments.

The AHP performs better against many of these characteristics than other alternative evaluation techniques. The AHP results in a faster and more intuitive analysis which is useful in building consensus. The management of change is largely about managing expectations and perceptions, and involves numerous stakeholders with differing perspectives. The AHP is uniquely suited to that type of problem. The hierarchical structure of the AHP is entirely consistent with the concepts of competency mapping and strategic planning discussed in Chapters 2.0 and 5.0. The opportunity for near seamless integration of the AHP with the strategic planning process used to establish goals and identify alternatives suggests that the AHP is well suited for developing a decision model for managing design change.

Earlier research performed through the NSRP supports the AHP as an advantageous approach. The 1992 SP-4 project "Development of Producibility Evaluation Criteria" concluded

> There are several very important advantages to the use of the AHP method. One is that this technique has a rigorous methodological basis...Another advantage of the AHP is that this process can make use of "hard" numerical data when it is available...But if hard data is not available or the different attributes that must be considered cannot be measured in common units, this technique is still effective...The validation tests have yielded results that are consistent with the findings of the shipyards from which the design alternatives were obtained. [Wilkens, Kraine, Thompson, 1992]

This conclusion is also supported in the literature regarding evaluation of R&D proposals.

> As managers tend to accept only methods which they can basically understand, difficult and sophisticated selection models are hardly considered valuable in R&D project selection. Therefore we emphasize deterministic rather than stochastic modeling, and strongly favour decision processes where both risk and uncertainty are assessed in qualitative terms. [Fahrni, Spatig, 1990, p.159]

Skibniewski and Chao came to a similar conclusion regarding the relative complexity of AHP and MAUT which they summarized well in their research regarding alternative approaches to the evaluation of adaptation of advanced technology in the construction industry. They wrote

> Since a decision maker bases judgments on knowledge and experience, then makes most decisions accordingly, the AHP approach agrees well with the behavior of a decision maker. The strength of this approach is that it organizes tangible and intangible factors in a systematic manner, and provides a structured yet relatively simple solution...The use of utility theory in evaluation problems to help decision making is already a well-known formal approach. However, the decision-making models based on utility theory necessitate the establishment of utility functions representing the decision maker's value scales for different criteria or goals. Often in a given decision-making situation, the utility functions are difficult to formulate and develop precisely enough to represent a particular decision maker's perception of the impact and value of a certain outcome. Further, the use of these models requires extensive effort to collect information for estimating possible outcomes on each multidimensional criterion. This is often a costly, time-consuming process. Also, the inflexibility of this approach causes difficulty in adapting to changes in either the attributes or the utilities of the model. [Skibniewski, Chao, 1992, p.578]

In the next Chapter the Analytic Hierarchy Process is used to develop a decision model for evaluating and prioritizing proposals.

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7.0 DEVELOPING AND TESTING THE MODEL

In the previous discussion the AHP was established as the methodology of choice for the problem of evaluating and ranking alternative change proposals. In this section an AHP application to evaluating alternative design change proposals is developed within the context of an overall decision system. W. Sauder of the University of Pittsburgh illustrates the range of project selection activities which can occur when faced with project proposals. [Sauder, 1980, p.138] His approach is illustrated in figure 7.0.

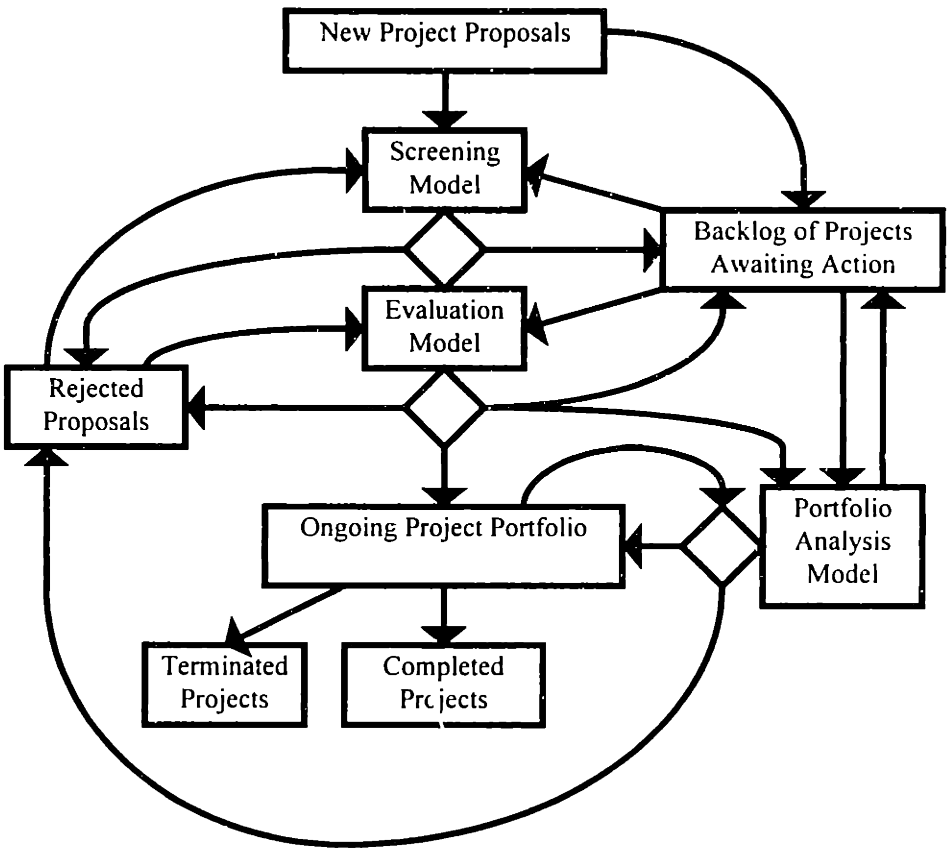


FIGURE 7.0 - PROJECT SELECTION DECISION PROCESS

The approach described by Sauder is representative of the evaluation and prioritization stages of the design change framework, as the selection of productivity enhancing design change proposals is a specific case of project selection. In this section, first the model parameters are defined and the AHP model's hierarchy is established. Next the general form of the AHP model is discussed. Issues associated with screening are discussed followed by evaluation and prioritization. Finally, utilizing one of the shipyards as an industrial lab, the applicability and results of the model are tested.

7.1 MODEL PARAMETERS AND HIERARCHY

The objective of the model is to rank and weight feasible alternatives with respect to their capacity to contribute to the goal "enhance shipyard competitiveness." Throughout the previous discussions in this Chapter, reference was made to benefits, costs and risks. Benefits, costs and risks represent the highest level of criteria which a decision model must consider. These three high level parameters can be further described in terms of lower level criteria. These three high level criteria are well recognized within the decision analysis community as an effective means to describe the contribution of a proposal to the success of a business as a whole. The use of these three parameters allows the decision model to structure the problem in a meaningful way which is conceptually simple and intuitively understood by management. It is also consistent with the conclusions and methods of Chapters 2.0 and 5.0 regarding the development of parameters based upon strategic responses to the competitive environment.

The Construction Industry Institute (CII) concluded in their publication "Project Change Management" that "the engineering and construction industry in general does a poor job of measuring and analyzing the impact of changes on project costs and other project outcomes," and that "changes should be evaluated against the business drivers and success criteria for the project in order to minimize the negative impacts on critical objectives." Business drivers and success criteria are associated with benefit, cost and risk. "Each alternative must be analyzed and evaluated in terms of its value [benefit], cost and risk characteristics." [Souder, 1980, p.20]

A variety of sources were utilized to identify the appropriate parameters to use in the model. As was discussed in Chapter 4.0, several shipyards participated in this research by filling out a number of questionnaires and made their process and procedure manuals available for review. In the course of this review, a number of metrics were identified. Although not all the shipyards used the same language or identified all of the same metrics, they all relate in some way to costs, benefits and risks. Some shipyards' procedures seek to quantify metrics at a detailed level. Others, in an effort to speed the process and in recognition of the subjective and imprecise nature of many important metrics, utilize scales to quantify subjective measures. In addition to the process and procedure manuals, MIL-STD-973 (Configuration Management) was reviewed. This standard calls out a number of metrics which are also to be considered when evaluating change proposals in navy contracts. Many of these also appear in the shipyard process and procedure manuals which have often been developed based upon this standard. In addition, the Construction Industry Institute (CII) identifies change management metrics in a number of their recent reports. [CI, 1994] Prior work reported by the NSRP and in the shipbuilding literature also served as a foundation for establishing model parameters. The 1992 project "Development of Producibility Evaluation Criteria" resulted in an example of an AHP application for evaluating the producibility of design alternatives. Their research was different in focus and more limited in scope, but is directly applicable here and was used as a reference for identifying additional appropriate parameters as well as AHP model structure. The work of Bosworth and Graham, reported in "Producibility as a Design Factor in Naval Ships", also identified metrics useful in evaluating proposals.

As discussed earlier, attention to organizational risks and needs is important in predicting the success of proposal implementation. The Ship Design for Producibility Workshop referenced earlier concluded that any proposed methodology must consider issues associated with people, methods, processes and products in order to be successful. Similarly, Souder suggests that some of the factors which must be considered in evaluating alternatives include "the acceptability of the alternative to those who will implement and use it" and "the changes in behavior patterns required if the alternative is chosen". [Souder, 1980, p.21] For these reasons, the lessons learned from supporting theory in the area of organizational change discussed in Chapter 3.0 were used to develop additional model parameters, especially with respect to risks.

Three types of attributes, or parameters, are generally used in the development of a decision model. [Keeney, 1992, p.101] These include natural, constructed and proxy attributes. Natural attributes are in general use with common interpretation to everyone. An example is man-hours for a given process. Constructed attributes are developed specifically for a given context and may combine multiple natural attributes. Such parameters utilize verbal descriptors which are associated with a numerical value. An example would be the five technology levels of the shipyard technology survey popularized by Appledore as well as Storch et. al. Proxy attributes are used when a parameter of interest cannot easily directly be measured. An example would be the use of man-hours of production rework as a proxy for engineering quality. The proposed model parameters are associated with the entire spectrum of attribute types. The mechanism of the AHP, which utilizes direct pairwise comparisons, makes the underlying scales and parameter types less significant than they would be if absolute measures were being used. Later the use of constructed attributes for the development of a screening model will be discussed.

The AHP model parameters are presented next followed by an illustration of the resulting model hierarchy. Ultimately, the hierarchy developed here evolved from the synthesis of a variety of sources within the context of close participation with the shipyard that acted as the industrial lab.

7.1.1 Benefits

The word benefit is defined in Webster's Dictionary as "something that is advantageous or good; an advantage". The benefit of a particular proposal is defined as the extent to which it provides the organization competitive advantage. The means to achieving competitive advantage should be reflected in the goals and strategy of the organization. As was discussed earlier, the first step towards quality management and decisionmaking is the clear definition of these goals. Thus the competency map discussed in Chapters 2.0 and 4.0 is used directly in the construction of the benefits branch of the model hierarchy, linking it directly to the model of competitive advantage discussed earlier in the research. "The value of an alternative is measured in terms of its contributions to the achievement of each of the goals [of the organization]. The value of each alternative should be assessed in terms of the benefits that can be expected to result if it is chosen, and in terms of the regrets that can be suffered if it is not chosen." [Souder, 1980, p.20] The research described earlier in Chapter 4.0 regarding strategic planning and the identification of alternatives, together with discussions with shipyard experts at the "industrial lab", revealed that a proposed project would be considered to be supportive of this shipyard's strategic objectives and therefore beneficial:

- If it reduced the cycle time or duration required to design and construct a ship
- If it reduced the total cost to produce a ship
- If it improved the performance or quality of the ship in the eyes of the customer

These benefits are associated with sub-criteria model parameters and their relative weights reflect shipyard strategic objectives.

Reduction of cycle time is a strategic objective which has value independent of cost or quality. Cycle time refers to the total duration of a stage of construction regardless of the number of man-hours actually worked or the costs incurred. It is associated with labor hours, material handling time and any waiting or lost time associated with tasks. Cycle time ultimately impacts market share and impacts on the amount and type of work the shipyard can bid on. It is of keen interest to a customer, and the market demands increasingly shorter program durations.

Reduced cycle time is generally believed to lead to lower costs, but also has value independent of costs. For example while reducing labor content, and therefore manhours, will always result in reduced cost it does not necessarily result in reduced cycle time. The reduction of cycle time is dependent on whether the tasks being made easier are actually on the critical path. If they are, a reduction in cycle time will occur in addition to a reduction in costs. A shipyard may choose a strategy which focuses heavily on reducing cycle time without emphasizing reduced costs. A yard may even be willing to increase costs (in the short run) to reduce cycle time (believed to have profit implications in the long run). It is all a matter of their competitive position and the demands of their markets, made explicit through strategic planning.

Ship production can be described as taking place in a variety of stages. These form sub-criteria to reduced cycle time, as a shipyard may determine that reductions in a particular stage are of greater strategic importance due to facility constraints or product mix. It would not be necessary to utilize sub-criteria if a yard could readily evaluate the impact on overall project cycle time, but experience has shown this to be difficult and that breaking the problem down into stages of construction has proven useful for prioritizing projects. It also allows shipyard strategy to be reflected more readily in the model. As the strategy changes the parameter weights can also be changed. For example, a yard may find that steel throughput is its critical path and may choose to focus more heavily on projects that reduce durations in steel stages of construction. Eventually, outfitting may become a bottleneck, at which point a reassessment of the criteria weights would be appropriate to reflect a changing shipyard strategy. The AHP approach facilitates this continual reflection and accommodates changes in strategy readily.

For the purposes of developing the model, these stages are defined as:

- Engineering
- SOC 1 - Fabrication, Steel
- SOC 1 - Fabrication, Outfit
- SOC 2 - Sub Assembly (Steel)
- SOC 3 - Assembly, Steel
- SOC 3 - Assembly, Outfit
- SOC 4 - On - Unit Outfitting
- SOC 5 - On - Block Outfitting
- SOC 6 - On - Board
- SOC 7 - Test and Trials

Engineering here is synonymous with "development" and could be further broken into stages. For the purposes of this model it is included as a composite.

Dollar savings as a parameter represents the dollars associated with labor or material content which the proposal will save. It is the intensity of preference for one proposal over another with respect to the total dollar value of man-hour reduction, substitution or reduction of material, and other proposal characteristics. It is independent of dollars which are not due to labor or material content. Those that are associated with reduced cycle time (such as incentives for meeting or beating schedule or costs associated with time in the yard that are not directly linked to labor content or design features) are considered when evaluating alternatives with respect to cycle time and the weight allocated to that parameter.

Performance or Quality Improvement as a parameter is associated with a number of sub-criteria which reflect performance or quality features of importance to the owner. The weights of these sub-criteria should reflect the "voice of the customer" as it relates to their desires. The weight of performance improvement in comparison to cycle time reduction or dollar savings is a function of shipyard strategy and objectives. The parameter reflects the intensity of preference for one proposal over another with respect to improving performance.

7.1.2 Costs

Webster's Dictionary defines a cost as "the price paid to acquire, produce, accomplish, or maintain anything" and a "sacrifice, loss or penalty". This basic definition implies that the initial costs, follow on costs, and opportunity costs must all be considered. The following parameters were identified and used in this model.

Dollars Invested:

This parameter represents the intensity of the decisionmaker's aversion to the total cost, in dollars, that is estimated to be required to implement one proposal relative to another. This should include consideration of non-recurring and recurring costs, labor, and material.

Schedule Delay:

This parameter represents the intensity with which one alternative negatively impacts schedule with respect to other alternatives. The dollar value of schedule delay is generally very difficult if not impossible to predict. The interest here is the intensity of the aversion to projects which impact schedule regardless of the estimated dollar investment in the project. This parameter has also been associated with sub-criteria to allow the strategic importance of certain stages to be accounted for.

Additional Manning Required:

The requirement for additional manpower by those involved in the implementation effort represents a cost which is distinct from budget and schedule. Manpower is a resource which contributes to dollar costs, but is also an independent consideration of importance to decisionmakers. Forcing an overtime situation, or addition of people to the team, represents a destabilizing force which management would prefer to avoid but is difficult to evaluate strictly in terms of dollars or schedule. The commitment of manpower means that this resource is now unavailable to handle current workload or unforeseen requirements. The necessity to consider manpower as a separate parameter was made clear during the industry surveys, as reported in Chapter 4.0. The weight associated with this parameter represents an aversion to increased manpower requirements.

Additional Information Systems Resources Required:

The requirement for additional computer equipment or software represents a cost which has significance independent of dollars invested. As was the case with manpower, this requirement contributes to dollars invested, but is generally considered as an additional parameter by management. The parameter represents the intensity with which one proposal ties up (or requires acquisition of additional) information system resources as compared to another resource.

Product Performance or Quality:

This parameter represents the intensity with which one proposal negatively impacts product performance or quality as compared to another proposal. As was the case in the discussion of benefits, it is a function of sub-criteria which are of importance to the customer.

7.1.3 Risks

Webster's Dictionary defines a risk as "exposure to the chance of injury or loss." Risk must be assessed both in terms of the potential magnitude of the loss as well as the likelihood of the loss. Risk can be described as a probability distribution which associates possible magnitudes of loss with their likelihoods, if these probabilities are known or can be estimated. A number of risk parameters were identified.

Cost Risk:

This parameter represents the intensity with which the costs estimated for a proposal may have been underestimated. It is a measure of cost uncertainty with respect to the combined impact of magnitude and likelihood. It is a representation of the intensity of preference for one proposal over another with respect to their cost uncertainty.

Benefit Risk:

This parameter represents the intensity with which the benefits estimated for a proposal may have been underestimated. It is a measure of benefit uncertainty with respect to the combined impact of magnitude and likelihood. It is a representation of the intensity of preference for one proposal over another with respect to their benefit uncertainty.

Technical Risk:

This parameter represents the intensity with which one proposal is preferable over another with respect to the likelihood that the proposal may fail for technical reasons.

Organizational Support Risk:

This parameter represents the intensity of preference for one proposal over another with respect to the likelihood that one may fail due to a lack of organizational support, despite all other measures of merit being promising. This parameter is a function of a number of sub-criteria as follows.

The "Cultural" parameter represents the intensity with which one proposal requires changes in people's attitudes or daily work-habits as compared to another proposal. It represents the impact that the change will have on people personally in the way they conduct their daily work.

The "Visible Rapid Benefits" parameter represents the intensity with which a proposal is believed to have highly visible short-term benefits as compared to another proposal.

The "Resource Availability" parameter represents the intensity of the uncertainty associated with the availability of resources to implement one proposal as compared to another.

"Breadth of Rework Required" represents the intensity of preference for one proposal over another with respect to the number of documents and product models which will require rework to implement the proposal.

"Breadth of Cooperation Required" represents the intensity of preference for one proposal over another with respect to the degree of cooperation required by numerous people or groups. It is a measure of the risks associated with the degree of communication and cooperation which is required for a proposal to be successful.

"Visible Support" represents the intensity of preference for one proposal over another with respect to the amount and quality of visible management support for the proposal.

The "Urgency, Strategy, Need" parameter measures the intensity of preference for proposals which clearly are aligned with a communicated and understood strategy or shipyard objective which the people or organizations tasked with implementation support.

"Complexity & Capability" refers to the intensity of preference for proposals which do not require knowledge or workforce capabilities which are scarce or missing, and for which the means and requirements for implementation are readily understood and achievable.

"Stability" refers to the intensity of preference for proposals which require action related to processes or interim products which are standardized and understood, and by people or groups which are not presently stressed by a high degree of change.

Regulatory Risk:

This parameter represents the intensity of preference for proposals which are less likely to be delayed or rejected by regulatory bodies (or the customer).

Schedule Risk:

This parameter represents the intensity of preference for proposals which exhibit less uncertainty with respect the both the magnitude and likelihood of schedule delays beyond those estimated in the consideration of costs.

7.2 Model Form

Alternatives exist regarding how to model and synthesize judgments associated with benefits, costs and risks. The approach generally recommended by Saaty is to model benefits, costs and risks on three separate hierarchies, establish that benefits justify the costs of alternatives via screening, and then prioritize according to the ratio of the assigned priorities of B/(C*R). An alternative approach is to link the benefit, cost, and risk hierarchies together into a single hierarchy with a global objective of improving shipyard competitiveness. This approach strives to model differing preferences for maximizing benefit, minimizing costs and minimizing risks associated with proposals by pairwise comparing these high level criteria and synthesizing the results accordingly. Both approaches have been used by practitioners in prioritizing projects. The principal argument in favor of the first approach is that respondents often become preoccupied with benefits, costs or risks and have difficulty providing consistent answers to pairwise comparisons for all three categories at the same time. It has also been suggested that answers to pairwise comparisons between the high level criteria of benefit, cost and risk are not easily answered. The principal argument in favor of the second approach is that benefit, cost and risk are not equally valued and that aversions to some of these parameters can only be accounted for by modeling a single hierarchy.

In fact, the single hierarchy approach can be used, but the pairwise comparisons can be broken into separate sessions to avoid problems associated with preoccupation for one parameter or another biasing results. In the course of testing the application of the model the difficulty in assessing preference for projects that maximize benefits vs. those that minimize costs or risks was found to be acute in the absence of any knowledge of the proposals in question. This problem was found to be less significant if it was suggested that proposals had first been screened against a set of baseline criteria and that those under consideration met the criteria. If the AHP model parameters are weighted equally, the two approaches appear to result in the same ranking but different weightings as illustrated in figure 6.3. The B/CR approach results in more extreme differences between the priorities, but the ranks remain unchanged. The results of the industry survey indicated that relative preference for benefit, cost and risk varied from yard to yard and within a yard. For this reason, the single hierarchy model was used to facilitate exploring these differences and developing a strategic policy representing a consensus regarding what types of proposals are necessary for a particular environment. The resulting model is illustrated in Figure 7.1.

MODEL FORM RESULTS

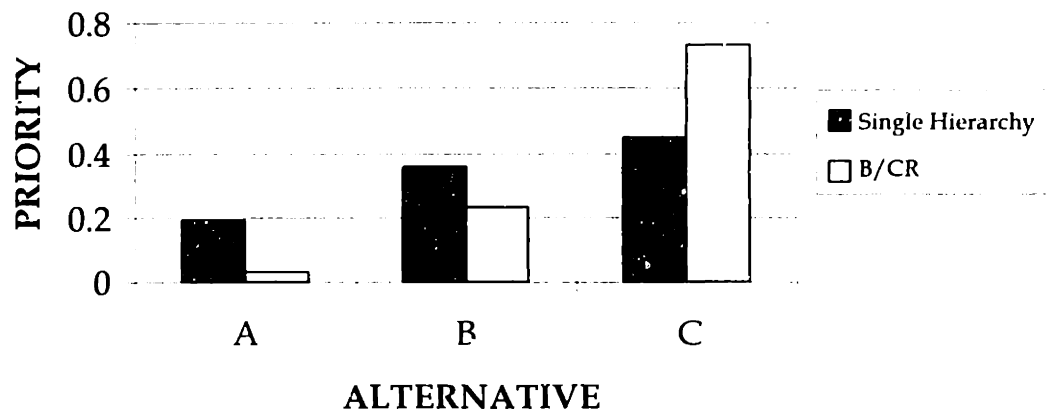


FIGURE 7.1 - MODEL FORM

7.3 APPLICATION AND TEST OF THE MODEL

As was mentioned previously, one of the shipyards involved in this research was used as an "industrial lab" for the purposes of a test application of the model. This test application consisted of three significant phases:

- Establishment of criteria weights
- Evaluation of case study proposals
- Analysis of results and conclusions regarding the test application

Two additional surveys were used for this purpose. The first of these surveys was intended to elicit the pairwise comparisons which would result in criteria weights. This survey presented the hierarchy and parameter definitions to a set of respondents. The survey also addressed thresholds and goals, as a means for screening and providing the necessary context suggested previously. This survey also addressed tests for dependencies between parameters. The results were used to synthesize group judgments regarding the parameter weights. The second survey utilized a number of case studies as alternative proposals to be evaluated by the model. Eight case studies based upon recent (last two years) design improvement proposals from the same shipyard were utilized. The respondents chosen were personnel knowledgeable of the cases. The proposals were pairwise compared with respect to the parameters based upon the information that was available some time ago, prior to decisions regarding their implementation. Respondents were asked to "travel back in time" and put themselves back in that frame of mind. Later, the respondents would pairwise compare the same set of proposals relative to all that is known about them today. Appendix B provides additional background regarding the case studies, as well as excerpts from the questionnaires.

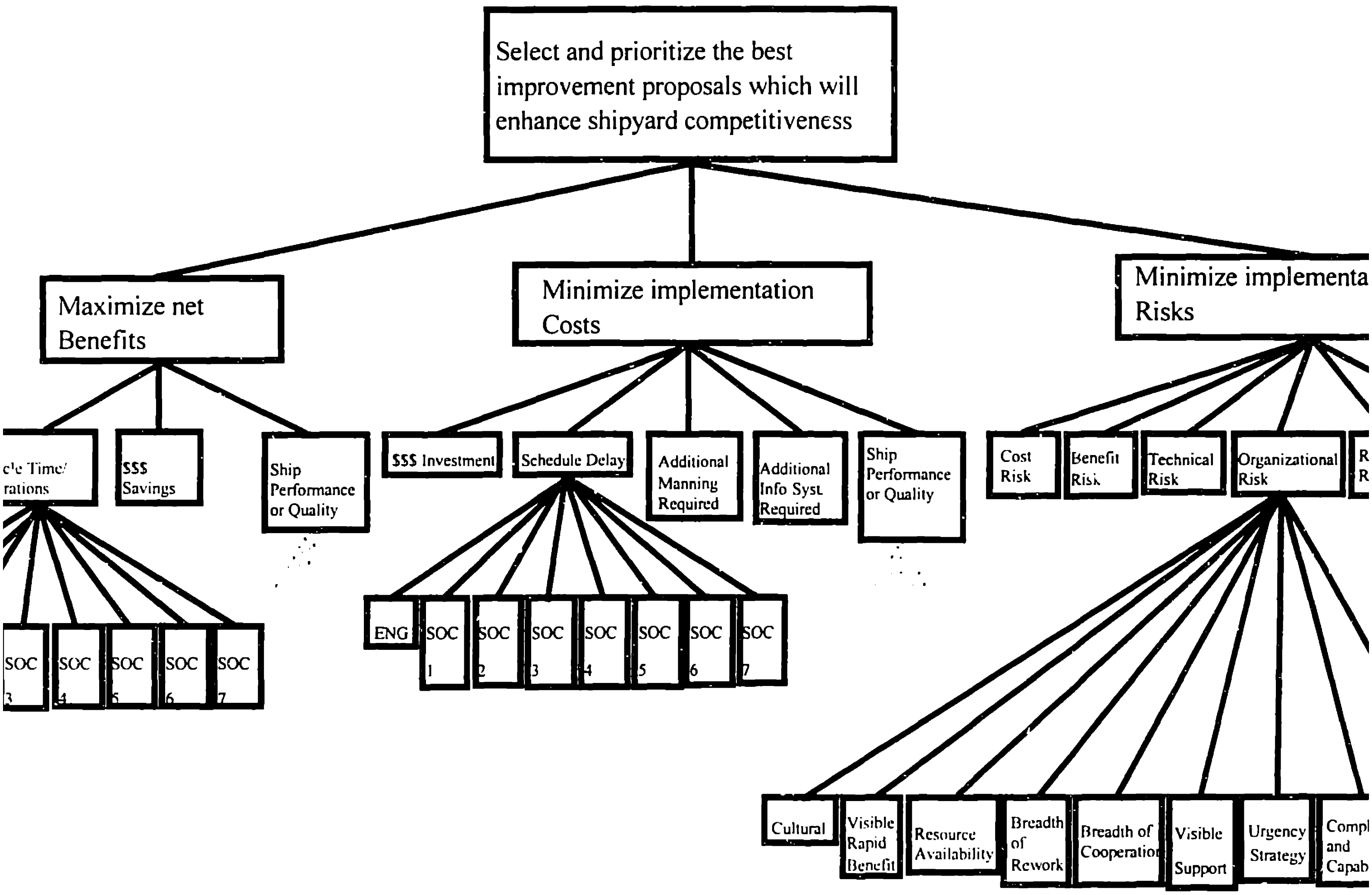
The objectives of this excersise were two-fold:

- Determine how applicable this decision modeling approach would be in practice
- Determine if the results of the decision model adequately reflect quality decisionmaking

7.3.1 Thresholds and Goals

Prior to establishing criteria weights, thresholds and goals were examined for each of the model parameters. Respondents were asked when considering the benefits, costs or risks of proposals, to describe the threshold level for each sub-criteria. These threshold levels were intended to represent the minimum level of achievement accepted to consider implementing a proposal. They were also asked to describe the goal level. This represented a "stretch goal" or the best they would expect to see a proposal achieve. These thresholds and goals would be useful in setting the context for the subsequent pair-wise comparisons and would also aid in the development of a pre-prioritization screening model. As will be shown, establishing tight thresholds and goals for each of the model parameters was not trivial and the results did not yield explicit consensus. One of the results of this excursus was a realization that thresholds and goals reflect shipyard policy and consensus. It is the task of upper management to facilitate establishing such a policy. A second result was the realization that thresholds and goals are not independent, and a more appropriate approach would be to utilize constructed attributes which combine parameters using a descriptive scale as described earlier. An example of such a constructed attribute scale is the McCarthy preparedness scale presented in Chapter 2.0.

In an effort to establish the thresholds and goals, respondents were asked to assume that the only cycle time reduction a proposal results in is for that particular stage. In setting the threshold and goal for "all stages" they were to consider the reduction they would expect to see for any given proposal with respect to total construction cycle. These were expressed as % improvement over current performance. The ranges of results are provided in Table 7.1. The responses ranged from "positive" representing any positive value to an explicit percentage. With respect to dollar savings, the responses for goals ranged from positive to $25,000. Goals ranged from $300,000 and higher. Performance improvement goals were simply viewed as "positive." It was clear from the responses that respondents had varying views, especially with respect to stretch goals.



)C = Stage Of Construction

FIGURE 7.2 - MODEL HIERARCHY

With respect to implementation costs, some respondents viewed dollar investment as a meaningful threshold while others were unable to consider costs independently of benefits when explaining thresholds. These respondents preferred to think in terms of benefit to cost ratios or payback periods as thresholds. The goal in this case was to spend zero dollars. Thresholds ranging from $100,000 to $10 M were suggested, with the high end qualified as representing high benefit projects for which the "money would be found." Benefit to cost ratios of 3:1 were suggested. Figure 7.3 illustrates the payback period relationship that was suggested. These varied responses and difficulty in separating parameters when considering thresholds strongly suggests the need for an alternative approach to screening, utilizing constructed attributes, and the need for shipyard policy.

STAGE	THRESHOLD	GOAL	STAGE	THRESHOLD	GOAL
Engineering:	+ to 10 %	+ to 50 %	SOC 4:	+ to 10 %	+ to 40 %
SOC 1:	+ to 20 %	+ to 50 %	SOC 5:	+ to 10 %	+ to 50 %
SOC 2:	+ to 20 %	+ to 50 %	SOC 6:	+ to 5 %	+ to 25 %
SOC 3:	+ to 10 %	+ to 50 %	SOC 7:	+ to 10 %	+ to 25 %
All Stages:	+ to 10 %	+ to 50 %			

TABLE 7.1 - CYCLE TIME BENEFIT THRESHOLDS AND GOALS

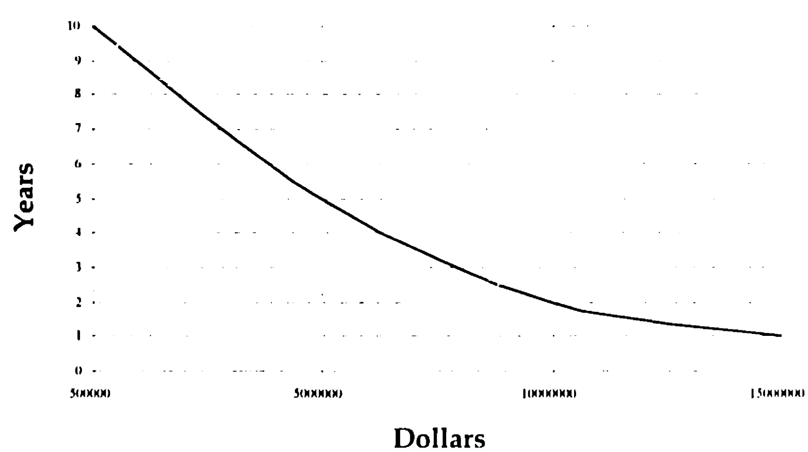


FIGURE 7.3 - PAYBACK PERIOD

With respect to schedule delays, the goal was no schedule delay. Thresholds varied, but to a lesser extent than was the case with benefits. Table 7.2 provides these results.

STAGE	THRESHOLD	GOAL	STAGE	THRESHOLD	GOAL
Engineering:	2 to 10 %	0 %	SOC 4:	5 to 20 %	0 %
SOC 1:	5 to 20 %	0 %	SOC 5:	4 to 10 %	0 %
SOC 2:	5 to 20 %	0 %	SOC 6:	0 to 5 %	0 %
SOC 3:	5 to 10 %	0 %	SOC 7:	0 to 10 %	0 %
All Stages:	5 to 10 %	0 %			

TABLE 7.2 - SCHEDULE DELAY THRESHOLDS AND GOALS

With respect to manning costs, the threshold was expressed in a variety of ways ranging from 25% increase, 10 to 20 Engineering and 100 to 200 Production and 50 overall. The goal was no manning increase. With respect to information systems, responses varied including 33% increase and 10 to 100 terminals/licenses. Again the goal was zero. With respect to ship performance/quality impact, the goal was no negative impact. The threshold was expressed as a level related to the specifications and "good shipbuilding practice." It is understood that some negotiation with the customer can modify the specifications.

With respect to a variety of risks, respondents were asked to indicate the threshold uncertainty which they would accept. The following summarizes these results. Once again, the responses were very broad. Respondents found it very difficult to set thresholds for schedule risk. Qualitatively, the threshold is that confidence is high that the thresholds for schedule delay will not be surpassed.

- 50 to 70% probability that implementation cost is as estimated
- 5 to 60% probability that implementation cost is 10% higher
- 20 to 75% maximum increase in cost estimate acceptable
- 2 to 50% probability that cost estimate increases by that amount
- 10 to 90% probability that implementation benefit is as estimated
- 5 to 60% probability that implementation benefit is 10% lower
- 20 to 30% decrease in benefit below estimate acceptable
- 2 to 50% probability that implementation benefit is that much lower
- 0.25 to 15% probability that technical risks block implementation
- 0.25 to 15% probability that regulatory risks block implementation
- 1 to 25% probability that the organization will not be supportive

Thus we can conclude that the setting of thresholds and goals is not trivial, and that looking at parameters in isolation is difficult for most people when setting thresholds and goals. Respondents found setting goals against specific parameters to be less difficult then setting thresholds. Goal setting is an outcome of even the most basic strategic planning process, and is therefore better understood by most personnel. What is missing in most strategic planning excursuses is policy development with respect to thresholds. Provided that proposals were deemed "feasible" by respondents, they did not find it difficult to pairwise compare them with respect to individual parameters as will be discussed shortly. The real objective is to establish what "feasible" means. This involves shipyard policy with respect to acceptable costs and risks, as well as desired "hurdle rates" for benefits. As an alternative to looking at parameters in isolation, constructed attribute scales can be developed as necessary to describe a feasibility scale for benefit, cost and risk. This can then be used to screen proposals.

7.3.2 Criteria Weights Assuming Independence

Criteria were first examined ignoring dependencies. Later the impact of dependencies were considered. The results ignoring dependency are presented first, followed by a discussion of how dependencies were accounted for. Prior to filling out the surveys, a session was held with each respondent to discuss how to interpret the pairwise comparisons and to insure that each of the parameters was clearly understood. A commercial software package, "Expert Choice", was used to facilitate synthesis of the pair-wise comparison results. As Figure 7.4 illustrates, both opportunity oriented and danger oriented preferences were exhibited in the prioritization of the high level criteria. This reinforces the conclusion that shipyard strategic policy must be established regarding objectives and attitudes towards benefit, cost and risk. Establishing such a policy for this shipyard was beyond the scope of this research. It is interesting to note that the AHP serves not only as a decision analysis tool, but also as a mechanism for facilitating such policy setting by making differing perceptions explicit and focusing discussion on critical issues. The differing attitudes were largely along position lines. Those in Engineering and Cost Engineering tended to be more risk averse than those is Production Engineering and Production. Table 7.3 provides a tabular summary of the eigenvector results for each respondent and the synthesis of their results using the normalized geometric mean. Overall, this shipyard's prioritization reflects opportunity seeking which is consistent with the results of the industry survey presented in Chapter 4.0.

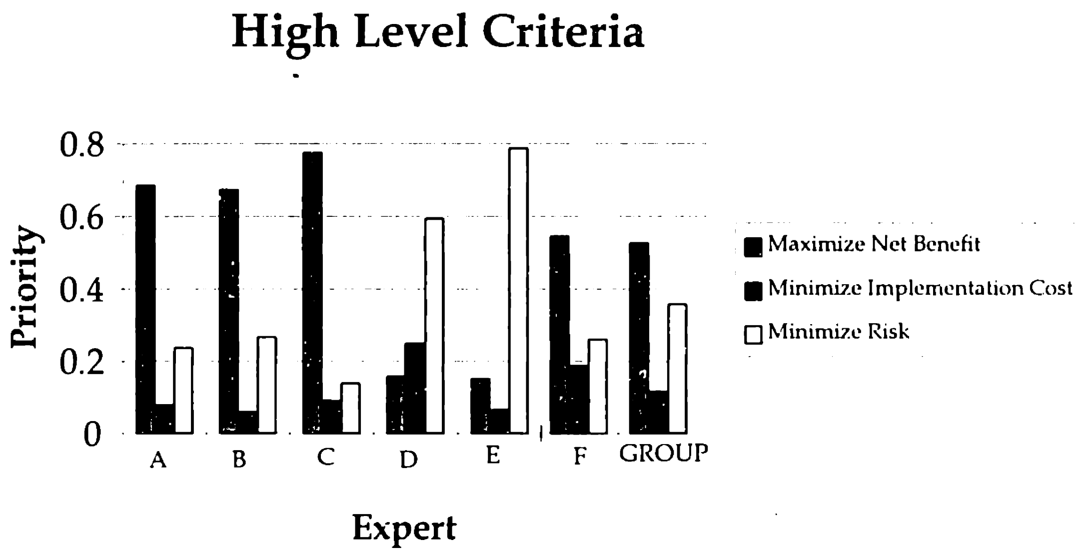


FIGURE 7.4 - HIGH LEVEL CRITERIA

High Level Criteria									Normalized	
	A	B	C	D	E	F	G	GEOMEAN	GROUP	AVERAGE
Maximize Net Benefit	0.685	0.672	0.773	0.157	0.149	0.547	0.733	0.443	0.527	0.531
Minimize Implementation Cost	0.08	0.063	0.088	0.249	0.066	0.19	0.068	0.099	0.118	0.115
Minimize Risk	0.234	0.265	0.139	0.594	0.785	0.263	0.199	0.298	0.355	0.354
								0.840	1.000	1.000

TABLE 7.3 - HIGH LEVEL CRITERIA SUMMARY

With respect to maximizing net benefits, greater consensus is evident in the results which are illustrated in Figure 7.5 and table 7.4. The results also support those presented in the industry survey, with cycle time reduction considered to be the highest priority.

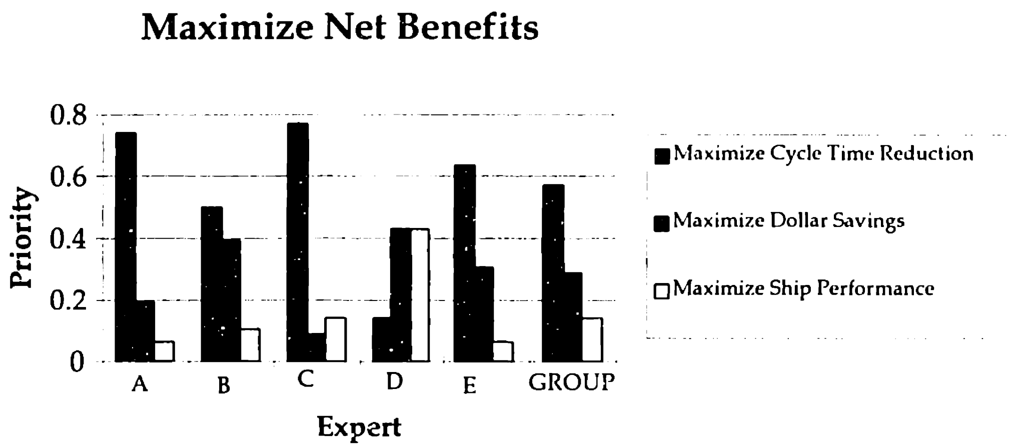


FIGURE 7.5 - NET BENEFIT CRITERIA WEIGHTS

Net Benefits						GEOMEAN		
						Normalized		
	A	B	C	D	E	GEOMEAN	GROUP	AVERAGE
Maximize Cycle Time Reduction	0.743	0.499	0.773	0.143	0.633	0.482	0.569	0.558
Maximize Dollar Savings	0.194	0.396	0.088	0.429	0.304	0.245	0.289	0.282
Maximize Ship Performance Improvement	0.063	0.105	0.139	0.429	0.063	0.120	0.142	0.160
						0.847	1.000	1.000

TABLE 7.4 - NET BENEFIT CRITERIA SUMMARY

Sub-criteria to cycle time benefits were similarly examined as illustrated below. The responses show clear agreement that stage of construction 6 is a high priority. The majority of respondents also considered stage 7 to be a high priority.

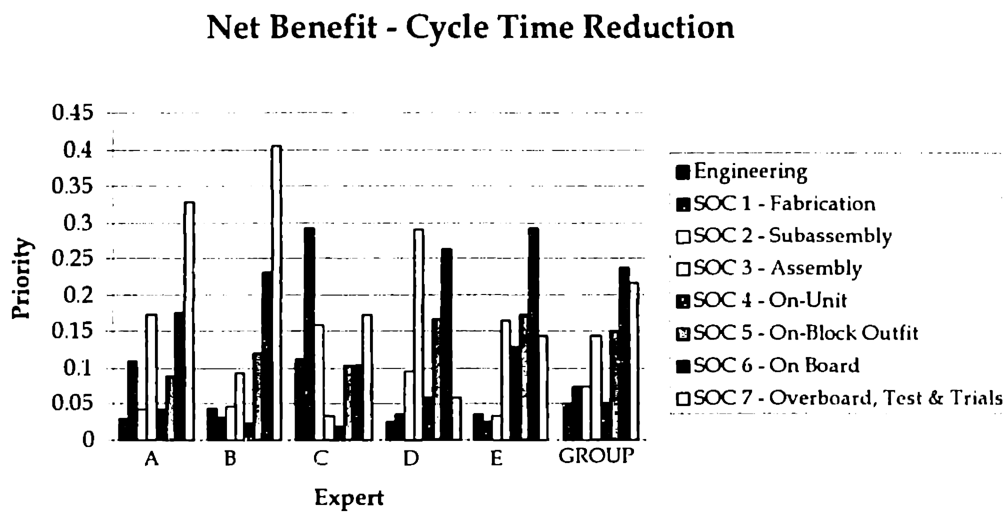


FIGURE7.6 - CYCLE TIME REDUCTION CRITERIA WEIGHTS

Net Benefit - Cycle Time Reduction						GEO MEAN		
						NORMALIZED		
	A	B	C	D	E	GEO MEAN	GROUP	AVERAGE
Engineering	0.030	0.045	0.113	0.026	0.037	0.043	0.051	0.050
SOC 1 - Fabrication	0.111	0.032	0.293	0.036	0.025	0.062	0.074	0.099
SOC 2 - Subassembly	0.043	0.046	0.160	0.095	0.033	0.063	0.075	0.075
SOC 3 - Assembly	0.175	0.093	0.035	0.291	0.166	0.122	0.145	0.152
SOC 4 - On-Unit	0.043	0.024	0.019	0.060	0.129	0.043	0.051	0.055
SOC 5 - On-Block Outfit	0.090	0.122	0.103	0.168	0.174	0.127	0.151	0.131
SOC 6 - On Board	0.177	0.232	0.103	0.264	0.293	0.201	0.238	0.214
SOC 7 - Overboard, Test & Trials	0.330	0.406	0.175	0.059	0.144	0.182	0.216	0.223
						0.844	1.000	1.000

TABLE 7.5 - CYCLE TIME REDUCTION SUMMARY

With respect to minimizing implementation costs, respondents showed a clear preference for minimizing schedule delay as the most important sub-criteria. Sub-criteria to schedule delays were similarly examined.

Minimize Implementation Costs						GEO MEAN		
						Normalized		
	A	B	C	D	E	GEO MEAN	GROUP	AVERAGE
Minimize Dollars Invested	0.074	0.227	0.042	0.082	0.160	0.098	0.109	0.117
Minimize Schedule Delay	0.358	0.538	0.550	0.395	0.497	0.461	0.508	0.468
Minimize Additional Manning Required	0.164	0.108	0.076	0.253	0.259	0.155	0.170	0.172
Minimize Additional Info Systems Rqd	0.057	0.054	0.076	0.100	0.054	0.066	0.073	0.068
Minimize Ship Performance Impact	0.347	0.074	0.256	0.170	0.030	0.127	0.140	0.175
						0.907	1.000	1.000

TABLE 7.6 - MINIMIZE IMPLEMENTATION COSTS SUMMARY

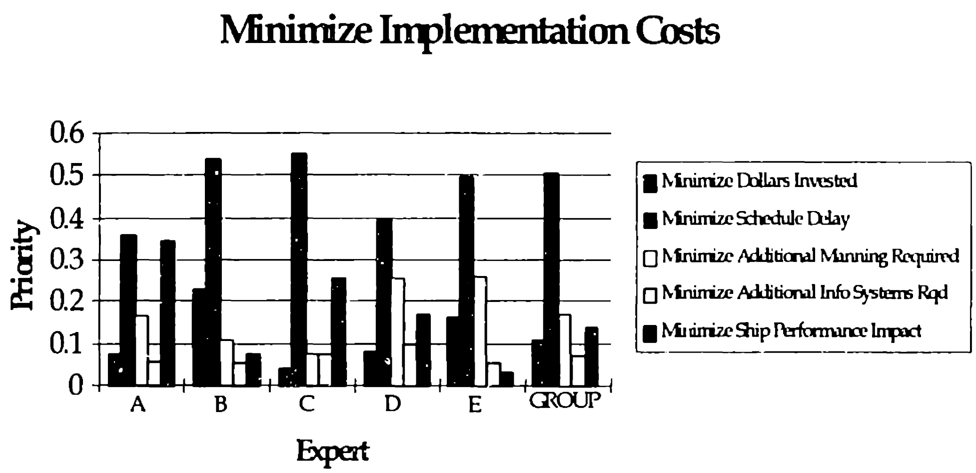


FIGURE 7.7 - MINIMIZE IMPLEMENTATION COSTS CRITERIA WEIGHTS

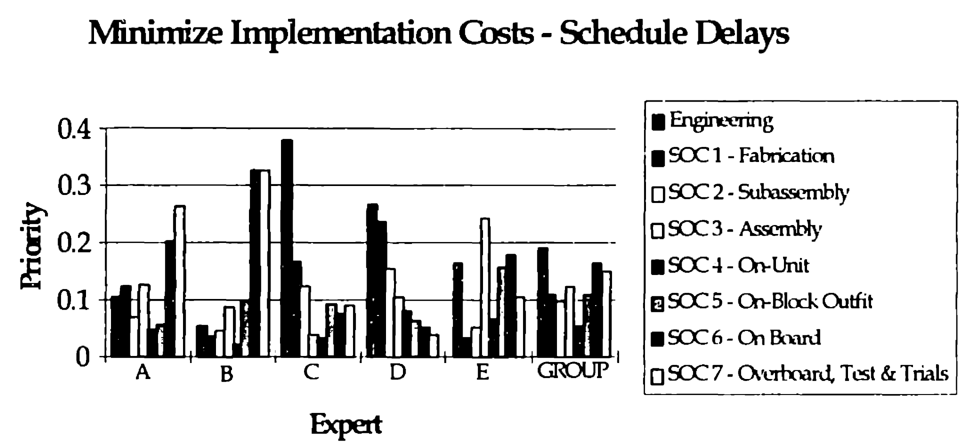


FIGURE 7.8 - SCHEDULE DELAY CRITERIA WEIGHTS

Minimize Costs - Minimize Schedule Impact						GEO MEAN NORMALIZED		
	A	B	C	D	E	GEO MEAN	GROUP	AVERAGE
Engineering	0.105	0.054	0.379	0.267	0.164	0.157	0.190	0.194
SOC 1 - Fabrication	0.123	0.036	0.166	0.236	0.033	0.089	0.109	0.119
SOC 2 - Subassembly	0.071	0.046	0.125	0.155	0.051	0.080	0.097	0.090
SOC 3 - Assembly	0.126	0.088	0.038	0.105	0.241	0.101	0.123	0.120
SOC 4 - On-Unit	0.050	0.022	0.033	0 083	0.066	0.046	0.056	0.051
SOC 5 - On-Block Outfit	0.059	0.098	0.093	0.065	0.158	0.089	0.108	0.095
SOC 6 - On Board	0.203	0.328	0.075	0.051	0.180	0.136	0.165	0.167
SOC 7 - Overboard, Test & Trials	0.263	0.328	0.090	0.038	0.107	0.126	0.153	0.165
						0.823	1.000	1.000

TABLE 7.7 - SCHEDULE DELAY SUMMARY

Responses associated with priorities for averting different types of risks are illustrated in the following. The results indicate the greatest priority being given to averting risks associated with schedule.

Minimizing Risks							GEOMEAN	
							NORMALIZED	
	A	B	C	D	E	GEOMEAN	GROUP	AVERAGE
Cost Risk	0.099	0.207	0.025	0.270	0.046	0.091	0.113	0.129
Benefit Risk	0.099	0.183	0.028	0.270	0.200	0.122	0.152	0.156
Technical Risk	0.179	0.106	0.368	0.082	0.092	0.139	0.173	0.165
Organizational Support Risk	0.227	0.026	0.082	0.148	0.180	0.105	0.130	0.133
Regulatory/Customer Risk	0.198	0.060	0.335	0.082	0.037	0.104	0.129	0.142
Schedule Risk	0.198	0.418	0.161	0.148	0.444	0.245	0.303	0.274
						0.807	1.000	1.000

TABLE 7.8 - RISK SUMMARY

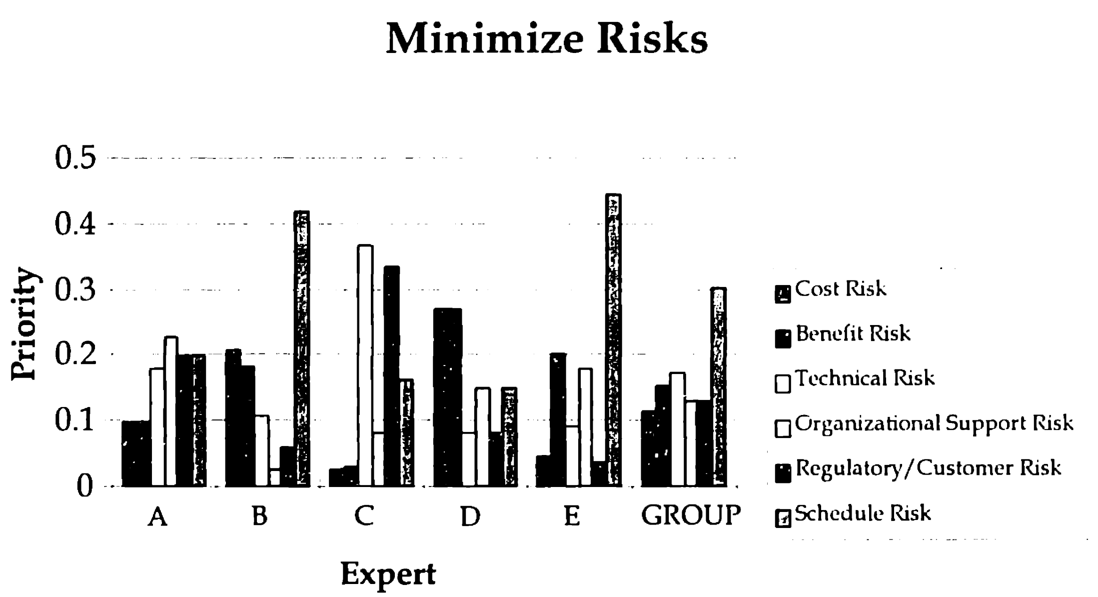


FIGURE 7.9 - RISK CRITERIA WEIGHTS

Minimize Risks - Organizational Support						GEO MEAN NORMALIZED	
	A	C	D	E	GEO MEAN	GROUP	AVERAGE
Cultural	0.142	0.031	0.205	0.078	0.092	0.107	0.114
Visible Rapid Benefits	0.106	0.081	0.118	0.040	0.080	0.093	0.086
Resource Availability	0.083	0.108	0.073	0.312	0.120	0.139	0.144
Breadth of Rework	0.058	0.138	0.061	0.096	0.083	0.097	0.088
Breadth of Cooperation	0.123	0.036	0.111	0.163	0.095	0.110	0.108
Visible Upper Mgt Support	0.152	0.081	0.118	0.034	0.084	0.098	0.096
Urgency and Strategic Fit	0.200	0.134	0.197	0.033	0.115	0.134	0.141
Complexity & Capability	0.071	0.205	0.073	0.068	0.092	0.108	0.104
Stability	0.065	0.188	0.043	0.177	0.098	0.115	0.118
					0.857	1.000	1.001

TABLE 7.9 - ORGANIZATIONAL RISK SUMMARY

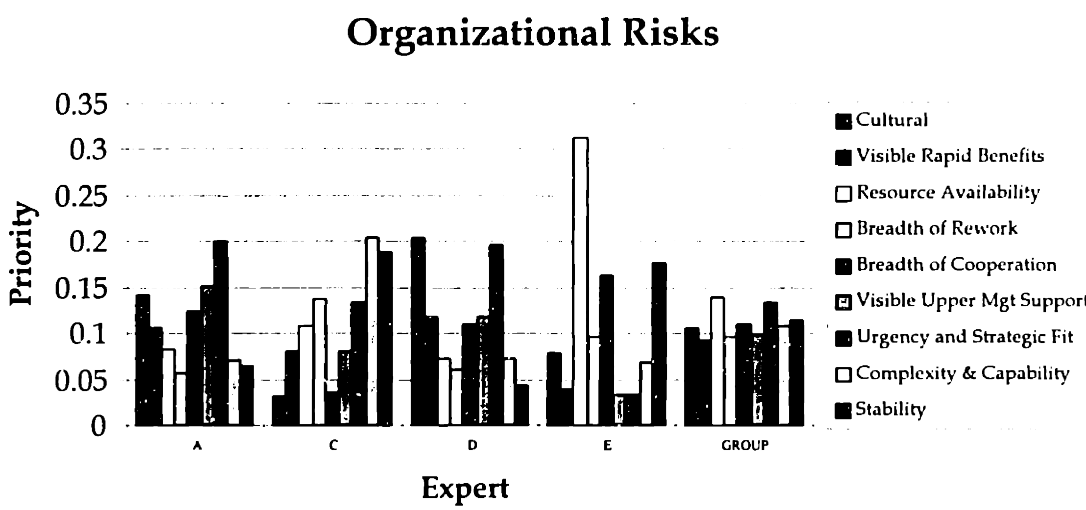


FIGURE 7.10 - ORGANIZATIONAL RISK CRITERIA WEIGHTS

7.3.3 Criteria Weights with Dependence

The five respondents agreed that dependencies existed between model parameters, but all had difficulty exploring and expressing these in isolation. It was necessary to sit with each to discuss the parameters and how they impacted one another. The supermatrix extension of the AHP is used to account for these dependencies as discussed in detail earlier in the previous section.

> A hierarchy is a particular type of system, which is based on the assumption that the entities...can be grouped into disjoint sets, with the entities of one group influencing the entities of only one other group...,

> and being influenced by the entities of only one other group. The elements in each group (also called level, cluster, stratum) of the hierarchy are assumed to be independent. If there is dependence among them we study independence and dependence separately and combine the two... [Saaty, 1994, p.11]

The relationships between criteria were explored as in input-output feedback system analysis. The concern is the degree to which one parameter assists another in its contribution. Figure 7.11 illustrates such a system with feedback as it would relate to the high level criteria of benefits, costs and risks. Table 6.10 provides a summary of the consensus regarding the interaction of these high level criteria. The adjusted priority vector is the cross product between the dependence relationship matrix and the independent priority vector. Figure 7.12 illustrates the adjusted priorities. The adjusted high level criteria weights show an increased weighting associated with minimizing cost, due to its strong association with minimizing risks. Minimizing risks and minimizing costs were not believed to contribute to maximizing benefit by the respondents. In addition to examining relationships between the high level criteria, the relationships between the lower level criteria were also examined. These adjustments lose significance as one moves deeper into the hierarchy because the contribution of differences between lower level criteria weights to alternative ranking is diminished as compared to the contribution of differences between the higher level criteria.

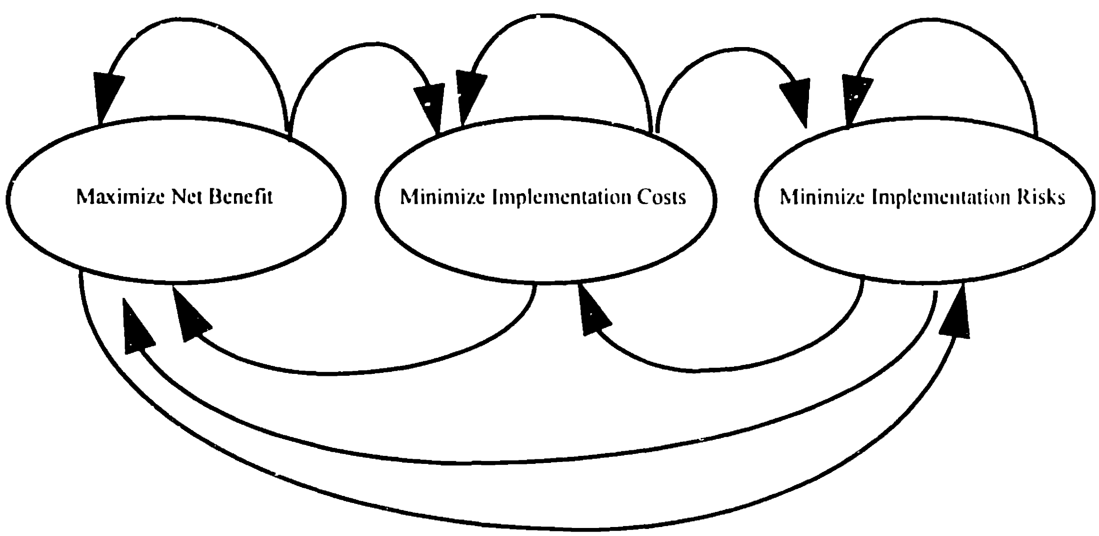


FIGURE 7.11 - SYSTEM WITH FEEDBACK

With Respect To Prioritizing Design Improvement Proposals	Maximize Net Benefit	Minimize Implementation Cos	Minimize Implementation Ris	Independent Priority	Intercependence Priority
Maximize Net Benefit	1.000	0.000	0.000	0.527	0.527
Minimize Implementation Costs	0.000	0.700	0.300	0.118	0.189
Minimize Implementation Risks	0.000	0.300	0.700	0.355	0.284
	1.000	1.000	1.000	1.000	1.000

TABLE 7.10 - HIGH LEVEL CRITERIA INTERDEPENDENCE

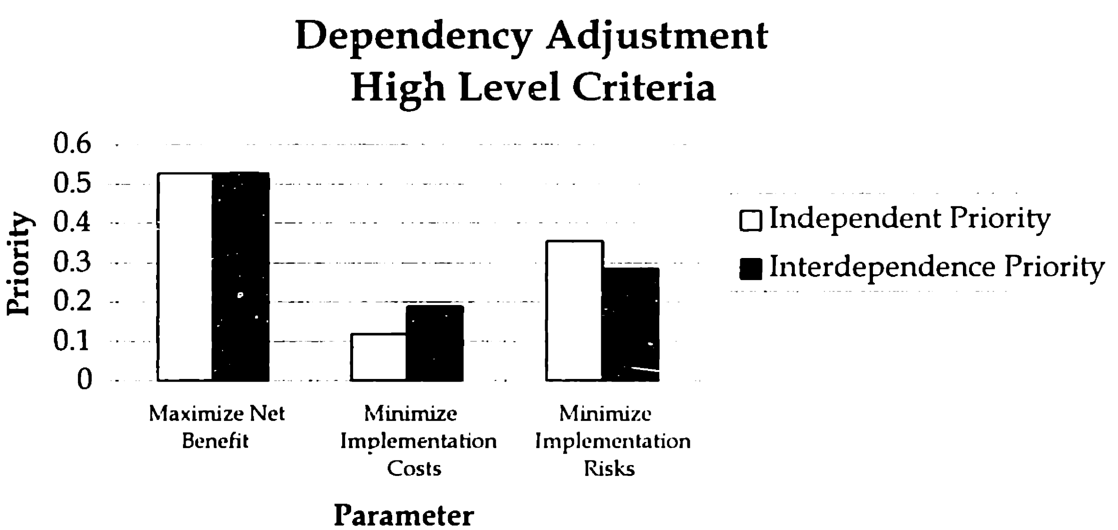


FIGURE 7.12 - ADJUSTED HIGH LEVEL CRITERIA WEIGHTS

Later, after an initial evaluation of case studies had been performed, the validity of the assumptions made regarding the dependence between parameters was explored. This was accomplished by looking for correlation between the benefit, cost and risk priorities assigned to the case studies. The results are illustrated in the following figures. Each data point represents a case study. The figures demonstrate that, at least for the eight cases studied, minimizing cost appears to be associated with minimizing risk. On the other hand, maximizing benefit contributes in a positive way to neither minimizing costs nor risks. These findings suggest that the relationships established above are reasonable and simply validates what most program managers know, that higher risk and cost projects are associated with greater potential gains.

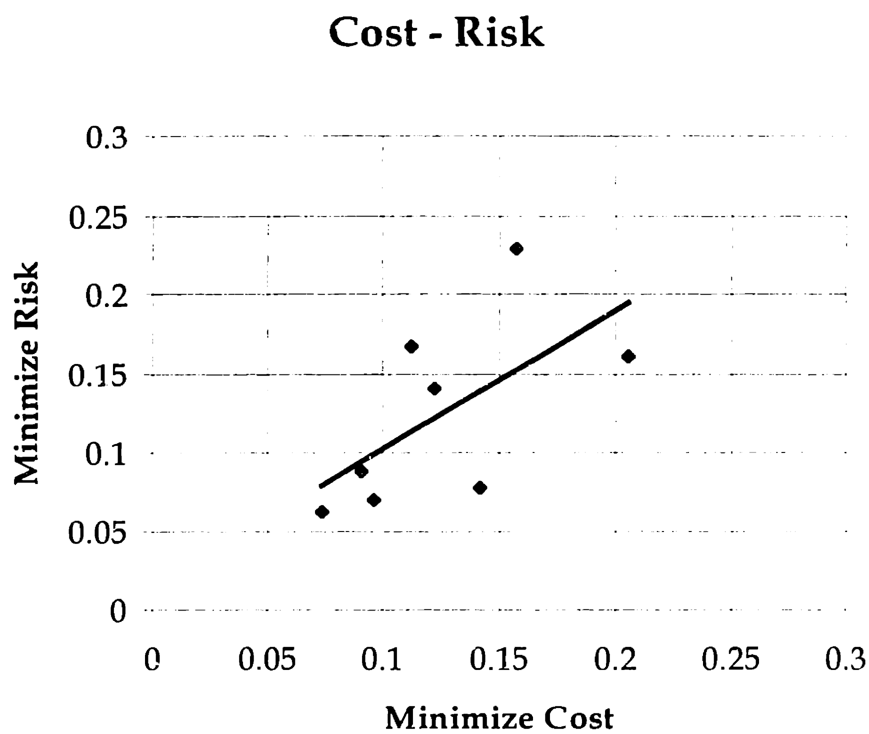


FIGURE 7.13 - COST-RISK RELATIONSHIP

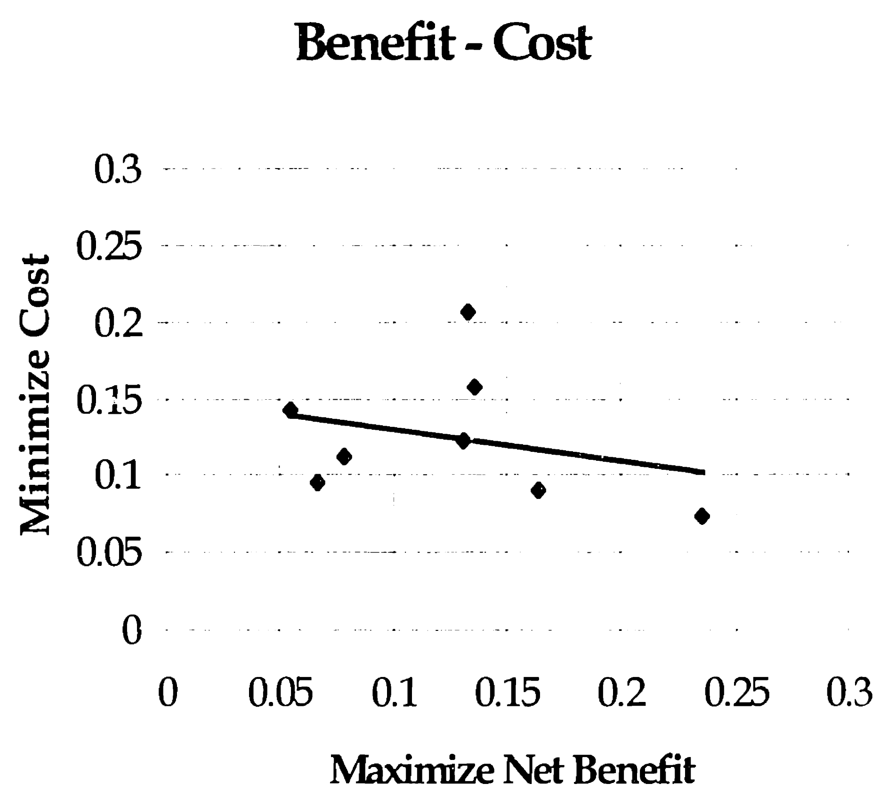


FIGURE 7.14 - BENEFIT-COST RELATIONSHIP

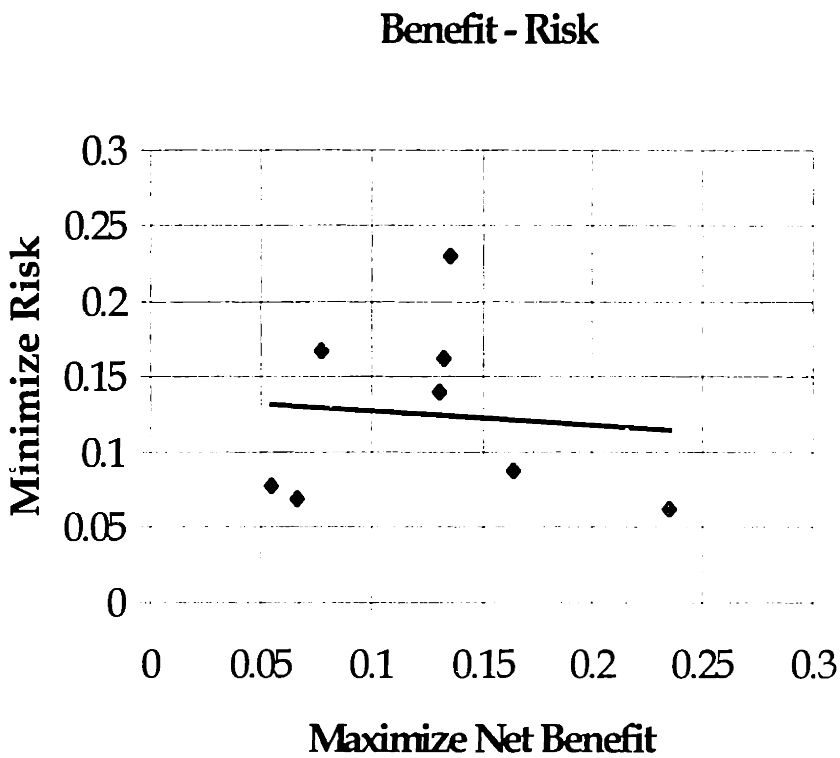


FIGURE 7.15 - BENEFIT-RISK RELATIONSHIP

7.3.4 Case Study Evaluation With Independence

Having established criteria weights for the model, the next task was to test an application of the model utilizing case studies. Eight case proposals were used in this analysis. The proposals were selected because:

- They were familiar to all the respondents
- They were all representative of the type of productivity enhancing design changes the participating shipyard was involved with
- They had all been acted upon in some way and some assessment of actual results could be used to judge the quality of the decision analysis model that had been developed

The synthesized priorities are based upon the weighting developed as described in 7.3.2. The participants were also asked to pairwise compare the proposals directly with respect to the degree to which they believed they had actually contributed to shipyard competitiveness. First the results assuming no dependency were examined. Later adjustment of the criteria and alternative weights to consider dependency were explored.

Figure 7.16 compares the initial synthesis results with the group judgment (as the normalized geometric mean). The synthesis represents the model output considering the relative weights assigned to all the parameters including the high level criteria weights for benefit, cost and risk. Fewer respondents participated in this phase of the research than had in setting the criteria weights. The criteria weights were based upon five respondents. The group judgment representing "reality" is based upon four of these respondents' feedback. Three respondents participated in establishing the proposal evaluation relative to the criteria. During the first run through the model, inconsistency was high for a number of the respondents' identified preferences. After the initial analysis of the results, those evaluations for which the inconsistency ratio was greater than 0.11 were explored with the respondents. The Expert Choice software facilitates this by calculating the inconsistency of the responses and highlighting which responses are most inconsistent. Through discussion, the consistency was improved such that no responses exhibited inconsistency above 0.1, which is regarded as the limit for quality decisions.

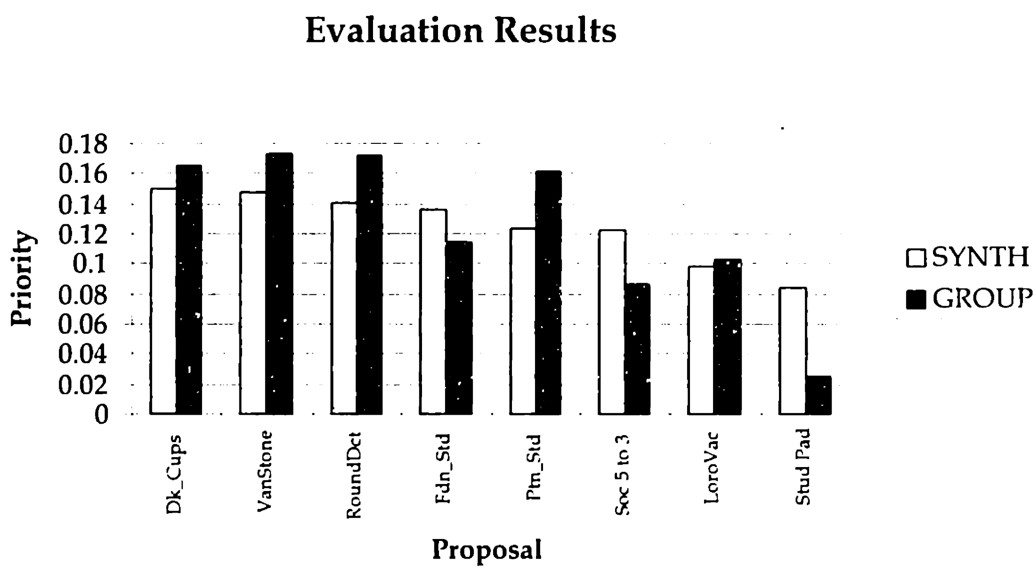


FIGURE 7.16 - SYNTHESIS VS. GROUP

The correlation of the synthesis results, representing the model output considering the relative weighting of benefit, cost and risk, was not as strong as might have been expected. This is particularly evident for the penetration standard case. The group judgment regarding how well these proposals contributed to competitiveness relative to others in reality is significantly higher than the model synthesis results. Dependencies between criteria and alternatives will ultimately adjust these results, so it is too early to draw final conclusions.

While dependency has not yet been considered, some data available at this point sheds light on factors that are contributing to the discrepancy. During the evaluation process, an analysis of the initial results should be performed to establish the degree of consensus that exists among the respondents and other factors which may bias results.

With respect to the weighting of the criteria, it is possible they may not reflect the actual outcome. It should be pointed out that the comparison made in the above chart is between an assessment of actual results and a decision priority reflecting considerations regarding benefit, cost and risk. If the shipyard mitigated risks associated with particular projects very well during implementation, then the actual results may not reflect what had been a perfectly reasonable concern regarding risks during the evaluation phase. In fact, a key element of the evaluation phase and a key benefit of the AHP approach proposed here is that relative risk, cost and benefit is made explicit; therefore means for improving proposals can be explored. In addition, the shipyard did not track the actual results of each proposal in a rigorous way, and so the group judgment represents expert opinion rather than absolute measures. When a comparison is made between the model output for benefit only and the group judgment regarding the actual outcome, the correlation is much improved both with respect to weight and rank as illustrated in Figure 7.17. This may suggest that the shipyard weighted risk and cost criteria more heavily than their actual experience would suggest is necessary. It also suggests that the yard was successful in mitigating what were considered at the time to be considerable risks and costs. This is illustrated in Figure 7.18.

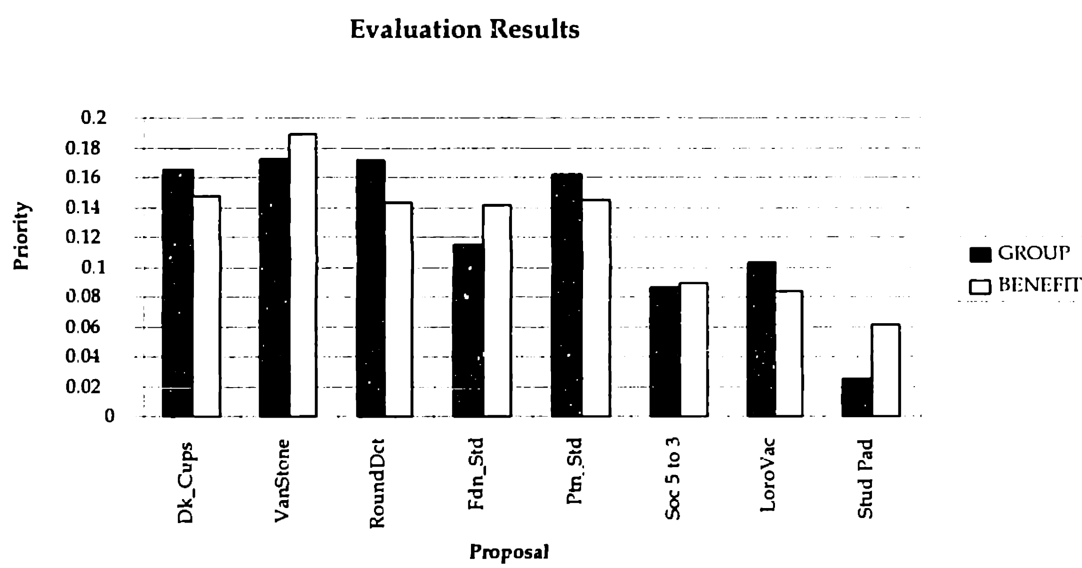


FIGURE 7.17 - MODEL BENEFIT VS. GROUP JUDGMENT

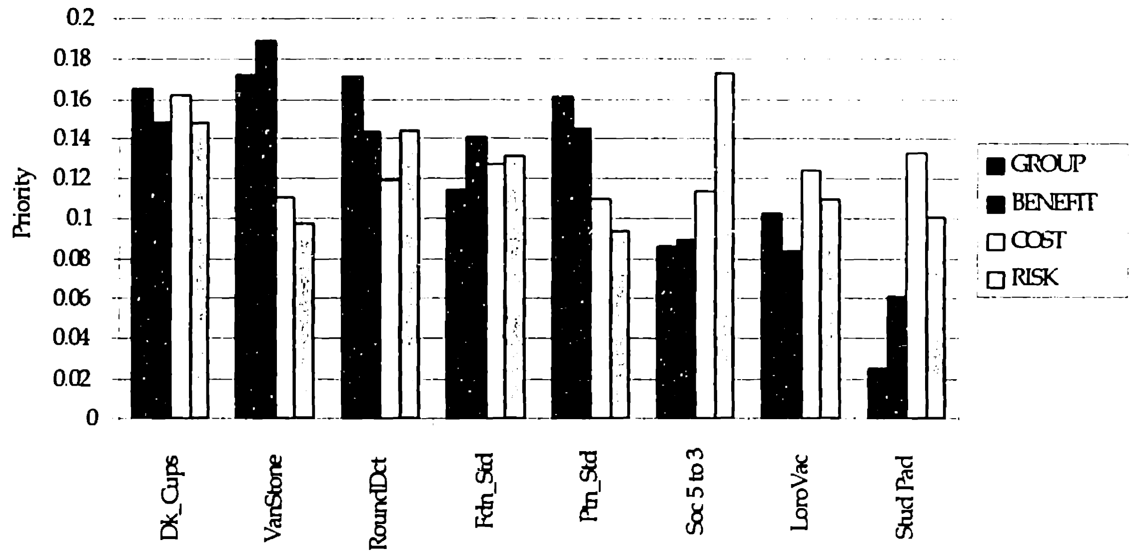


FIGURE 7.18 - COST, RISK, AND BENEFIT RESULTS

In addition, the individual respondent's priorities are not representative of a consensus. The more variation between respondents' priorities, the less likely it is that a deterministic synthesis will yield a correlation. This was eluded to earlier during this discussion of the applicability of deterministic synthesis of group judgments. They are considered representative when the respondents have equal access to information and have an opportunity to discuss the problem. The respondents in this case were unable to spend any significant time discussing the excursus with one another.

One of the contributions which an AHP model such as this can make to the decisionmaking process is to facilitate developing such consensus by making these priorities explicit. This is an important step in the evaluation process to insure that the criteria reflect shipyard policy and that decisionmakers are evaluating proposals based upon the same information. The following figures illustrate the point. Note that consensus between individuals (experts represented as A through D) would be reflected by all the data points representing their priorities landing on the diagonal on a scatter plot. Significant variation exists for several of the case studies, and in a practical application the reasons for this discrepancy would need to be examined at this point, prior to moving on to the final phases of the evaluation.

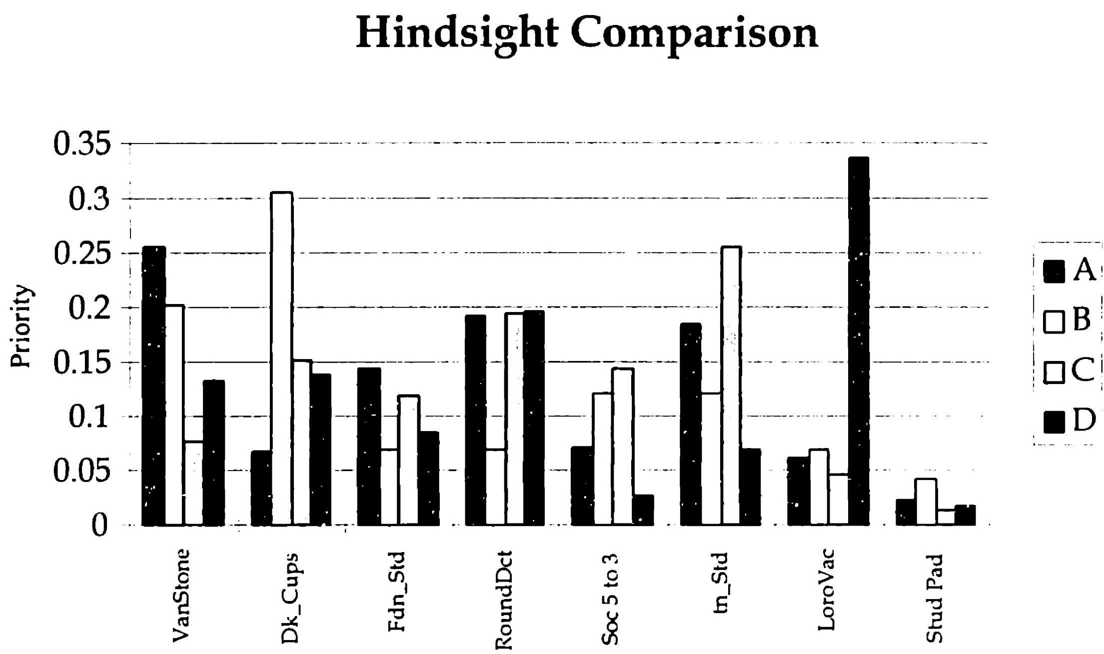


FIGURE 7.19 - GROUP JUDGMENT VARIATION

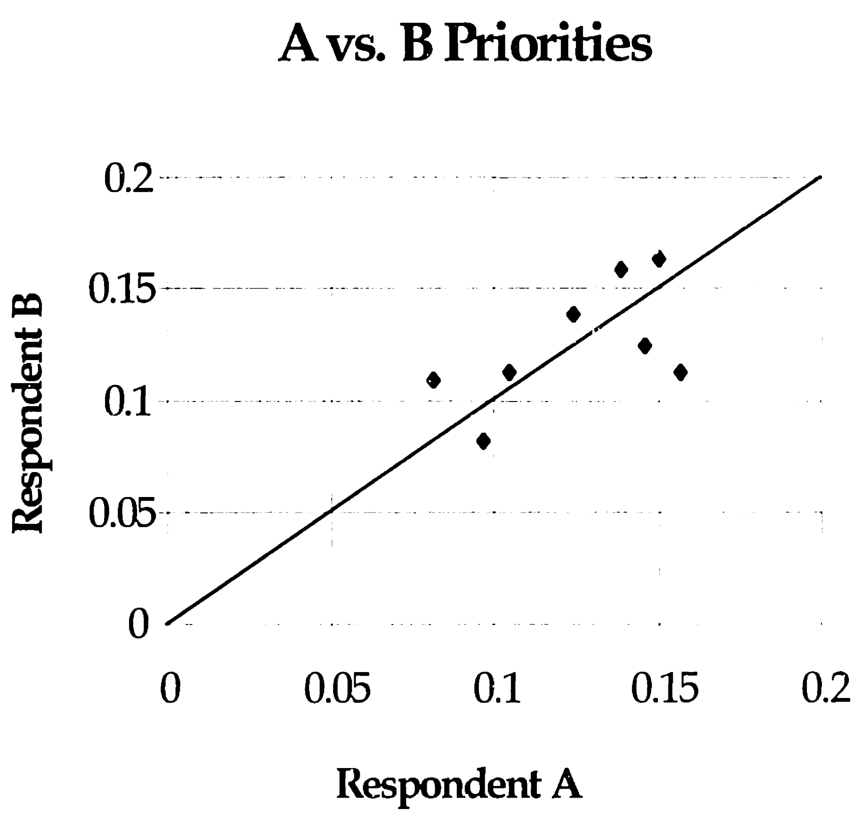


FIGURE 7.20 - A VS. B MODEL RESULTS

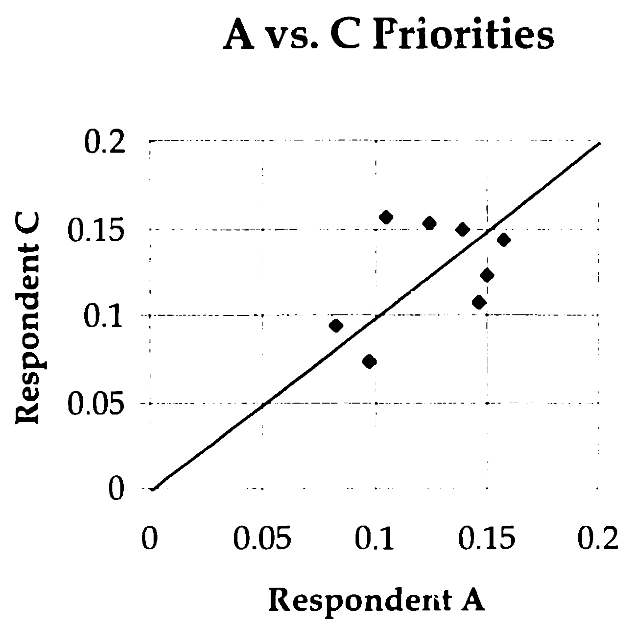


FIGURE 7.21 – A VS. C MODEL RESULTS

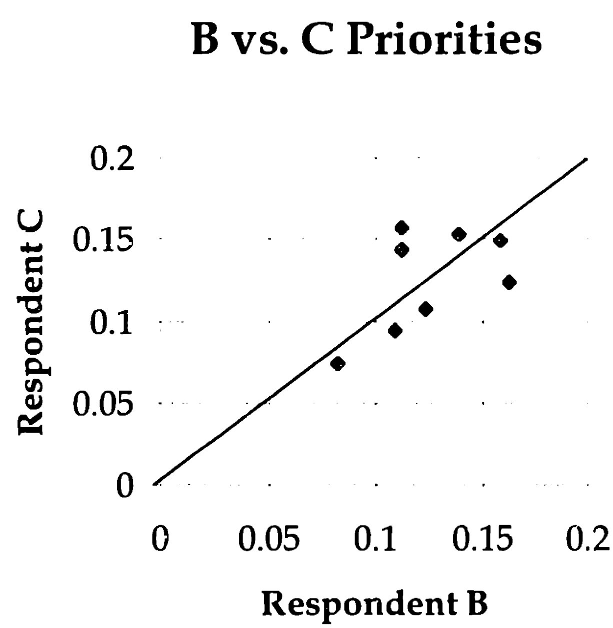


FIGURE 7.22 - B VS. C MODEL RESULTS

7.3.5 Case Study Evaluation With Dependency

Next the impact of dependency was accounted for in the model. First the adjusted criteria weights, discussed and presented earlier, were entered into the model. Figure 7.23 illustrates that the criteria dependencies had little impact on the outcome.

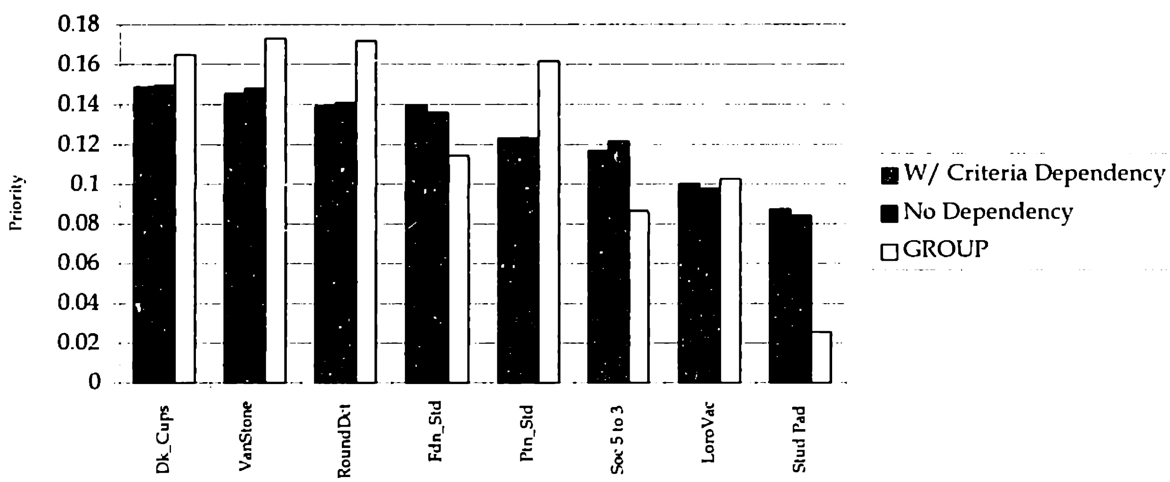


FIGURE 7.23 - RESULTS WITH CRITERIA DEPENDENCY

It was also clear that there were dependencies between proposals. These were explored next in a manner similar to the approach taken for criteria, and accounted for in the model prior to drawing final conclusions regarding relative rank and weight. Discussion with respondents indicated that dependencies were judged to exist between proposals relative to benefits only. The most significant of these was that several of the proposals depended upon the penetration standard to achieve full impact. This is because distributive system proposals required larger openings to meet their full potential. In addition, the proposal to move work content from stage 5 to stage 3 requires these penetrations and penetration parts to be cut and installed earlier to fully support it. Figures 7.24 and 7.25 and Tables 7.11 and 7.12 illustrate these adjustments with respect to cycle time and dollar savings priorities.

ALL	RoundDct	Dk_Cups	VanStone	Fdn_Std	Ptn_Std	Soc 5 to 3	LoroVac	Stud Pad	INDEPENDENT PRIORITY	INTERDEPENDENT PRIORITY
RoundDct	0.7	0	0.05	0.2	0.1	0	0	0	0.158	0.166
Dk_Cups	0	1	0	0	0	0	0	0	0.128	0.128
VanStone	0.05	0	0.75	0.2	0.05	0.05	0	0	0.174	0.183
Fdn_Std	0	0	0	0.55	0	0	0	0	0.167	0.092
Ptn_Std	0.2	0	0.2	0.05	0.8	0.1	0.1	0	0.137	0.202
Soc 5 to 3	0.05	0	0	0	0	0.8	0	0	0.077	0.070
LoroVac	0	0	0	0	0.05	0.05	0.9	0	0.096	0.097
Stud Pad	0	0	0	0	0	0	0	1	0.064	0.064

TABLE 7.11 - CYCLE TIME DEPENDENCY

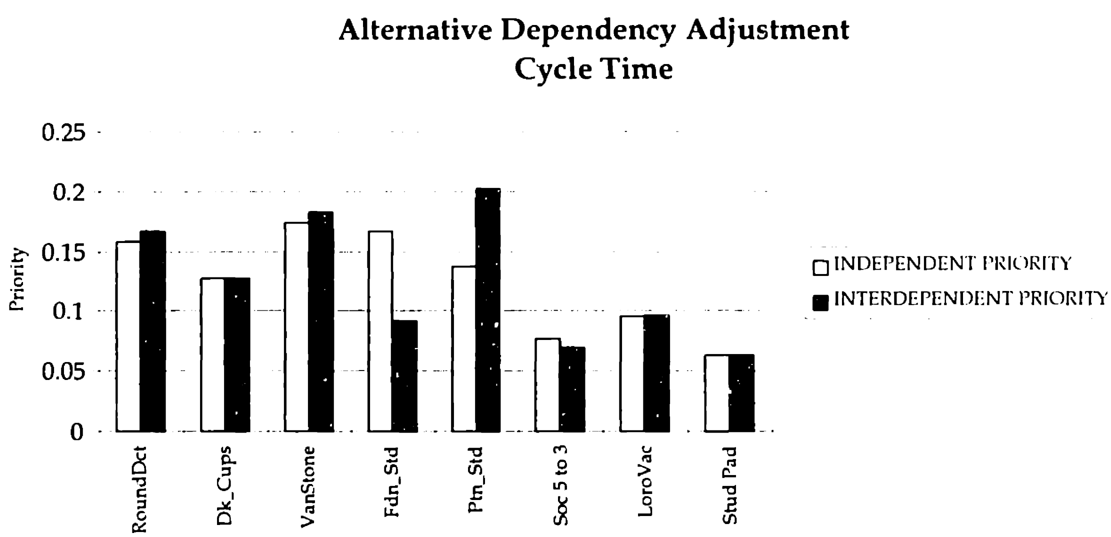


FIGURE 7.24 - CYCLE TIME DEPENDENCY

DOLLARS	RoundDct	Dk_Cups	VanStone	Fdn_Std	Ptn_Std	Soc 5 to 3	LoroVac	Stud Pad	INDEPENDENT PRIORITY	INTERDEPENDENT PRIORITY
RoundDct	0.95	0	0	0	0	0	0	0	0.128	0.122
Dk_Cups	0	1	0	0	0	0	0	0	0.176	0.176
VanStone	0	0	0.95	0	0	0.05	0	0	0.246	0.238
Fdn_Std	0	0	0	1	0	0	0	0	0.116	0.116
Ptn_Std	0.05	0	0.05	0	1	0.05	0.1	0	0.172	0.200
Soc 5 to 3	0	0	0	0	0	0.85	0	0	0.095	0.081
LoroVac	0	0	0	0	0	0.05	0.9	0	0.044	0.044
Stud Pad	0	0	0	0	0	0	0	1	0.022	0.022

TABLE 7.12 - DOLLAR SAVINGS DEPENDENCY

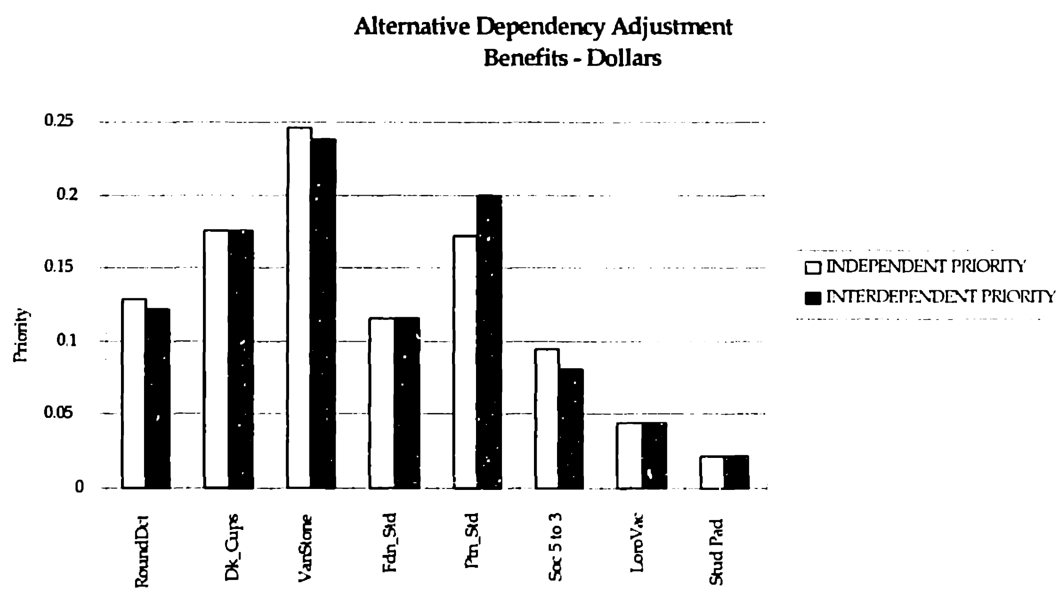


FIGURE 7.25 - DOLLAR SAVINGS DEPENDENCY

Figure 7.26 illustrates the final adjusted weighting of the alternatives, considering all dependencies. Dependencies between the alternatives themselves had a significant impact upon the ranking and weighting of the proposals. The model ranking and weighting correlates to the group judgment regarding the actual outcome with some exceptions as illustrated in the figure. Of significance is the fact that the model clearly predicted which groups of proposals were most important to consider. In reality, early into the evaluation process, the initiative to implement stud mounted padeyes was abandoned because it became clear that expectations were unrealistic. This is why the group judgement regarding actual contribution is so low as compared to the model output. When the model priorities are adjusted with the stud mounted padeye proposal removed, the correlation is improved as illustrated in Figure 7.27. It is likely that the remaining discrepancies are a result of the lack of consensus discussed earlier. It is critical that during the evaluation phase, every effort is made to build a common understanding of the proposals among all the decisionmakers/stakeholders. Equally critical is that the weighting of the relative preferences for benefits, costs and risks reflect shipyard policy. It is likely that had either of these been possible during this excersise, that the results would have been improved. As they are, it is clear that the AHP approach provides significant data which will be useful during decisionmaking, The ranking and weighting of the proposals appears to reflect a quality decision regarding the priority of proposals.

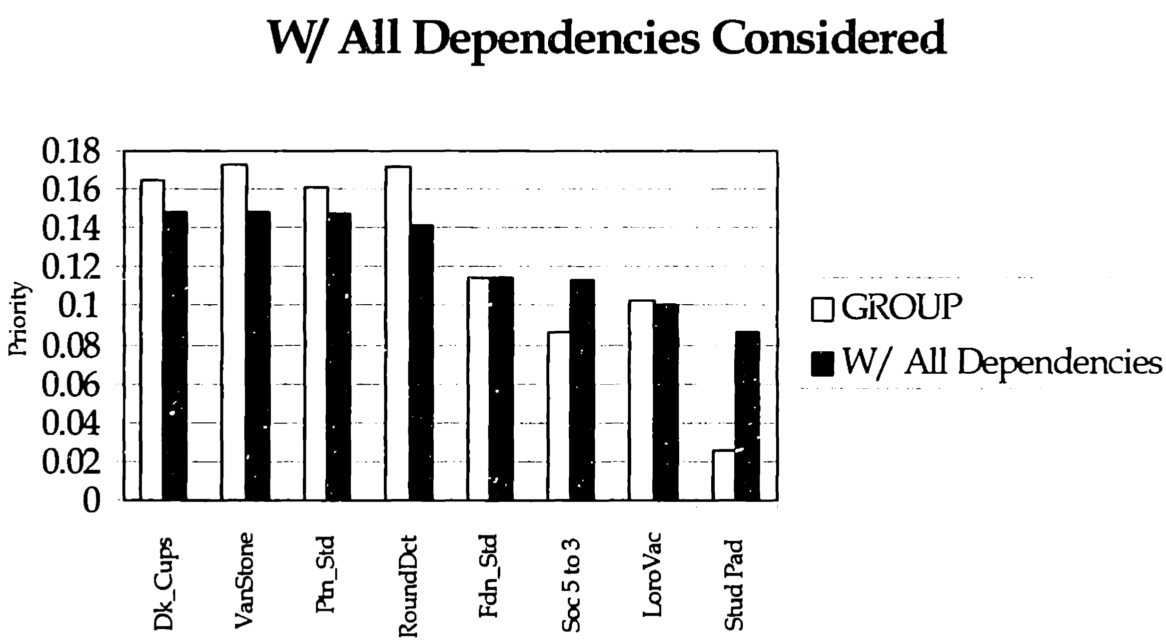


FIGURE 7.26 - RESULTS CONSIDERING ALL DEPENDENCIES

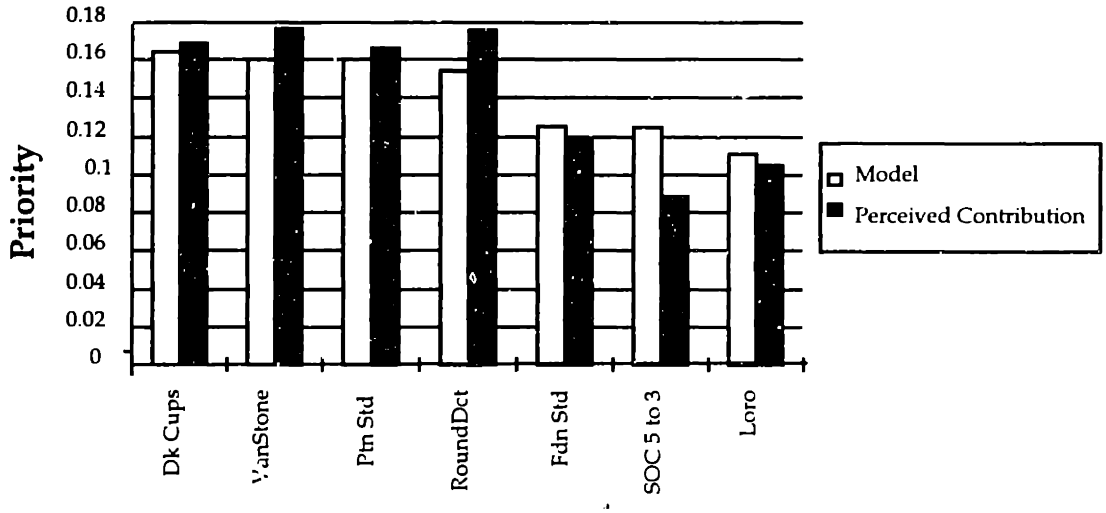


FIGURE 7.27 - RESULTS WITHOUT THE STUD PADEYE OPTION

Of particular interest is a comparison of the model output to the actual decisionmaking process that occurred at the shipyard when these proposals were under consideration. The deck cups proposal was implemented without much question. Initially there was concern regarding risks that regulatory bodies might not approve the proposal, but these were quickly dealt with via physical tests. These tests demonstrated that the regulatory body and customer concerns were not issues, and therefore this proposal was implemented quickly after that. It required little or no training and had no organizational resistance. It was a clear winner, although it did not have the greatest benefit potential.

The Vanstone, Round Duct and Penetrations proposals were considered at the same time. While each could be implemented independently, the impact of each was improved by the others. The Vanstone proposal would replace numerous welded joints with mechanical pipe joints. Regulatory bodies had concerns regarding leakage, and so a pilot project was proposed. Testing was performed to demonstrate that fatigue concerns would not be an issue. The effectiveness of that proposal would be enhanced if all pipe sizes could be addressed, but because the Vanstone flange requires a larger opening through ship structure, the penetrations proposal was required. The round duct proposal would replace costly rectangular duct with expensive penetration parts with less expensive and easier to install round duct. Its effectiveness would be enhanced if all the duct that would have been rectangular could be round. This would necessitate larger openings. The penetrations proposal had as its goals the establishment of new penetration standards regarding standard sizes, the need for compensation and the type of compensation. Implementation of these proposals, using a phased implementation approach, began at the same time as that for the deck socket cups.

The foundation project was invested in shortly thereafter. Investment in the Loro proposal began in concert with that of the Vanstone flange. This was because they shared common concerns and the regulatory, customer and shipyard stakeholders were the same for each. In essence, it was a piggybacked proposal.

As will be discussed later regarding decisionmaking, the output of the AHP model and other considerations are made to see if proposals can be enhanced. One such enhancement is adding on additional content to proposals with little or no increase in risk or cost. Moving content from SOC 5 to SOC 3 was implemented in a phased manner after the other proposals were well underway. Research regarding the stud mounted padeye was begun, but despite favorable testing was discontinued. This was because of differences regarding expectations between the customer and the yard, as well as doubts on the part of major stakeholders regarding its benefits. The expectations of the customer were believed to discount many of these benefits and the decision was made not to proceed.

7.4 SYNOPSIS AND LESSONS LEARNED

In previous Chapters it was illustrated that a means for evaluating and prioritizing proposals was necessary for a successful change management process. In this Chapter it was demonstrated that the Analytic Hierarchy Process can be used for this purpose. The model results appear to reflect quality decisionmaking based upon a test application at a shipyard. While dependency between parameters did not appear significant to this problem, dependencies between alternatives had a significant impact.

Assumptions regarding the deterministic synthesis of group judgments should be tested by examining the discrepancy between these judgments. Model performance might be improved if greater consensus can be reached. The AHP approach facilitates this.

While intuitively appealing and less time consuming than a utility theory application, the AHP approach is by no means "fast" when many criteria are being considered. It is a time consuming process when numerous parameters are being considered and for this reason, simplicity must be considered important. Every effort must be made to minimize the number of parameters in the model and focus on key criteria. Several of the parameters were prioritized low, and could have been eliminated without a significant impact on the results. This would have reduced the number of pair-wise comparisons required and subsequently reduced the amount of time required to complete the evaluation. Some parameters might be combined using constructed or proxy attributes, for example. It should be remembered that dominance of criteria diminish as one moves further down the hierarchy. A simple approach to screening should be used to eliminate inferior proposals. Such a screening method may utilize constructed attributes. This is necessary to place the evaluation in context. It also acts to reduce the amount of time the AHP evaluation will take.

The inconsistency ratio was very useful. It identified when additional thought or data might be required. This unique feature of the Analytic Hierarchy Process serves to further facilitate consensus building.

The model provides a meaningful way to examine alternatives under conditions of uncertainty using all the available information. Pairwise comparisons and ratio scale prioritization appear to successfully assess the relative benefits, costs and risks associated with proposals. The AHP approach serves well as a decision analysis tool. In the next Chapter, the means by which the output of the model can be used in the decisionmaking, planning and implementing phases will be explored.

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8.0 DECISIONMAKING, PLANNING, IMPLEMENTING AND MEASURING

In the previous Chapter, a decision model was developed using the Analytic Hierarchy Process for evaluating and prioritizing design improvement proposals. In this Chapter, it is demonstrated that the output from that model can be utilized for much more than merely ranking proposals. There are a great many aspects which must be addressed to properly make decisions, plan and implement design improvement proposals. These include traditional program planning and project management issues as well as configuration management. While these are critical for success, they are not the focus here. Many papers and texts have been written about project and configuration management. Instead, the focus here is on how the output of the AHP model can be used to improve that process and on aspects which are unique to the problem of managing design improvement proposals.

The decisionmaking stage consists of two primary sub-elements. These include:

- Post process sensitivity analysis and proposal improvement
- Proposal selection and resource allocation

The output of this stage is a set of proposals which a decisionmaker or group has decided to move forward with in some way. This is followed by a period of implementation planning. It will be shown that the AHP output can be utilized to suggest varying implementation strategies. The measuring stage relates to monitoring of proposals and development of lessons learned to improve both the proposals underway and the change management process itself.

8.1 DECISIONMAKING

8.1.1 Sensitivity Analysis

This stage begins with a period of reflection, a post process sensitivity analysis, to insure that all the available information has been reasonably considered. This is consistent with the conclusions of Keeney regarding "value focused thinking" and Sauder's model of structured decision making.

> It is important to attempt to create desirable alternatives throughout the decisionmaking process. After a set of alternatives has been completely evaluated for the first time, significantly more information is available than before the evaluation. Any of this information may stimulate creative thought to generate new or improved alternatives. [Keeney, 1992, p.211]

The evaluation and prioritization stages result in an improved understanding of the proposals. The AHP model output provides information which can be used to suggest if proposals can be improved. Sensitivity analysis can be performed to demonstrate whether there would be value to obtaining additional information prior to proceeding.

Sensitivity analysis refers to exploration of how robust the ranking and weighting of the alternatives are to perturbations of the criteria weights. This analysis might demonstrate that the ranking is not very sensitive to the adjustment of the weighting of criteria, in which case the result is robust. On the other hand, the analysis might demonstrate that the results are very sensitive to changes in the priority of one or several criteria. This may suggest that there is value in collecting additional information regarding the intensity of preference for alternatives with respect to those criteria if there is any question about the validity of the evaluation. Figure 8.1 illustrates such sensitivity analysis being performed using the "Expert Choice" software. This package provides a graphical user interface which facilitates adjustment of parameters with instant feedback regarding changes to the results. This allows "what if" scenarios to be explored. For example, one may wish to examine how sensitive results are to risk or cost.

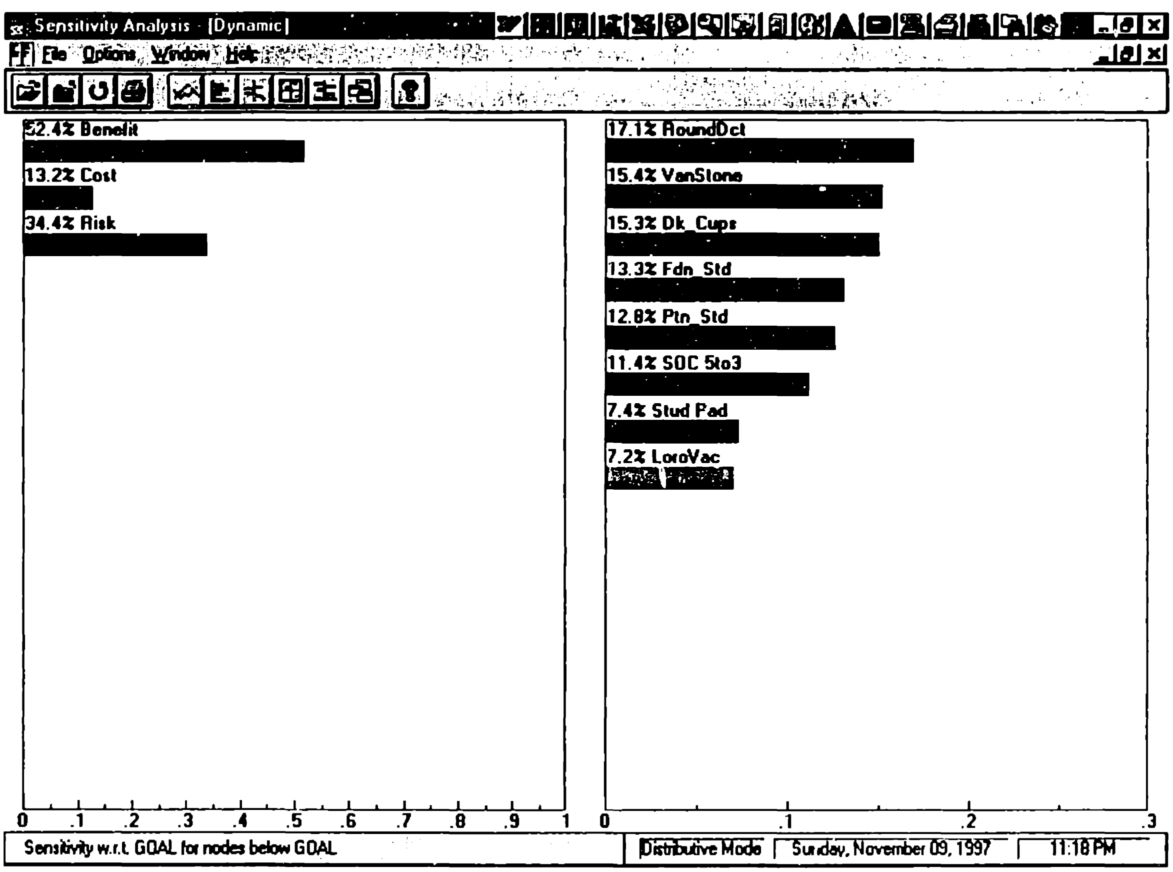

FIGURE 8.1 - SENSITIVITY ANALYSIS

8.1.2 Improving Proposals

After basic sensitivity analysis has been performed, and the analyst is satisfied that the results are robust, one can work to improve the proposals. This is a further application of "value focused thinking" to the problem. Any new information or understanding which has surfaced during the evaluation might be used to improve the performance of proposals. With full understanding of the proposals, one should ask similar questions to those that were asked during the identification stage. Can alternatives be synergistically combined, for example? This may be the case if they can share or require the same resources or their sum is greater than their parts. One should look for any add-on opportunities for highly prioritized proposals.

The output of the model, specifically the priority vectors against benefit, cost, or risk and any of their subelements, can be used to suggest which proposals might be improved. Furthermore, as was illustrated in the previous Chapter, the output of the model can be used to review agreement between stakeholders' perceptions. Any variation may suggest an opportunity to improve a proposal. Figure 8.2 illustrates how the output might be used to improve proposals. For each of the proposals, one should ask what might be done which could improve performance with respect to criteria.

Similarly, one should explore the level of consensus that exists. This can shed light on misunderstandings which need to be addressed prior to implementation. This is illustrated in Figure 8.3.

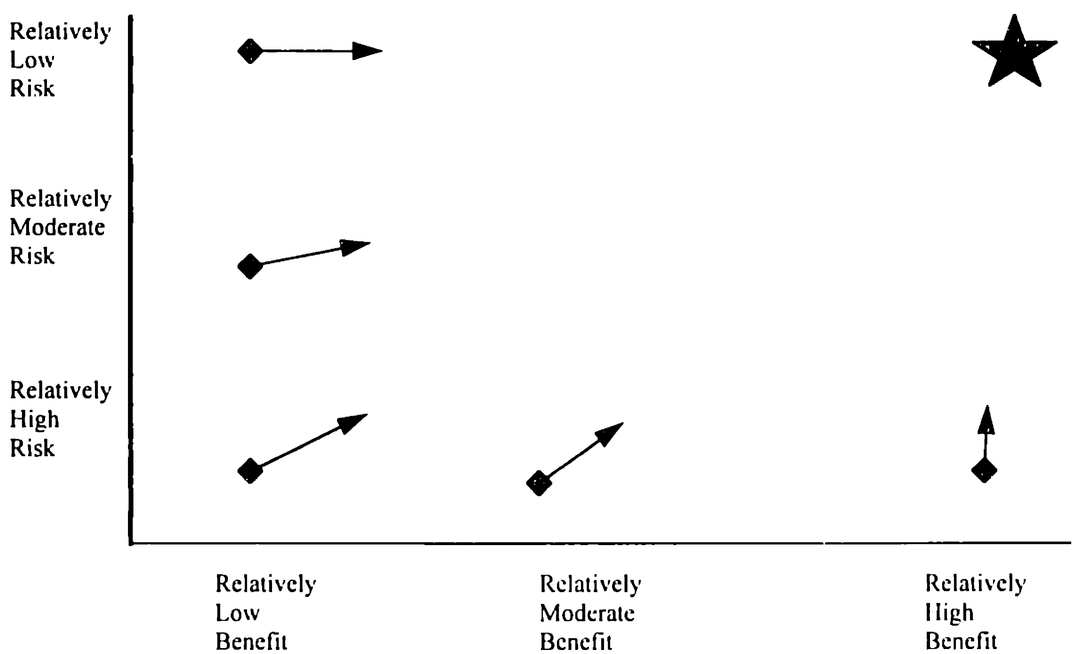

FIGURE 8.2 - IMPROVING PROPOSAL CRITERIA PERFORMANCE

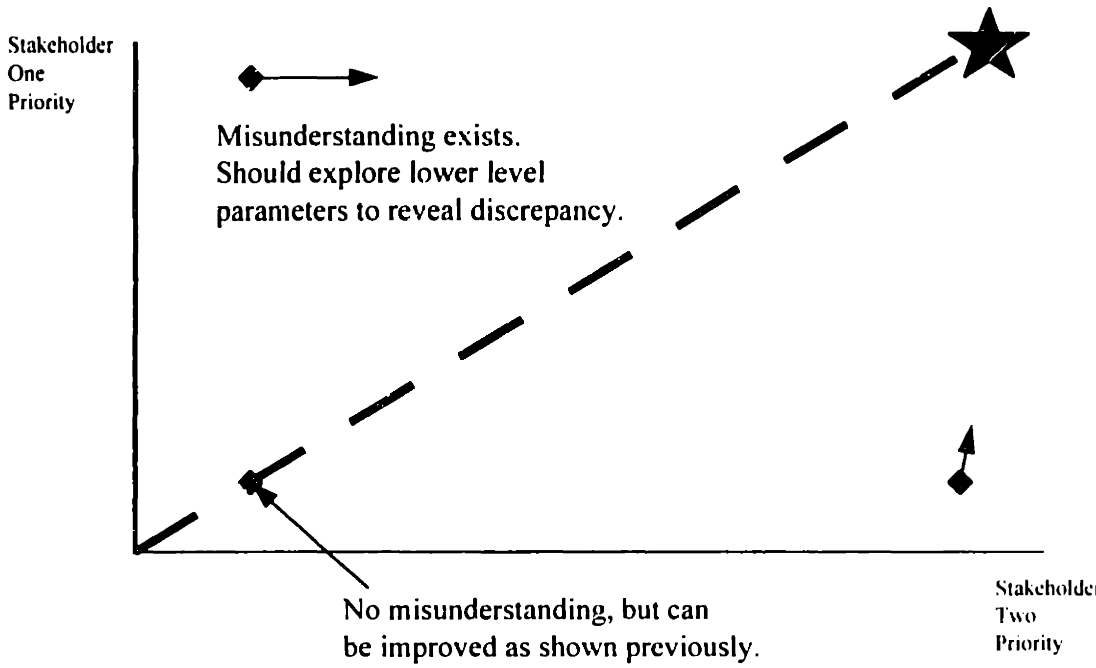

FIGURE 8.3 - IMPROVING CONSENSUS

8.1.3 Selecting Proposals and Allocating Resources

Once there is reasonable certainty that all the necessary information has been considered, and that proposals represent the best means available for achieving the goals identified through the strategic planning process, it is necessary to select proposals on which to initiate activity. This decision must be based upon consideration of the available resources and the capacity of the organization to support the changes. The model has considered relative costs and organizational risks when prioritizing the proposals, resulting in a ranking and a weighting. If the resource requirements for each proposal were known, and the resource availability were known as well, one could utilize an optimization algorithm to allocate these resources. Such an approach has been used in conjunction with AHP in the past.

Kuei et. al. (1994) proposed a greedy heuristic algorithm for allocating resources using the output of the AHP. The approach has also been recommended by Saaty and Alexander (1981) and Madu (1993). If the only costs being considered were dollars, and the resource requirements and constraints were known, one would construct a simple linear program using the global priority vector results as the coefficients in the objective function. For example, in a case with 4 alternatives one would have:

Resource requirements R_1, R_2, R_3, and R_4
Resource Availability (budget) B

Max $z = P_1W_1 + P_2W_2 + P_3W_3 + P_4W_4$; (P being priorities, W being resource allocations)

Subject to
$0 \leq W_1 \leq R_1/B$
$0 \leq W_2 \leq R_2/B$
$0 \leq W_3 \leq R_3/B$
$0 \leq W_4 \leq R_4/B$

$\Sigma W = 1$

The approach illustrated above really amounts to allocating resources in the order suggested by the AHP model until resources are expended. The LP function is not necessary to achieve that result. Extensions to that approach might include consideration of combinations of discrete and continuous investment levels as well as more than one type of resource constraint. In the case of design improvement proposals, at least dollars and manning would need to be considered. One might even allocate an "assimilation budget" to the organization and assign assimilation costs to the proposals based on the model's priority vector against organizational risks.

It was beyond the scope of this research to fully explore various mathematical approaches that might be used for allocating resources. The ranking and weighting output of the AHP decision model suggests the order in which proposals should be addressed. This was tested against actual shipyard activity in the previous Chapter, and the test suggests that the ranking provides a quality assessment of the order in which to consider proposals. The organization must be sensitive to the resources available when deciding how many proposals to proceed with, and this sensitivity must include all the organizational issues discussed in detail in Chapter 2.0. The power of the AHP model is its ability to suggest which proposals may be most important to achieving strategic objectives, and if a group of proposals is superior to another group. It also provides a mechanism for focusing attention and building consensus. Its output, being ratio scale weights rather than merely interval scale ranks, is well suited to use in conjunction with other resource allocation techniques including linear programming.

8.2 Planning, Implementing and Measuring

In this section issues associated with planning for implementation are discussed. When considering implementation, there are two primary issues associated with the design change process. The first of these relates to the implementation of the Design Change Management process itself. The second relates to the implementation of proposals identified and selected as a result of utilizing the process. The first issue is associated with organizational change. The second is associated with project management and configuration management as well as organizational change. The output of the decision model can be used to assist with the second of these concerns.

8.2.1 Implementing the Design Improvement Process

With respect to the first issue, the lessons learned from the field of organizational change can be applied to develop an implementation plan for the change management process. Some of these lessons were reviewed in Chapter 2.0. The strategy employed will be a function of the degree to which the present state of the organization is similar to the desired state (being one which employs an effective design improvement process). It is beyond the scope of this work to provide an in depth discussion of the management of organizational change, but an overview will be provided.

Organizational change strategies tend to range from gradual and participative to rapid and coercive. There are staunch supporters of each, as was illustrated in Chapter 1.0. Recall the conflicting arguments of Heifetz and Pritchett. Dunphy and Stace provide the following observation.

> On the whole, the O.D. [Organizational Development] model presents an ideology of gradualism, for effective change management is seen to proceed by small, incremental adjustments...and the strategies for organizational change advocated typically involve widespread employee participation to ensure emergent consensus among the key parties affected...By contrast what we can observe happening with increasing frequency in contemporary organizations is markedly different...In advocating rapid coercive restructuring, they often express impatience and contempt for O.D. approaches, which they regard as trivial and time consuming. [Dunphy & Stace, 1988]

The collaborative approach is argued by numerous researchers and consultants to be superior because it ensures that organizational resistance is properly dealt with and that the employees internalize the new processes such that there will not be a relapse or sabotage. It is argued as the best way to establish shared vision and values in the majority of the organizational change literature. It "increases confidence amongst employees, reducing organizational dependence on outsiders" [Dunphy & Stace, 1988] In Chapters 1.0 and 2.0 several other arguments were put forth for why a collaborative approach is valuable. It has also been argued that while collaborative approaches work well when change is not thrust upon the organization rapidly, there are many situations in which greater speed is necessary. This would be the case if the need for change was not realized until it was very late, such that little time is available to react. In fact a primary conclusion of organizational change theory is that change will not occur until pain and discomfort is significant, and this is usually the case when there is little time left to change. Some, such as Handy, have illustrated this using the sigmoid curve, which is representative of many life cycles, including organizational life cycles. In Figure 8.4, point A represents when the organization should react, and point B represents when the organization typically reacts. At point A, all the signals are that all is well and there is no pain to trigger the change. At point B the need is understood, but the organization may not have what it takes to rebuild the necessary momentum. A coercive or dictatorial approach may also be required if key stakeholders' interests are not compatible and can only be resolved by an authoritative directive, or by coercive influence of a stronger party. [Dunphy, Stace, 1988]

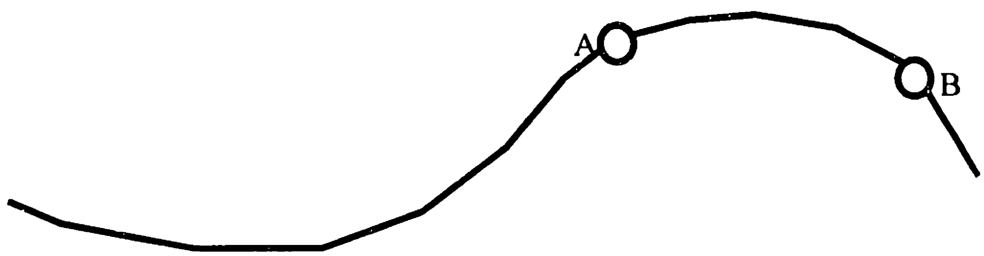

FIGURE 8.4 - SIGMOID CURVE (FROM HANDY)

Dunphy and Stace concluded that each approach has its place, and provided a typology of change strategies and suggestions for when to utilize them. Their work responds to the fact that "we need a theory of organizational adaptation that incorporates all types of interventions, applying them to the management of the numerous crises all organizations face." [Beer, Walton 1987] Several researchers have adopted and expanded upon their typology. Those who wish to implement an improved design improvement process must first assess the current state of the organization. That, coupled with their authority and influence, will determine the appropriate strategy. Table 8.1 illustrates their typology of strategies (from Jick's adaptation of Dunphy and Stace).

	Incremental Strategies	Transformative Strategies
Collaborative Mode	Participative Evolution: Use when the organization is in good condition but needs minor adjustment, or is not in good condition but time is available and interest groups favor change.	Charismatic Transformation: Use when the organization is not in good condition and though there is little time for extensive participation there is support for radical change within the organization.
Coercive Mode	Forced Evolution: Use when the organization is in good condition but needs minor adjustment, or when it is not in good condition and key interest groups oppose change, but time is available.	Dictatorial Transformation: Use when the organization is not in good condition, there is no time for extensive participation and no support within the organization for radical change, but radical change is vital to organizational survival and fulfillment of its basic mission.

TABLE 8.1 - IMPLEMENTATION STRATEGY - COLLABORATIVE VS. COERCIVE MODES

If the shipyard already has a production engineering function in place, does not believe it has a dire need to "cost-down" its existing or anticipated designs, and the relationships between stakeholders are strong, it is likely that a participative evolution will allow many of the elements of the proposed process to be put in place. Implementing Concurrent Engineering, Build Strategy development, and standardization will be significantly easier in this environment, but will require considerable care and feeding on the part of management. If the Build Strategy process establishes goals and objectives as recommended in Chapter 3.0, implementing the change management framework and evaluation process is likely to represent an evolution of existing activity.

On the other hand, if the shipyard has not embraced production engineering and the other elements of design for competitiveness, and relationships between stakeholders are strained, it is likely that a coercive mode change will be required, at least to "kick off" the process. This would especially be the case if the shipyard faced a dire need to reduce costs and cycle time and had waited too long to take action. Evidence for this was seen in the shipyard feedback presented in Chapter 4.0. A dictatorial transformation was often required to establish the expectation that there will be a new order of things, that this would include production engineering and design improvement, and that engineering had no choice but to improve their design for competitiveness capability despite the need to reduce their own design cycles. The approach is not without its costs, and while it establishes the expectation and results in design improvements, it demoralizes the targets of the change. Such a transformation must be quickly followed by efforts to stabilize the targets and shift to a participative environment.

8.2.2 Implementation of Improvement Proposals

Implementation of proposals begins with an understanding that an improvement is a change if it is contrary to any stakeholder's expectations. Change can therefore occur at the start of the concept design stage as discussed in Chapter 3.0. Change management principles must be addressed throughout all the design phases regardless of the management approach taken.

The AHP model ranks and prioritizes proposals, suggesting the order in which they should be implemented. The next concern is the best strategy for implementing each selected proposal. The output of the AHP decision model provides information which can assist in developing implementation strategies for individual proposals.

Implementation planning is concerned with establishing the project management strategy, defining activities, schedules and costs, allocating resources, and establishing performance measures and a reward system. The focus of this research was on how the output of the decision model can be used to indicate project implementation strategy. Implementation can be considered to be broken into three sub-elements. These include the initiation phase, an interim monitoring phase, and a transfer phase. A fourth element follows which is identified as a separate stage of the design change framework, measuring and feedback. This is a final monitoring phase. During initiation, the implementation plan is established and the implementation begins. During the interim monitoring phase, feedback regarding progress is used to make necessary "course corrections." The focus during initiation and the interim monitoring phases is action and accomplishment of goals. During the transfer phase, action is taken to establish new processes and standards to insure that lessons learned are made permanent, and that these gains will be shared on future programs. During the final monitoring phase, additional feedback is gathered regarding both the proposal and the implementation process to insure that lessons learned are used to improve future similar proposals and the change management process itself.

The attributes of the implementation strategy are trade-offs between short term efficiency and long term organizational learning. The fastest implementation approach is not often the one which will result in a lasting change, but rather a local change to a particular contract. This trade-off might also be expressed as that between effective proposal implementation and effective ongoing work in the line organization, direction vs. participation and flexibility vs. control. The characteristics of the change will suggest the best implementation strategy.

Wheelwright and Clark established a typology of implementation strategies for new product development in manufacturing firms. These relate to alternative forms of project management and are also applicable to design improvement proposals. The shipyard feedback obtained during the surveys demonstrated that the full range of these approaches are used in practice. The implementation strategies which they identify include functional or line, lightweight, heavyweight, and autonomous (described below). These strategies can be linked to proposals through the AHP output and the change characteristics identified in Chapter 1.0. These change characteristics include:

- Extent and Breadth
- Timing
- Focus and Interdependency
- Cost, Benefit and Risk (AHP output)

Functional or line refers to implementation through the existing configuration control process. This strategy relies on the line organization with little or no external monitoring. It is well suited to projects with minimal risk, cost, breadth/extent and low time sensitivity, moderate benefits. These proposals would require no significant changes to design or production processes, and minimal follow on effort. The change is "finished" in a short and definable period.

Lightweight project management strategies rely on the line organization and a modified configuration control process to accomplish the change, but assign a project manager who schedules, encourages and track's performance. This approach provides coordination between departments and enhances communication. It provides coordination with subcontracts as required. The project manager does not have direct control of resources, and the assignment may often be used to "grow" management skills in a less experienced project manager. The project manager reports to a steering committee of sponsors. This is often the case in shipyards with a production engineering organization. In these cases a production engineer is often assigned to this role. The workload of the project manager is generally spread over multiple projects. Liaison is with members of the line organization who report to their own supervisors. This is suited to well defined projects with minimal to moderate risk and cost, of moderate breadth and extent, moderate time sensitivity, moderate risk, and moderate to significant benefit. The projects involve moderate process changes and will generally require some follow on effort. The projects are of longer duration than those implemented directly through the line organization, and involve multiple departments. They often require some testing and analysis or phased implementation with a customer or regulatory approval stage.

Heavyweight project management is a related strategy which involves the assignment of a senior project manager who brings expertise and "clout." The project manager generally reports to a steering committee. The project manager is responsible for the total project effort and its success. The project manager is given influence on resources within constraints set out by the project charter. Members of the line organization are dedicated to the project with conditions set out in the project charter. The project manager is given influence regarding members' evaluations and rewards. This approach is suited to proposals which require ongoing definition and refinement, with significant risk, cost and benefit, moderate to significant time sensitivity and moderate to significant breadth and extent. These proposals will require significant process changes and follow on effort. They will be of longer duration and involve multiple departments, testing, analysis and/or approval.

An autonomous strategy employs a heavyweight project manager with team members pulled from their functional organizations and collocated. These are often referred to as "change tiger teams." The project manager is given formal authority, rather than influence, over project resources and members' compensation, evaluation and rewards. These proposals generally have significant time sensitivity and strategic benefits justifying the disruption of ongoing work in the line organization to facilitate implementing them. These proposals have increased complexity and represent serious departures from traditional processes. Ultimately, additional effort will be required to integrate the lessons learned and process with the formal organization.

As the shipyard feedback demonstrated, different structures might be used for different phases in the case of phased projects. The initiation phase may require a highly projectized approach which eventually gives way to an approach more congruous with the line organization during the transfer phase. Hybrids can also be utilized. An approach which was shown to be effective at several of the shipyards is job rotation. The project manager from the initiation phase can be transferred to the line organization to supervise implementation during the transfer/install phase with appropriate reorganization to suit. This is essentially a conversion to a heavyweight model within the line organization itself. It was found to be very effective for a number of design improvements at several of the shipyards. For example, several of the case studies used in the previous Chapter were implemented with a lightweight project manager in production engineering during the initiation phase followed by a transfer to the line engineering organization during implementation. It is likely that this is one of the reasons why performance was better than might have been predicted for several of the proposals. Table 8.2 summarizes the range of implementation strategies that might be used.

The position of proposals in "benefit-cost-risk space" suggests alternative implementation strategies together with an assessment of issues associated with timing, phasing and complexity. The output of the AHP model suggests the relative degree of control that may be required for each of the proposals in the portfolio that had been evaluated. Figures 8.5 and 8.6 provide examples of how plotting the model output visually suggests which proposals require relatively more or less projectized approaches. Table 8.2 provides a summary of implementation strategies.

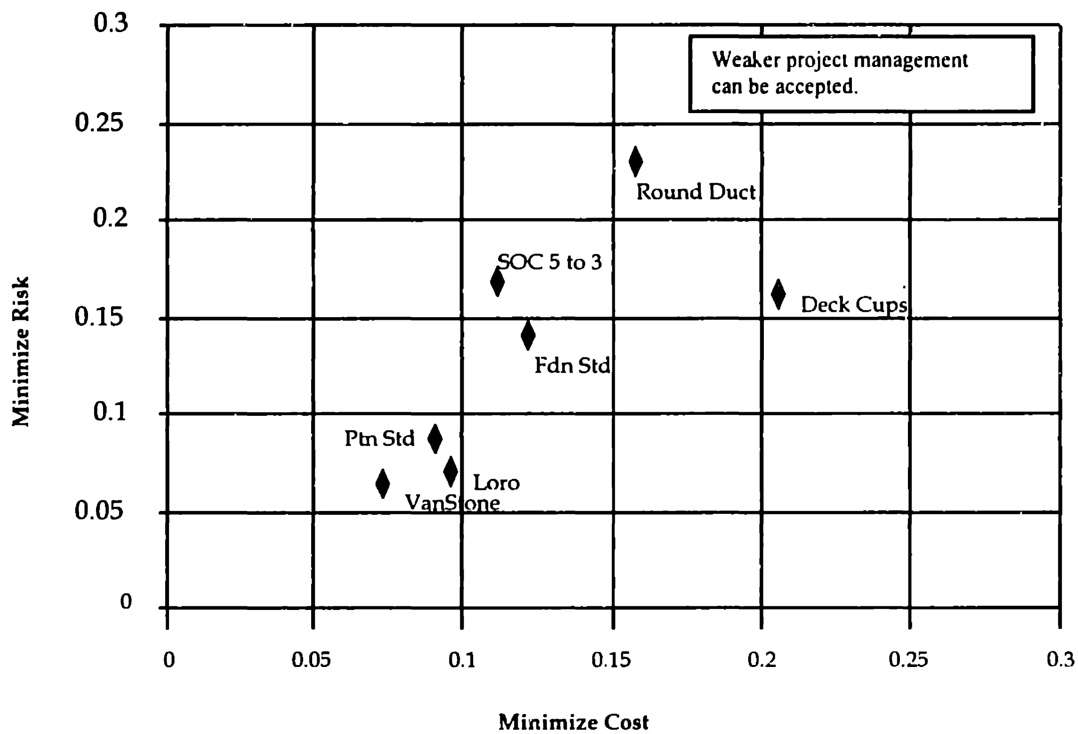

FIGURE 8.5 - "RISK - COST SPACE"

Those projects which are indicated to require additional control relative to others in the portfolio require additional monitoring. When targets and goals are set, a schedule for in process measurements to track progress should be established. This monitoring will guide implementation and facilitate corrective action. It will also build positive momentum by recognizing success. In addition, reflection on performance and lessons learned should be encouraged. The organization must reflect on lessons learned to improve. This is true both for the change management process itself as well as future similar proposals. The results of these measurements should be shared with the steering committe of management to serve as feedback to the strategic planning process. The sponsors and management must "spread the news" to build momentum based on success.

Implementation - Management Strategies

inimal complexity,
ower risk, less breadth,
nore easily integrated into
ngoing work.

↕

Increasing speed,
coordination, risk,
cost, benefit
complexity, innovation
as well as disruption of
ongoing work.

- Organization Design Types (adapted from Wheelwright & Clark)
  - Functional or Line
    - Implementation through existing configuration control process
    - Reliance on line organization with little or no external monitoring
    - Well defined projects with minimal risk, cost or breadth and low time sensitivity, moderate benefits.
    - No significant changes required to design or production processes and no follow on effort
    - Change is "finished" in a short and definable period
  - Lightweight
    - Reliance on line organization & modified configuration control process
    - Project manager assigned who schedules, encourages and tracks performance
    - Provides coordination between departments, enhances communication
    - Provides coordination with subcontractors as required
    - Does not have direct control of resources
    - Assignment is an opportunity to "grow" project manager
    - Reports to a steering committee of sponsors, generally led by production engineering
    - Workload of project manager spread among numerous projects
    - Liaison is with members of line organization who report to their supervisors
    - Suited to well defined projects with minimal to moderate risk and cost, of moderate breadth, moderate time sensitivity and moderate to significant benefit.
    - Projects involve moderate process changes as well as follow on effort.
    - Projects of longer duration involving multiple departments and possibly testing, outside analysis or approval.
  - Heavyweight
    - Assignment of senior project manager who brings expertise and "clout"
    - Reports to steering committee
    - Project manager has responsibility for total project effort and its success
    - Project manager given influence on resources within constraints set out by project charter
    - Members of line organization are dedicated to the project per conditions set out in project charter
    - Project manager has influence on members' compensation & reward, as well as evaluation
    - Suited to projects which require ongoing definition and refinement, with significant risk, cost and benefit, moderate to significant time sensitivity, moderate to significant breadth
    - Projects may require significant process changes and follow on effort.
    - Projects of longer duration involving multiple departments and some testing, outside analysis or approval.
  - Autonomous
    - Heavyweight teams where members are pulled from line organization and collocated
    - Project manager has formal authority over project resources and members' compensation/evaluation
    - Significant time sensitivity and risk, increased project complexity, "breakthrough" tiger team project
    - Project represents a serious departure from traditional processes
    - Ultimately additional effort will be required to integrate lessons learned with the line organization

TABLE 8.2 - IMPLEMENTATION STRATEGY - PROJECT ORGANIZATION DESIGN

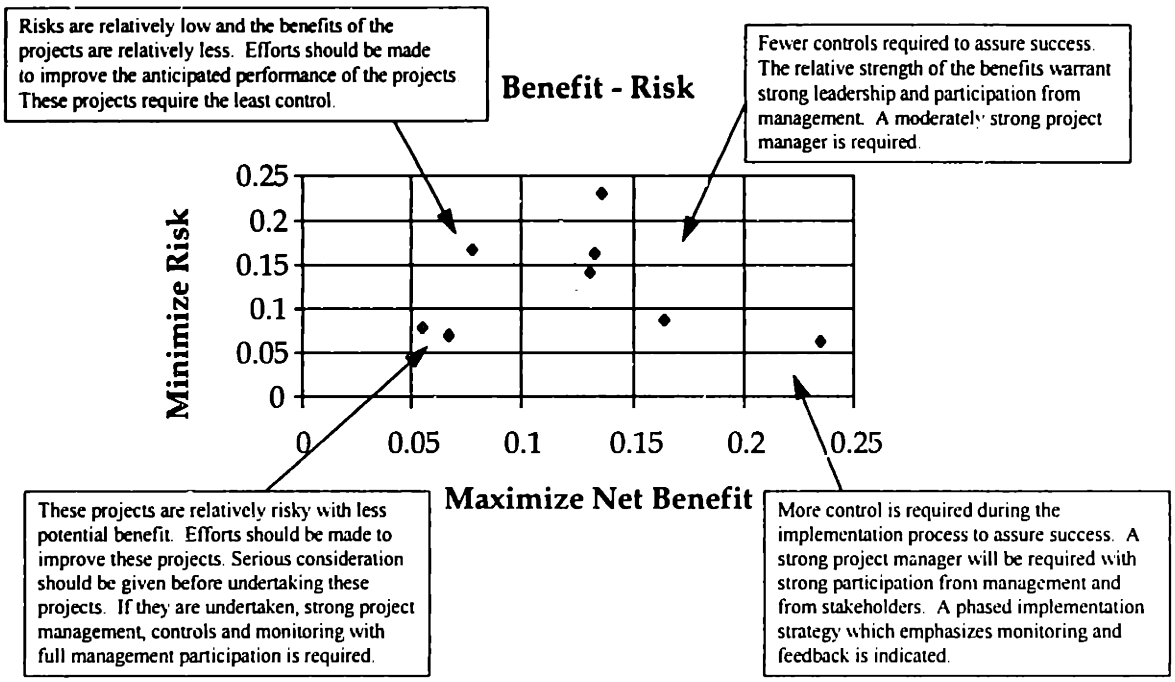

Figure 8.6 - "Benefit - Risk Space"

8.3 SYNOPSIS

In this Chapter, it was demonstrated that the AHP model output can be used to facilitate quality decisionmaking, planning and implementation. The decision model can be used to perform "what if" scenario sensitivity analysis to explore the value of obtaining additional information regarding proposals. It also serves to visually illustrate the level of consensus that exists. This can be used to improve stakeholder relationships and the proposals themselves. The output also suggests which proposals are candidates for further consideration regarding how they might be improved relative to particular criteria for which they have been ranked low.

The ratio scale model output can be used directly in the objective functions of mathematical programming approaches to resource allocation. The prioritization reflects the order in which proposals should be invested in. Implementation strategies are suggested for the proposals by examining the model output regarding relative benefits, costs and risks. These priorities suggest the relative level of control required for each proposal. In the next Chapter, an overview of the key research results is presented along with lessons learned and recommendations.

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9.0 CONCLUSIONS AND RECOMMENDATIONS

This research developed theory and process for managing design improvement in shipbuilding through the integrated study of management, organizational theory, decision theory, and engineering. In this Chapter the results associated with the primary research questions are reviewed. The research questions which were this study's focus included:

- Is Change Management a strategically important capability relative to other competitive capabilities?
- How strong is industry's understanding and skill with respect to Change Management relative to other capabilities?
- What facets of the Change Management process are most critical for success?
- What facets of the Change Management process require the most improvement?
- Can a decision analysis model be developed to significantly improve the process?

It was shown, both through an extensive literature review and data from an industry survey, that the capability to manage design change is of strategic importance. It was also shown through the industry survey that shipbuilders lack adequate strength in this area. In fact, the ratio of strength to importance for capabilities associated with managing design improvement are among the lowest of all the capabilities studied, validating the importance of this research. Figure 9.1 illustrates this result from the industry survey data.

Important facets of a successful process were shown to include methods for identifying, evaluating, prioritizing, planning, and implementing proposals. The need to link proposals to a high level business strategy and prioritize them based upon explicit goals was shown to be critical. An understanding that resistance to change is associated with variance from expectations is necessary to fully appreciate the contribution that Concurrent Engineering, Build Strategy development, Production Engineering and Standardization can make to the process. These elements of "Design for Competitiveness" were found to be foundations for a succesful Design Change Management process. The lack of a means to prioritize and select proposals was suggested to be a key contributor to failure. The industry survey results strongly suggest that a decision analysis model is desirable.

Numerous alternative methods for evaluating and prioritizing proposals were reviewed for applicability to this problem. The Analytic Hierarchy Process was chosen as the decision theory best suited to this application. AHP utilizes hierarchical composition. and is therefor consistent with the strategic planning processes described in this research. The AHP structures a problem in a manner that is inuitively appealing and is conducive to "what-if" type sensitivity analysis. A feature of the AHP is its ability to admit group judgements, which is significant because consensus is an important part of managing change. The AHP provides a mechanism for measuring inconsistency of judgements and can also model dependencies between criteria and alternatives. The Analytic Hierarchy Process utilizes pair-wise comparisons to establish intensity of preference. These have been found to be more easily understood than questions associated with probabilities of events such as in Utility Theory. AHP generates ratio scale data which is inherently more meaningful, and can be operated upon mathematically in more ways, than interval scale data of other methods.

A decision analysis model was developed using the Analytic Hierarchy Process, and it was found to be consistent with the objectives of prioritizing proposals based upon a business strategy linked to the competitive environment. The results of the model correlated well with participants' expectations, and it was found to be useful for implementation planning in addition to prioritizing and selecting proposals. Design Change Management is a critical capability for shipbuilders today, and it was demonstrated that a decision analysis model can be developed using AHP to significantly improve the process.

9.1 Discussion

Shipbuilders must think in terms of strategic objectives and how they are supported by capabilities and competencies. The design improvement process and decision analysis models must address the means by which competitive advantage, and therefore capabilities, will be supported by proposed design improvements. This is a strategic concern which will require analysis that goes beyond traditional engineering economic cost/benefit considerations.

Product and process are linked, and therefore process change generally requires product change to support it. A shipyard which emphasizes continuous or breakthrough improvement of production processes must be equally concerned with engineering support. A mechanism for introducing design improvements must be put in place. Doing so will require shipbuilders to balance flexibility and control. A mechanism for alternating between disorder/informality/innovation and stability/conservatism is required.

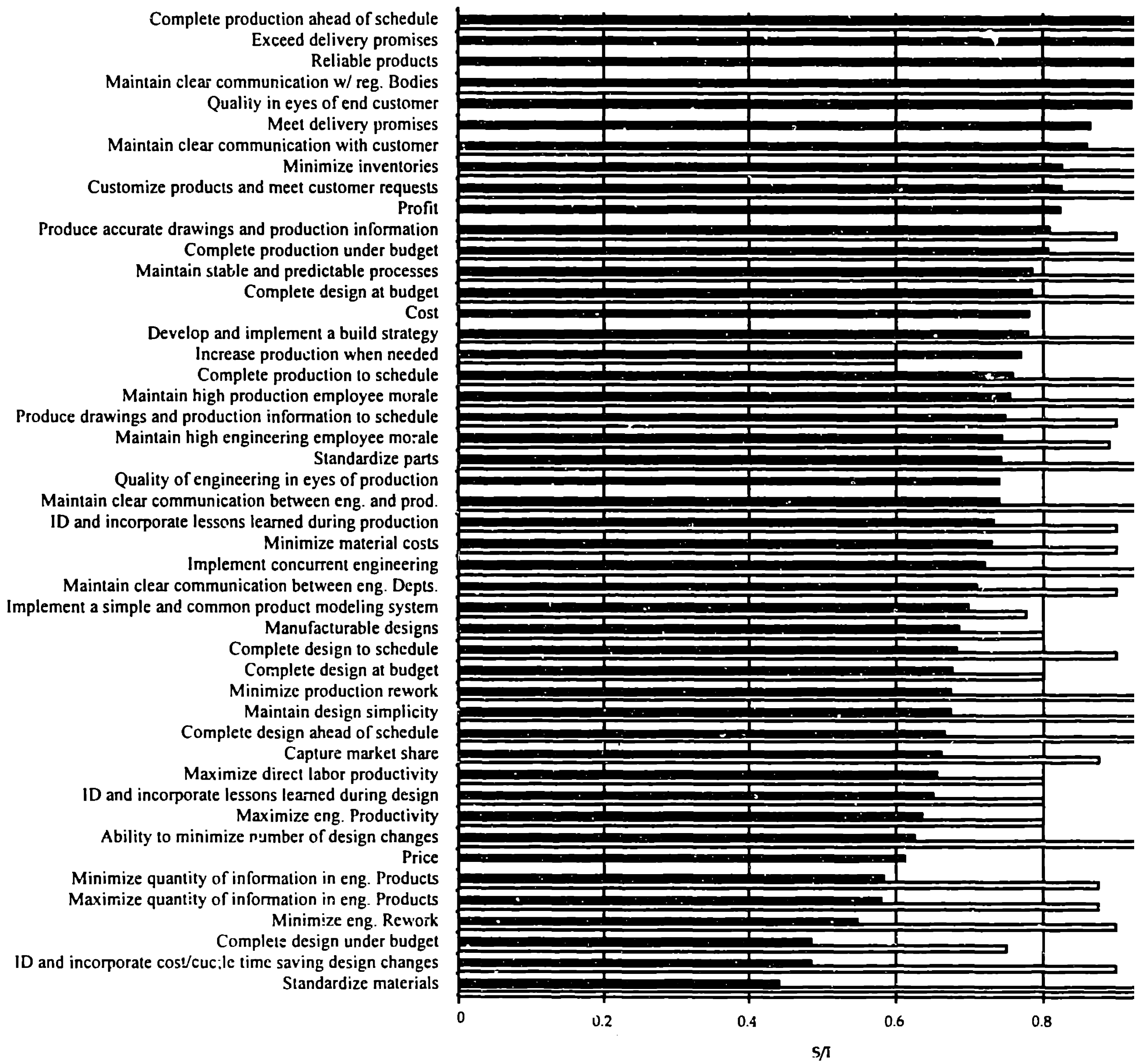

FIGURE 9.1 - STRENGTH/IMPORTANCE INDEX

Shipbuilding appears to be closely aligned with a mass customization model of production. Making standardization a distinctive competency will provide the shipyard with a greater capacity to balance flexibility and control, and enhance its ability to manage design improvement. Concurrent Engineering, Standardization/Mass Customization, Build Strategy development, and the Production Engineering function address this issue, in part by managing expectations. These facets of design for competitiveness serve as foundations for successful Design Change Management by providing a focus for change and a means of communicating change. They both reduce the "assimilation drain" on engineering organizations as well as expand the "assimilation budget" which the organization has.

Significant productivity advances are achieved through a combination of both incremental and major innovations. "All the evidence points to the need to innovate both with breakthrough products and processes and with regular incremental improvements. Any firm that plans to win the race to commercial success by being either a steady plodding tortoise or a swift-footed hare will find itself outpaced by firms that have developed the virtues of both." [Utterback, 1994, p.135] This implies a systematic approach to Design Change Management.

The history of the quality movement demonstrates that a chain of events has resulted in industry realizing the need for effective Change Management. The introduction of TQM led to greater rates of change, which ultimately was perceived as having many disruptive effects as well as successes. This triggered the latest wave of the quality movement which emphasizes strategic planning (Hoshin) and Change Management.

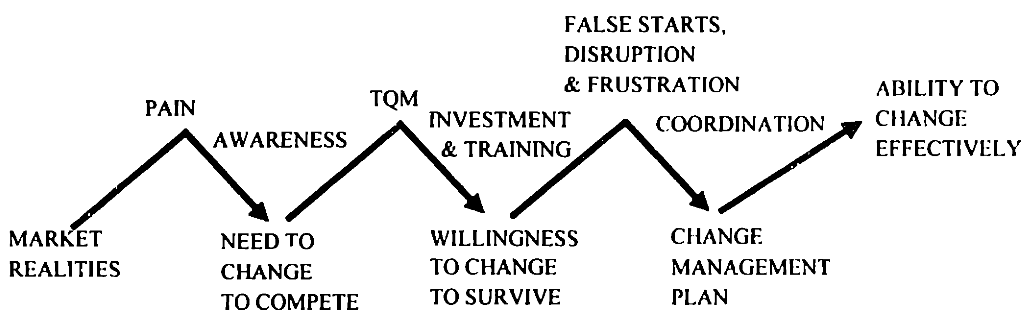

FIGURE 9.2 - CHAIN OF EVENTS LEADING TO CHANGE MANAGEMENT

The total quality movement was a response to the competitive environment and increased the pace of change. The engineering organization was unable to cope as well as it might have with the increased pressure, in part due to a lack of an overarching strategy which clearly associated change proposals with strategic objectives and in part due to the lack of a Change Management process. Shipyards must address this issue by adopting a strategic planning process which links means with objectives, which in turn are linked to responses to changes in the competitive environment. They must also adopt a procedural context for change that facilitates linking design improvement proposals with strategic responses, and prioritizes proposals to reflect an understanding that organizations have limits to the amount of change they can assimilate. Change implementation procedures must address both procedural and psychological roadblocks.

The changes in the ship design and production cycle, increases in automation, and development of standardized interim parts and work processes signaled a move away from craft production and the increasing irrelevance of the traditional learning curve model and notion of learning. While traditional thinking suggests that changes always disrupt the learning curve, it has been shown in this study that more learning is associated with deliberate rather than unconscious activity.

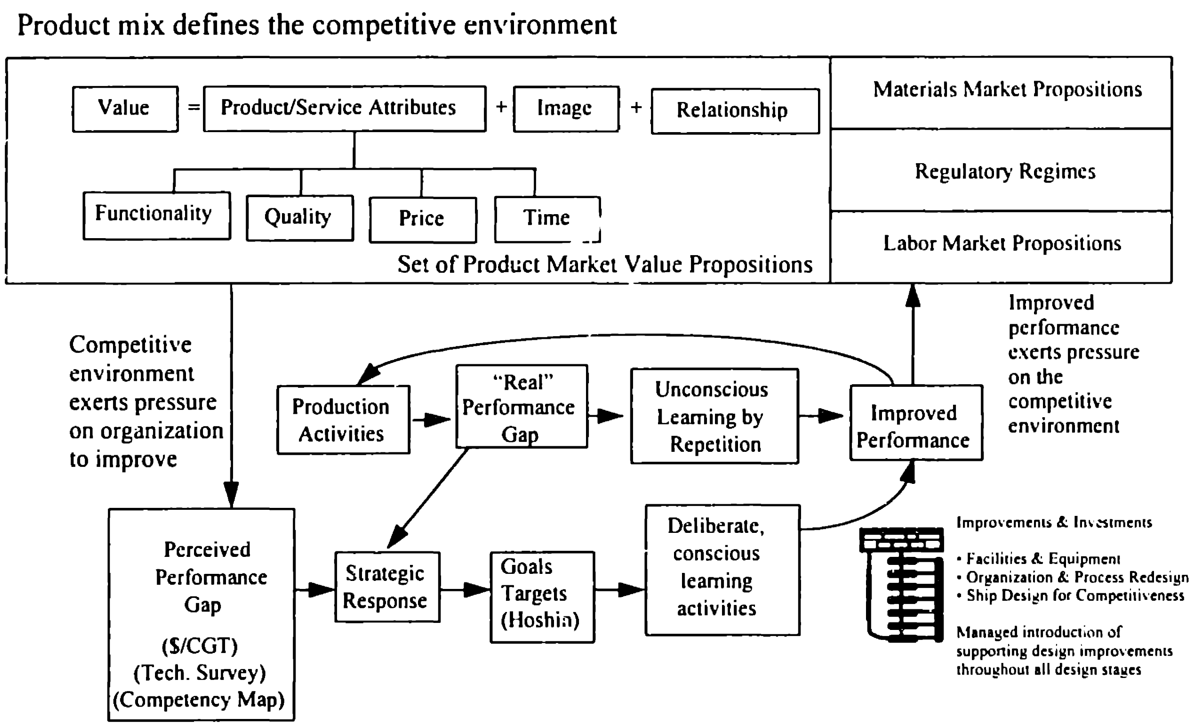

FIGURE 9.3 - MANAGED IMPROVEMENT PROCESS

A key element of success is the development of a procedural context for managing change. This research has yielded the following stage model, which has been verified as workable through discussions and testing with shipyard personnel. This stage model begins with a motivating force which leads to identification of a change proposal. This is followed by periods of evaluation, prioritization, decisionmaking, planning, implementing and measuring. A key element of this stage model is the evaluation phase. This research reviewed a variety of evaluation techniques and developed an evaluation model that is consistent with the strategic planning techniques described earlier.

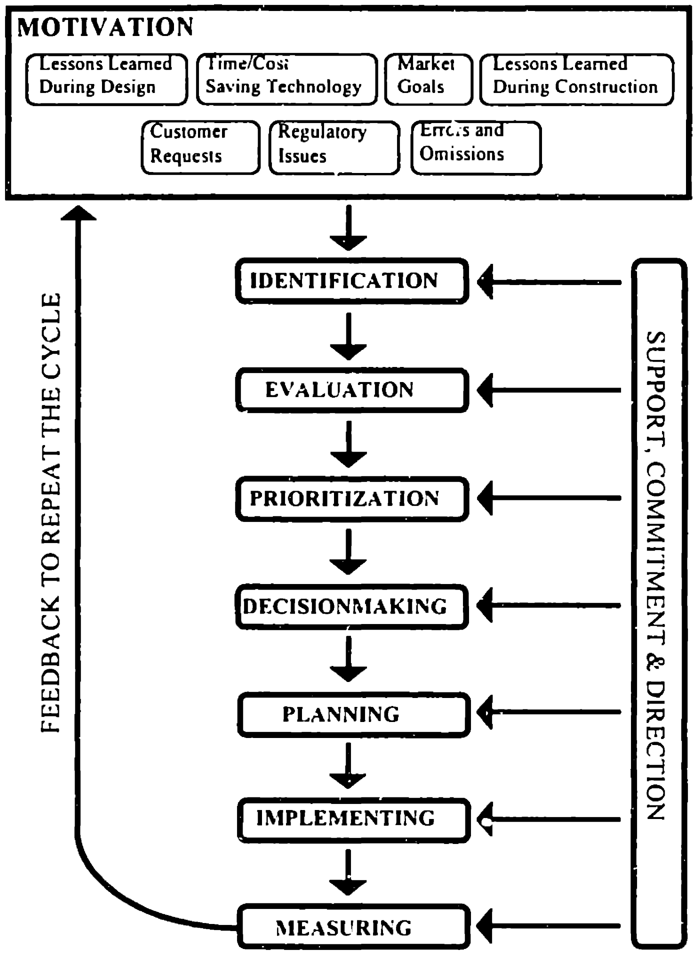

FIGURE 9.4 - DESIGN CHANGE FRAMEWORK

A survey of industry played a key role in this research. Among some of the most significant conclusions to be drawn from the industry survey are:

- Change Management and design improvement capabilities are considered to be strategically important, but industry strength in this area is low.

- The industry is actively seeking to improve its capabilities in the area of Design Change Management.

- U.S. shipyards exhibit a broad imbalance between the importance of capabilities and their strength relative to those capabilities. A Japanese shipyard representative of best in class exhibits a significantly greater balance (S/I = 1.0).

- U.S. shipyards exhibit a more diverse improvement program while the Japanese yard exhibited more focused improvement efforts.

- The existence of a visible corporate strategy which identifies performance gaps to be addressed with goals and objectives appears to be important to success.

- Activities associated with maintaining stability, prioritizing, planning, and decisionmaking are considered to be most critical to successful Change Management.

- A mechanism for quickly and effectively evaluating and prioritizing proposals and linking them to business strategy is essential. Decision criteria must be explicit.

- All of the Change Management goals introduced in Chapter 1.0 are considered to be equally important. These include extending the timeframe of effectivity, allowing changes to be made faster, minimizing the number of design changes, selecting potential design changes, evaluating potential design changes, prioritizing potential changes, allowing decisions to be made faster, insuring changes are effective, maximizing benefit potential, minimizing delays and disruption due to changes and identifying potential changes to reduce costs.

- Most organizations believe their procedures are effective for dealing with mandatory changes, but weak with respect to elective changes.

- Different shipyards have varying perspectives regarding decision criteria and the relative importance of maximizing benefits, minimizing costs, and minimizing risks associated with change proposals. A shipyard policy and strategy must make the position and guidelines clear.

- An active Production Engineering group appears to be present in those yards which reflect a preference for maximizing benefits over minimizing costs and risks.

- Close relationships and collocation of Production Engineering with Engineering and Planning appear important to success.

- The most significant roadblock to implementing elective change is manpower rather than budget. Change should be anticipated when allocating time and resources to a program.

- Participation and consensus are commonly used and appear correlated to success.

- Conclusions regarding the importance of Concurrent Engineering, Build Strategy Development, and standardization to Change Management success are reinforced by industry experience.

The identification procedure described in this study has been developed based upon lessons learned from the industry survey and the literature. In chapter 2.0 the history of the quality movement was reviewed and it was demonstrated that recent attention has been focused on mechanisms to align improvement activities with strategic objectives. The industry survey presented in chapter 4.0 supported that conclusion. The proposed identification approach addresses this issue.

The input to the identification stage is competitive pressure manifested as perceived or actual performance gaps. The output is a set of design improvement proposals focused upon strategic responses to the competitive pressures. The identification stage of the design change framework consists of a number of sub-elements aimed at first making the competitive environment explicit, followed by establishing objectives and goals, followed by identifying alternative proposals that support those goals. The theory and practice of value focused thinking and other methods aimed at eliminating or reducing cognitive biases are used to insure that a broad range of proposals is considered and to improve their performance relative to the identified goals. A hierarchical structure is used to facilitate this process. The approach recommended is consistent with structured decision analysis, and the hierarchy used in the identification stage serves as the benefits branch of the hierarchy structured for use with the Analytic Hierarchy Process (AHP) as a decision analysis tool for evaluation and prioritization of proposals.

A decision analysis model was developed and tested as a key contribution of this research. It was demonstrated that the Analytic Hierarchy Process can be used for this purpose, and proved capable of prioritizing proposals with respect to their contribution to strategic objectives. The model provides a meaningful way to examine alternatives under conditions of uncertainty using all the available information. Pairwise comparisons and ratio scale prioritization appear to successfully assess the relative benefits, costs and risks associated with proposals. The AHP permits prioritization of criteria, and adjustment of criteria to reflect changing objectives. The model results appear to reflect quality decisionmaking based upon a test application at a shipyard. Participants expressed interest in the process, and found it to be an appealing tool. While dependency between parameters did not appear significant to this problem, dependencies between alternatives had a significant impact. Both types of dependency can be considered using the AHP model. Assumptions regarding the deterministic synthesis of group judgments should be tested by examining the discrepancy between these judgments. It was shown that establishing consensus is important, and that the AHP model facilitates this. Model performance might be improved if greater consensus can be reached. The inconsistency ratio output of the Analytic Hierarchy Process was very useful. It identified when additional thought or data might be required. This unique feature of the Analytic Hierarchy Process serves to further facilitate consensus building.

Every effort must be made to minimize the number of parameters in the model and focus on key criteria. If several of the parameters are prioritized low, they can be eliminated without a significant impact on the results. This would have reduced the number of pair-wise comparisons required and subsequently reduced the amount of time required to complete the evaluation. Some parameters might be combined using constructed or proxy attributes, for example. It should be remembered that dominance of criteria diminish as one moves further down the hierarchy. A simple approach to screening should be used to eliminate inferior proposals. Such a screening method may utilize constructed attributes as discussed in chapter 6.0. This is necessary to place the evaluation in context. It also acts to reduce the amount of time the AHP evaluation will take.

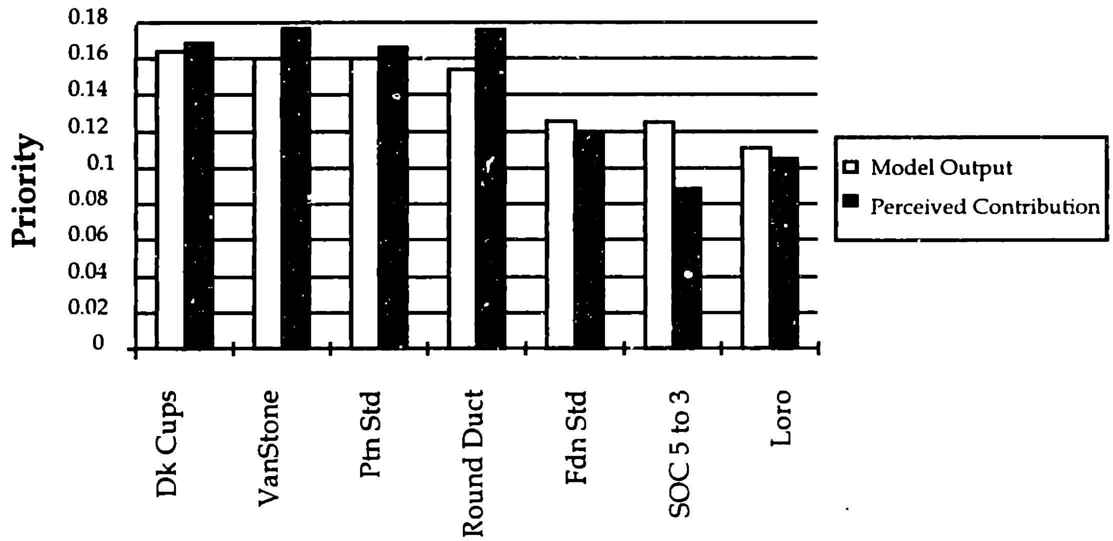

FIGURE 9.5 - COMPARISON OF MODEL RESULTS TO GROUP JUDGEMENT OF "REALITY"

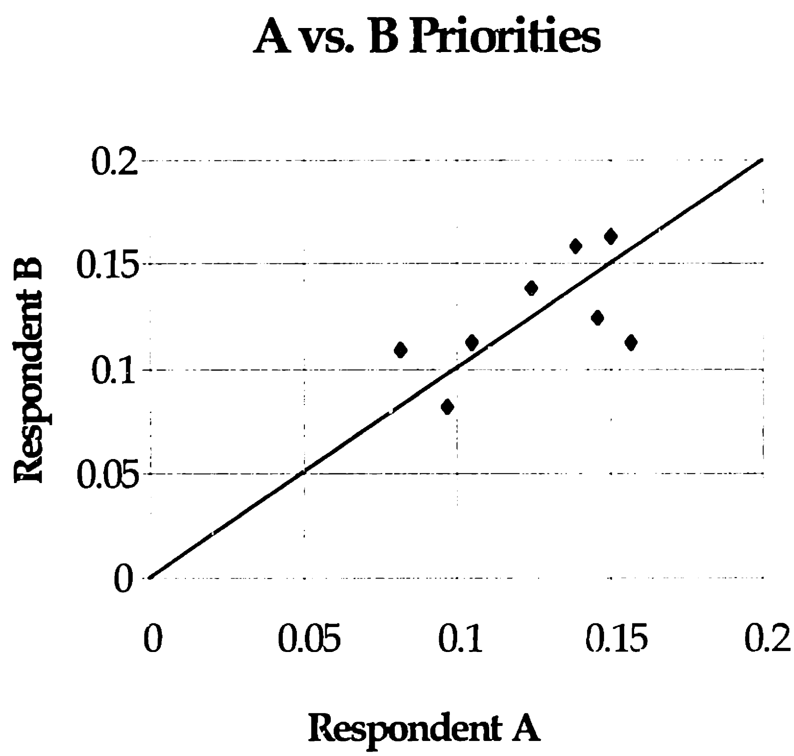

FIGURE 9.6 - MODEL OUTPUT USED TO EXPLORE CONSENSUS

It was demonstrated that the AHP model output can be used to facilitate quality decisionmaking, planning and implementation. The decision model can be used to perform "what if" scenario sensitivity analysis to explore the value of obtaining additional information regarding proposals. It also serves to visually illustrate the level of consensus that exists. This can be used to improve stakeholder relationships and the proposals themselves. The output also suggests which proposals are candidates for further consideration regarding how they might be improved relative to particular criteria for which they have been ranked low.

The ratio scale model output can be used directly in the objective functions of mathematical programming approaches to resource allocation. The prioritization reflects the order in which proposals should be invested in. Implementation strategies are suggested for the proposals, ranging from implementation through the line organization with no monitoring to highly projectized approaches, by examining the model output regarding relative benefits, costs, and risks. These priorities suggest the relative level of control required for each proposal.

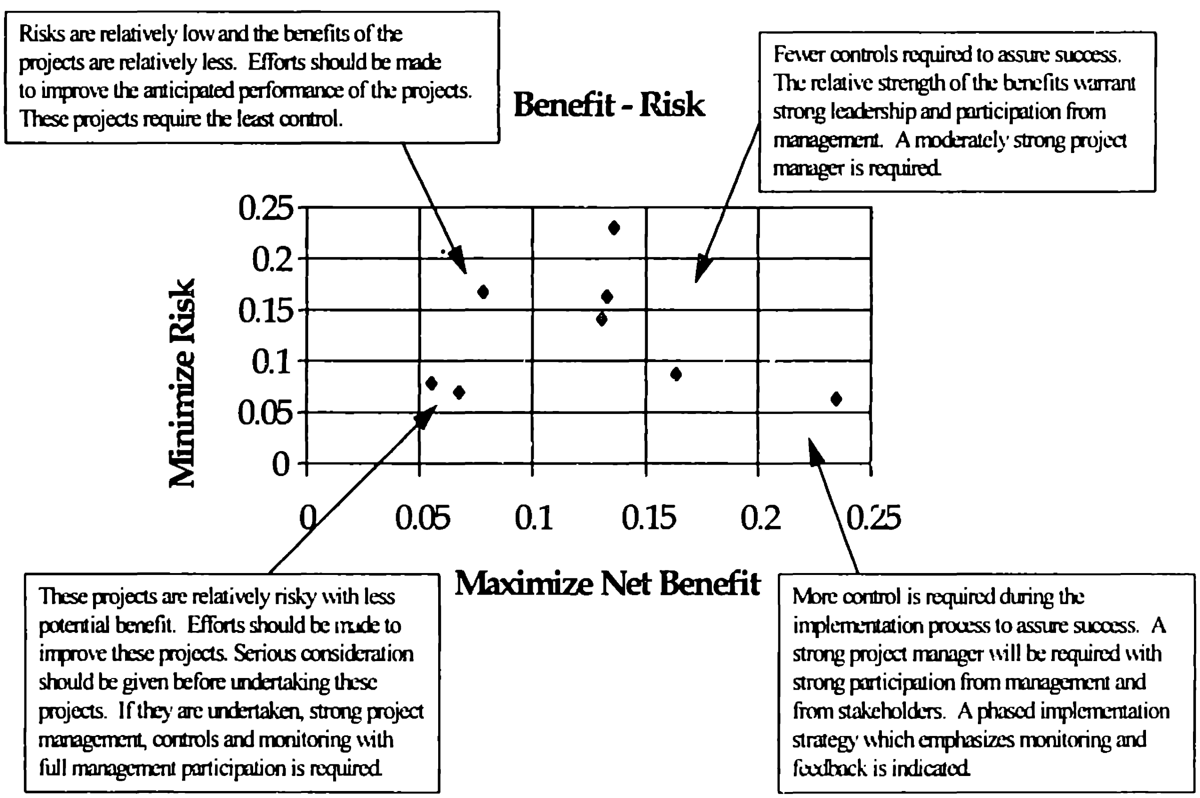

FIGURE 9.7 - MODEL OUTPUT SUGGESTING IMPLEMENTATION STRATEGY

9.2 Concluding Remarks

While all of the shipyards recognized the importance of this competitive capability, none of the U.S. shipyards considered its strength in this area to be high. This lack of strength is manifested in two ways. Many yards exhibit risk adversity to the point that they will not take action to improve the design throughout the design cycle. Other shipyards exhibit opportunity- seeking tendencies and introduce so many changes and "improvements" that "assimilation drain" is suffered and delay and disruption results.

The industry survey results validated conclusions drawn from the literature and experience, the most important of these being that proposals must not be introduced ad hoc, but must be prioritized and managed. This research yielded a Design Change Management framework and a decision analysis model which address this issue directly. The model and methods developed facilitate strategic planning and prioritization of proposals with respect to the strategic plan. The evaluation process and output serve to build consensus within the shipyard and focus attention upon shipyard strategy and policy. When the recommendations of this investigation are applied, it is anticipated that shipbuilders will significantly improve their ability to manage design improvement throughout the design cycle.

While the decision analysis model was developed to facilitate managing design improvement proposals, there is no reason to believe that the recommended approach is not general enough to be applied to other improvement activities. An example would be facility upgrades. Virtually any activity which must support strategic objectives could be evaluated using an approach similar to that recommended here. Further exploration and validation of the application of decision modeling with respect to strategic planning could be done with respect to other improvement activities.

Finally, the industry survey data suggests other avenues of related research. Design Change Management capabilities were not the only ones for which strategic importance is high but capability is low. While this study addressed all the stages of the Design Change Management framework, it was predominantly concerned with the evaluation and prioritization stages and how the output of the decision model can be used in the remaining stages. Additional research could be devoted to the implementation stage. Many design improvement proposals are implemented through the line organization's configuration management process. As was illustrated in the industry survey data, and Figure 9.1, shipyards need to reduce engineering rework. This rework is manifested as engineering change orders. The volume of mandatory changes directly impacts upon the "assimilation budget" which remains for elective changes. While industry survey data shows shipyards believe their processes associated with mandatory changes to be relatively strong, the conclusion that the S/I index for engineering rework reduction is low appears contradictory. Further exploration of the causes of engineering rework, and the processes shipyards use for dealing with it, will not only address an additional area of importance but will also directly contribute to introducing design improvements by reducing the "assimilation drain."

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APPENDIX A: INDUSTRY SURVEY QUESTIONNAIRE

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DESIGN CHANGE MANAGEMENT BENCHMARKING QUESTIONNAIRE

Rev C

SECTION A - OVERVIEW AND INSTRUCTIONS

- The purpose of this questionnaire is to assist in gathering information about your shipyard's design processes and procedures, leading to an analysis of design change management methodology.
- Please try to answer all questions. While it would be preferable if all sections could be completed by a range of people from designers through upper management, some segments can be targeted to individuals with specific roles or knowledge of the organization. Each section indicates who the questions are targeted to. If you do not believe that you are best suited to answer questions in a particular segment, please encourage someone to participate and answer those questions. If you feel that a question is not applicable to your organization, or that the information requested is proprietary, please indicate this in the space provided.
- If you feel that your response might be misinterpreted, or you have an example which could illustrate a point, you are encouraged to provide additional information.
- Should you have any questions or need interpretation, please contact:
- Please send final responses to the address above.
- All data will be treated as confidential. No reports will be published which make specific reference to any particular organization by name without written approval to do so. This research is being conducted by Matthew Tedesco in partial fulfillment of the requirements for a Ph.D. in the Ocean Systems Management program at the Massachusetts Institute of Technology. Matthew Tedesco works at the National Steel and Shipbuilding Company. All participants are welcome to a final report regarding the research results.

SECTION B - PARTICIPANT IDENTIFICATION

This section gathers information describing participants, and is to be completed by all participants.

1) Your name, address and phone number where you can be reached?

____

____

____

____

____

2) What is the name of your company? ________________________

3) What is your title at your company? ________________________

4) In your own words, please provide a short job description:

____

____

____

____

____

____

____

This survey will ask you questions about your "business unit". This may be your entire company when no such distinctions are made.

5) Indicate the business unit for which you are responding and describe its function and products:

____

____

6) How many people are employed by your division, department, and workgroup or section?

Division: ______________

Department: ______________

Workgroup: ______________

7) What are the primary functions of your division, department, and workgroup or section?

Division: ____

Department: ____

Workgroup: ____

8) Please check the item below that best describes who understands the goals, strategies and overall business plans in the business unit. Please provide your mission, values and guiding principles statements if they exist.

[ ] Top Management Only

[ ] Top and some middle management

[ ] Top and most middle management

[ ] Every manager and supervisor

[ ] Every manager, supervisor and employee

SECTION C - STRENGTHS AND IMPORTANCE OF ABILITIES

This section should be completed by management. On the left hand side of the page, please rate the degree of importance which you judge the competitive ability to have towards overall success in your business. On the right hand side of the page, please judge your business unit's strength with regard to the competitive ability relative to your best competition. Assume that two years ago represents 100%. Where do you stand today and where do you expect to be in two more years. Please add any competitive abilities which you judge to be important which have not been identified. Please provide additional information on separate sheets explaining what conditions exist which result in low scores for competitive strength in those cases where the ability was judged important.

DEGREE OF IMPORTANCE	*COMPETITIVE ABILITY*	*DEGREE OF STRENGTH*	*NOW*	*+ 2 yrs*
Unimportant.........Important		Very Weak.....Very Strong		
1 2 3 4 5 6 7 8 9 10	Ability to compete on price	1 2 3 4 5 6 7 8 9 10	___%	___%
1 2 3 4 5 6 7 8 9 10	Ability to profit in your market	1 2 3 4 5 6 7 8 9 10	___%	___%
1 2 3 4 5 6 7 8 9 10	Ability to meet cost expectations	1 2 3 4 5 6 7 8 9 10	___%	___%
1 2 3 4 5 6 7 8 9 10	Ability to offer consistent high quality in the eyes of the end customer	1 2 3 4 5 6 7 8 9 10	___%	___%
1 2 3 4 5 6 7 8 9 10	Ability of engineering to be seen as offering consistent high quality in the eyes of production	1 2 3 4 5 6 7 8 9 10	___%	___%
1 2 3 4 5 6 7 8 9 10	Ability to provide reliable products	1 2 3 4 5 6 7 8 9 10	___%	___%
1 2 3 4 5 6 7 8 9 10	Ability to meet delivery promises	1 2 3 4 5 6 7 8 9 10	___%	___%
1 2 3 4 5 6 7 8 9 10	Ability to exceed delivery promises	1 2 3 4 5 6 7 8 9 10	___%	___%
1 2 3 4 5 6 7 8 9 10	Ability to customize products and meet customer requests	1 2 3 4 5 6 7 8 9 10	___%	___%
1 2 3 4 5 6 7 8 9 10	Ability to minimize number of design changes	1 2 3 4 5 6 7 8 9 10	___%	___%
1 2 3 4 5 6 7 8 9 10	Ability to develop manufacturable designs	1 2 3 4 5 6 7 8 9 10	___%	___%
1 2 3 4 5 6 7 8 9 10	Ability to identify and incorporate lessons learned during design	1 2 3 4 5 6 7 8 9 10	___%	___%
1 2 3 4 5 6 7 8 9 10	Ability to identify and incorporate lessons learned during production	1 2 3 4 5 6 7 8 9 10	___%	___%
1 2 3 4 5 6 7 8 9 10	Ability to identify and incorporate cost/cycle time saving design changes	1 2 3 4 5 6 7 8 9 10	___%	___%
1 2 3 4 5 6 7 8 9 10	Ability to increase production when needed	1 2 3 4 5 6 7 8 9 10	___%	___%
1 2 3 4 5 6 7 8 9 10	Ability to complete design to schedule	1 2 3 4 5 6 7 8 9 10	___%	___%
1 2 3 4 5 6 7 8 9 10	Ability to complete design ahead of schedule	1 2 3 4 5 6 7 8 9 10	___%	___%

DEGREE OF IMPORTANCE	*COMPETITIVE ABILITY*	*DEGREE OF STRENGTH*	+ *NOW 2 yrs*
Unimportant.........Important		Very Weak.....Very Strong	
1 2 3 4 5 6 7 8 9 10	Ability to complete design at budget	1 2 3 4 5 6 7 8 9 10	____%____%
1 2 3 4 5 6 7 8 9 10	Ability to complete design under budget	1 2 3 4 5 6 7 8 9 10	____%____%
1 2 3 4 5 6 7 8 9 10	Ability to minimize engineering rework	1 2 3 4 5 6 7 8 9 10	____%____%
1 2 3 4 5 6 7 8 9 10	Ability to complete production to schedule	1 2 3 4 5 6 7 8 9 10	____%____%
1 2 3 4 5 6 7 8 9 10	Ability to complete production ahead of schedule	1 2 3 4 5 6 7 8 9 10	____%____%
1 2 3 4 5 6 7 8 9 10	Ability to complete production at budget	1 2 3 4 5 6 7 8 9 10	____%____%
1 2 3 4 5 6 7 8 9 10	Ability to complete production under budget	1 2 3 4 5 6 7 8 9 10	____%____%
1 2 3 4 5 6 7 8 9 10	Ability to minimize production rework	1 2 3 4 5 6 7 8 9 10	____%____%
1 2 3 4 5 6 7 8 9 10	Ability to produce accurate drawings or production information	1 2 3 4 5 6 7 8 9 10	____%____%
1 2 3 4 5 6 7 8 9 10	Ability to produce drawings or production information to schedule	1 2 3 4 5 6 7 8 9 10	____%____%
1 2 3 4 5 6 7 8 9 10	Ability to minimize the amount of information contained in engineering products	1 2 3 4 5 6 7 8 9 10	____%____%
1 2 3 4 5 6 7 8 9 10	Ability to maximize the amount of information contained in engineering products	1 2 3 4 5 6 7 8 9 10	____%____%
1 2 3 4 5 6 7 8 9 10	Ability to capture market share	1 2 3 4 5 6 7 8 9 10	____%____%
1 2 3 4 5 6 7 8 9 10	Ability to minimize material costs	1 2 3 4 5 6 7 8 9 10	____%____%
1 2 3 4 5 6 7 8 9 10	Ability to maximize direct labor productivity	1 2 3 4 5 6 7 8 9 10	____%____%
1 2 3 4 5 6 7 8 9 10	Ability to maximize engineering productivity	1 2 3 4 5 6 7 8 9 10	____%____%
1 2 3 4 5 6 7 8 9 10	Ability to maintain high production employee morale	1 2 3 4 5 6 7 8 9 10	____%____%
1 2 3 4 5 6 7 8 9 10	Ability to maintain high engineering employee morale	1 2 3 4 5 6 7 8 9 10	____%____%

DEGREE OF IMPORTANCE	*COMPETITIVE ABILITY*	*DEGREE OF STRENGTH*	*NOW*	*+ 2 yrs*
Unimportant.........Important		Very Weak.....Very Strong		
1 2 3 4 5 6 7 8 9 10	Ability to minimize inventories	1 2 3 4 5 6 7 8 9 10	____%	____%
1 2 3 4 5 6 7 8 9 10	Ability to standardize materials	1 2 3 4 5 6 7 8 9 10	____%	____%
1 2 3 4 5 6 7 8 9 10	Ability to standardize parts	1 2 3 4 5 6 7 8 9 10	____%	____%
1 2 3 4 5 6 7 8 9 10	Ability to maintain design simplicity	1 2 3 4 5 6 7 8 9 10	____%	____%
1 2 3 4 5 6 7 8 9 10	Ability to maintain clear communication between eng. and prod.	1 2 3 4 5 6 7 8 9 10	____%	____%
1 2 3 4 5 6 7 8 9 10	Ability to maintain clear communication between eng. depts.	1 2 3 4 5 6 7 8 9 10	____%	____%
1 2 3 4 5 6 7 8 9 10	Ability to maintain clear communication with customer	1 2 3 4 5 6 7 8 9 10	____%	____%
1 2 3 4 5 6 7 8 9 10	Ability to maintain clear communication with regulatory bodies	1 2 3 4 5 6 7 8 9 10	____%	____%
1 2 3 4 5 6 7 8 9 10	Ability to maintain stable and predictable processes	1 2 3 4 5 6 7 8 9 10	____%	____%
1 2 3 4 5 6 7 8 9 10	Ability to implement a simple and common product modeling system	1 2 3 4 5 6 7 8 9 10	____%	____%
1 2 3 4 5 6 7 8 9 10	Ability to implement concurrent engineering	1 2 3 4 5 6 7 8 9 10	____%	____%
1 2 3 4 5 6 7 8 9 10	Ability to develop and implement a design/build strategy	1 2 3 4 5 6 7 8 9 10	____%	____%
1 2 3 4 5 6 7 8 9 10	OTHER:____________________	1 2 3 4 5 6 7 8 9 10	____%	____%
1 2 3 4 5 6 7 8 9 10	OTHER:____________________	1 2 3 4 5 6 7 8 9 10	____%	____%

SECTION D - CRITICAL NEEDS

This section should be completed by management and supervision. Please indicate the degree to which you believe the items listed below contribute to successes or failures you have experienced while implementing design changes. A score of 1 indicates the item is a low contributor, a high score indicates an item is a high contributor. Please consider providing additional information regarding examples, additional reasons for success or failure, or the processes and procedures in place at your company which mitigate these problems.

	UNIMPORTANT IMPORTANT
Ability to properly implement concurrent engineering	1 2 3 4 5 6 7 8 9 10
Ability to identify critical needs early in design cycle	1 2 3 4 5 6 7 8 9 10
Ability to develop a robust design/build strategy	1 2 3 4 5 6 7 8 9 10
Ability to identify critical actions required to implement the change	1 2 3 4 5 6 7 8 9 10
Ability of engineering to react to new production processes	1 2 3 4 5 6 7 8 9 10
Ability to identify high payoff changes	1 2 3 4 5 6 7 8 9 10
Ability to demonstrate a compelling need for the change	1 2 3 4 5 6 7 8 9 10
Ability to avoid delays in decisionmaking, possibly from too many participants	1 2 3 4 5 6 7 8 9 10
Ability to avoid poor decisionmaking, possibly from too few participants	1 2 3 4 5 6 7 8 9 10
Ability to obtain sufficient interest from leadership	1 2 3 4 5 6 7 8 9 10
Ability to provide proof of progress to key people	1 2 3 4 5 6 7 8 9 10
Suitable analytical tools to quantify cost or benefit	1 2 3 4 5 6 7 8 9 10
Ability to assess the technical risks	1 2 3 4 5 6 7 8 9 10
Ability to assess the financial risks	1 2 3 4 5 6 7 8 9 10
Ability to assess of the organizational risks	1 2 3 4 5 6 7 8 9 10
Ability to maintain stable and predictable engineering processes	1 2 3 4 5 6 7 8 9 10
Ability to standardize	1 2 3 4 5 6 7 8 9 10
Ability to identify related auxiliary changes	1 2 3 4 5 6 7 8 9 10
Ability to coordinate changes within the context of a strategy	1 2 3 4 5 6 7 8 9 10
Ability to provide budget for the change effort	1 2 3 4 5 6 7 8 9 10
Ability to man the change effort	1 2 3 4 5 6 7 8 9 10
Ability to identify when the change is complete and irreversible	1 2 3 4 5 6 7 8 9 10
Ability to fully utilize product modeling (CAD/E/M)	1 2 3 4 5 6 7 8 9 10
Ability to avoid too many changes at once	1 2 3 4 5 6 7 8 9 10
Ability to prioritize proposals	1 2 3 4 5 6 7 8 9 10
Ability to avoid implementing unsound proposals	1 2 3 4 5 6 7 8 9 10

SECTION E - CHANGE MANAGEMENT GOALS

The following section should be completed by management and upper management. Which of the following do you consider to be the most important goals of a design change management process or program. Please rate each on a scale of 1 to 10, and provide further explanation below.

	Unimportant Important
Minimize number of design changes	1 2 3 4 5 6 7 8 9 10
Minimize delays and disruption due to changes	1 2 3 4 5 6 7 8 9 10
Extend the timeframe within which change is effective	1 2 3 4 5 6 7 8 9 10
Allow decisions to be made faster	1 2 3 4 5 6 7 8 9 10
Allow changes to be made faster	1 2 3 4 5 6 7 8 9 10
Insure changes are effective	1 2 3 4 5 6 7 8 9 10
Maximize benefit potential	1 2 3 4 5 6 7 8 9 10
Identify potential changes to reduce production costs	1 2 3 4 5 6 7 8 9 10
Evaluate potential changes	1 2 3 4 5 6 7 8 9 10
Prioritize potential changes	1 2 3 4 5 6 7 8 9 10
Select potential changes	1 2 3 4 5 6 7 8 9 10

SECTION F - AVAILABLE PROCEDURES

This section should be completed by supervision and designers. Please indicate which of the following motivations for design change your business unit has procedures in place for dealing with. Also rate, on a scale of 1 to 10, the effectiveness of your procedures.

MOTIVATION:	PROCEDURE	WEAK STRONG
Errors and Omissions	Y N	1 2 3 4 5 6 7 8 9 10
Customer Requests	Y N	1 2 3 4 5 6 7 8 9 10
Regulatory Requirements	Y N	1 2 3 4 5 6 7 8 9 10
Time/Cost saving technologies & Solutions	Y N	1 2 3 4 5 6 7 8 9 10
Lessons learned during production	Y N	1 2 3 4 5 6 7 8 9 10
Lessons learned during design	Y N	1 2 3 4 5 6 7 8 9 10
OTHER:________________________	Y N	1 2 3 4 5 6 7 8 9 10
OTHER:________________________	Y N	1 2 3 4 5 6 7 8 9 10
OTHER:________________________	Y N	1 2 3 4 5 6 7 8 9 10

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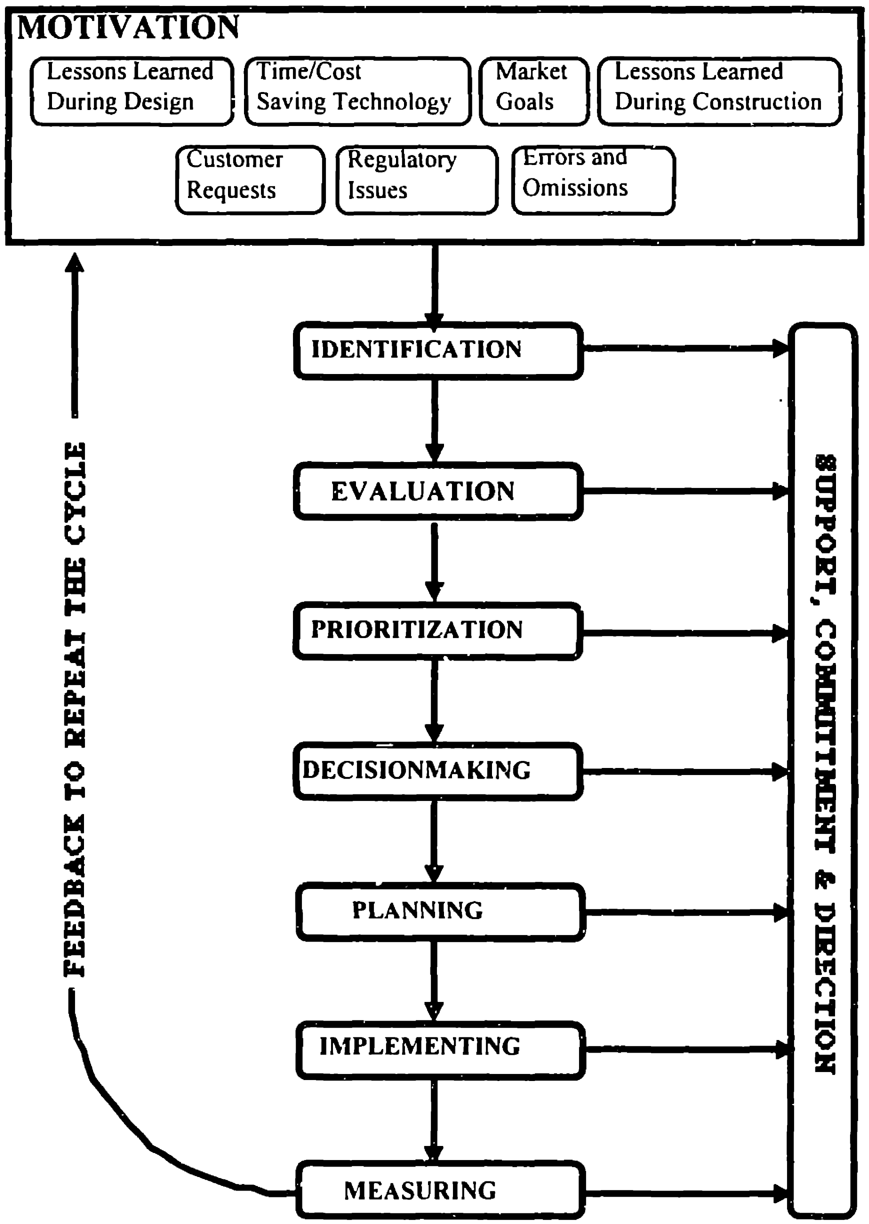
SECTION G - DESIGN CHANGE MANAGEMENT FRAMEWORK

The following framework describes a typical process of managing design change. The questions that follow pertain to the different stages illustrated by the framework. These questions should be answered by management and supervision.



1) For each of the following motivations, please indicate which individuals or group (by function) have primary responsibility for identifying potential design changes.

Errors and Omissions ______________________

Customer Requests ______________________

Regulatory Requirements ______________________

Time/Cost saving technologies & Solutions ______________________

Lessons learned during production ______________________

Lessons learned during design ______________________

2) What tools or "enablers" does your organization use to facilitate design change? These may include analytical tools, special meetings or forums, feedback systems, paperwork or data management systems. Please refer to the process stage for which the tool is intended (identification, evaluation, prioritization, decisionmaking, planning, implementing or measuring)

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3) Is there an individual or group responsible for each stage of your process? Who performs these functions? Please identify for each stage (identification, evaluation, prioritization, decisionmaking, planning, implementing, and measuring).

4) What are the means of documenting and communicating change proposals and progress?

5) What alternative approaches to each stage of the design change process does your organization employ, and what determines the approach used? Do the characteristics of the change alter the approach used? Some characteristics to discuss include source of the change, timing of the change, necessity, potential benefit and risk.

6) What roadblocks exist which hamper the success of each stage of the process?

7) When and how are decisions made regarding design changes?

____

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8) Are proposals captured for later use if the decision was made not to implement at this time?

____

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____

____

9) Please identify all the considerations given when deciding to implement proposals. Please rate the importance of each consideration on a scale of 1 (unimportant) to 10 (very important).

Cost to implement	[ ]	Potential benefit in $$$	[ ]
Time required to implement	[ ]	Potential benefit in cycle time	[ ]
Number of individuals/groups involved	[ ]	Technical risk	[ ]
Schedule risk	[ ]	Financial risk	[ ]
Regulatory risk	[ ]	Number of impacted documents	[ ]
Current design stage	[ ]	Available resources	[ ]
Current backlog of design changes	[ ]	Organization's "Readiness" for change	[ ]

Other Considerations:

____

____

10) Please discuss the role of the considerations identified in question (9) in the decisionmaking process.

11) How are issues related to budget and resources handled. What is the source of budget and resources for design changes aimed at reducing production costs and cycle time?

12) To what extent does management and upper management participate in the process of design change?

13) What incentives exist for design supervision to incorporate design changes?

SECTION H - CASE STUDIES

This section should be completed by supervision. The purpose of this section is to identify examples of design changes which have been successful, as well as those that have not.

1) Please identify and describe one or more successful design changes which you have been involved with which were identified and implemented for the purpose of reducing production costs. Please describe the process used to identify and implement the change, and the timing of this implementation in the design cycle. What significantly contributed to success? How do you define success?

2) Please identify and describe one or more unsuccessful design changes which you have been involved with which were identified and implemented for the purpose of reducing production costs. Please describe the process used to identify and implement the change, and the timing of this implementation in the design cycle. What significantly contributed to failure? How do you define failure?

SECTION I - CHARACTERIZATION OF THE COMPANY

This section gathers data related to the company and business unit which you represent.

1) Please identify your business unit's primary product(s). Identify product lines if they exist.

____

____

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2) If the company has several similar or related business units, please identify them, along with their primary products or product lines.

____

____

____

3) Please indicate which best describes your business unit:

[ ] A seller of capacity which markets their expertise, services and facilities to provide a customer with a tailor made end product which has been specifically contracted for.

[ ] A seller of products that develops products which serve a market, and markets those products to potential customers, with some customization within predetermined limits.

4) How many people are employed by your business unit?

Production:	__________	Administrative:	__________
Engineering:	__________	Industrial Eng.:	__________
Planning:	__________	Other Support:	__________
TOTAL:	__________		

5) Please provide organization charts for your business unit.

6) What is the mix of commercial to military work at your company?

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____

7) Is commercial work separated into its own division or business unit?

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____

8) What types of products has your business unit built in the last 5 years?

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9) Describe how the markets your business unit targets has changed in the last five years, and your plans for the future.

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10) Please characterize your products in relationship to other company's products by size and capacity. If your business is shipbuilding, please use length, beam and deadweight tonnage.

____

____

____

11) How many units do you complete each year? ________________

12) What is the average development duration, measured in months, for typical products? Please indicate with regard to conceptual through contract design and detail or production design. Please indicate any significant differences that may exist for different products.

Concept through Contract ______________________

Detail design ______________________

13) What is the average number of development man-hours expended for typical products? Please indicate any significant differences for different products.

Concept through Contract ______________________

Detail design ______________________

14) What is the average production duration, measured in months, from start of fabrication to delivery for typical products?

____

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15) How has the experience level, composition, or number of engineering/design personnel changed in the last 5 years?

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____

____

16) How has the experience level, composition, or number of production personnel changed in the last 5 years?

____

____

____

17) Did your business unit make a profit last year? Has it been profitable over the last five years?

____

____

18) What has been your average annual profit over the last two years:

[ ]	Less than 3 M	[ ]	11 to 15 M
[ ]	3 to 5 M	[ ]	16 to 20 M
[ ]	6 to 10 M	[ ]	21 M or greater

19) What is your business unit's market share of its primary products?

____

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____

20) Please describe key areas in which your company has invested towards training in the last two years. What results have you seen?

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21) What is the typical unit price for your typical products?

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APPENDIX B: DECISION MODEL DEVELOPMENT AND TEST

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DESIGN IMPROVEMENT PROPOSAL PRIORITIZATION MODEL

CRITERIA WEIGHTS QUESTIONNAIRE

October 1997
Rev 'A'

Please Return to: Matthew Tedesco

Your name and how you can be reached... ______________________

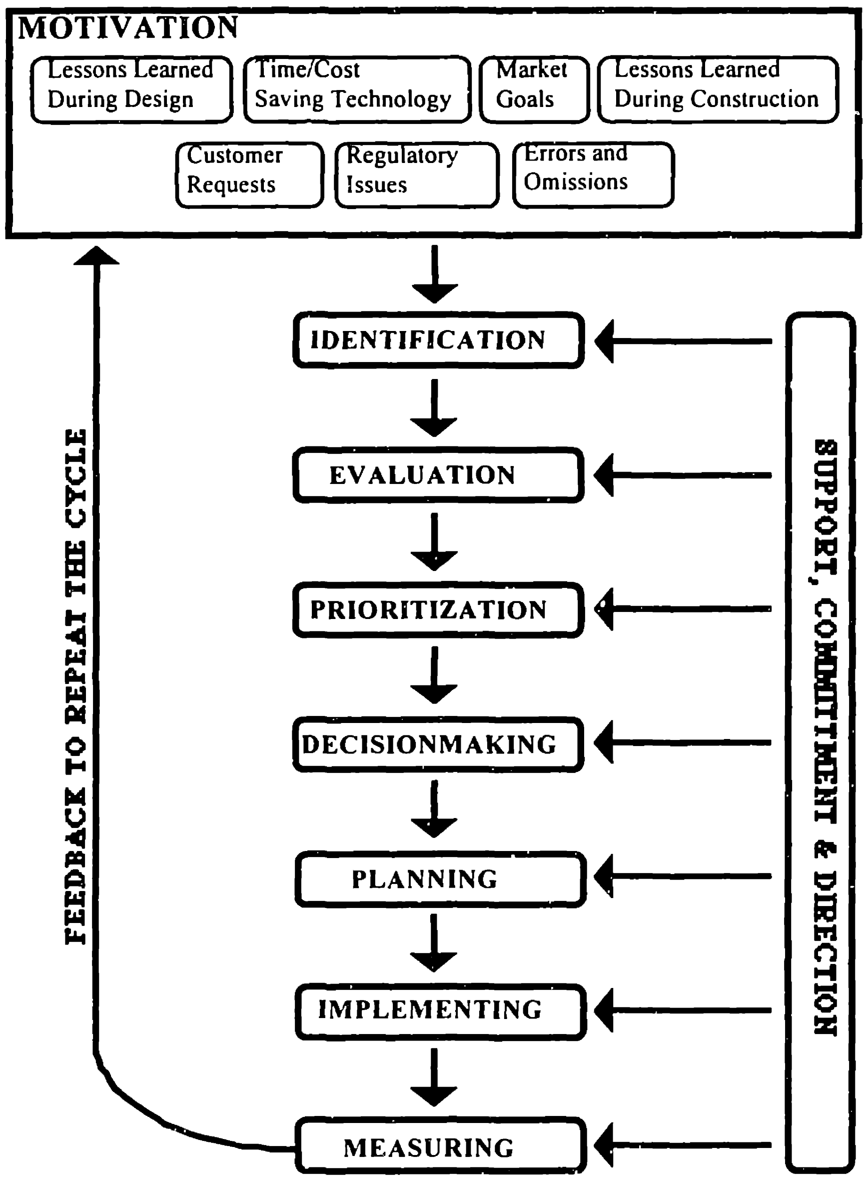
____

____

____

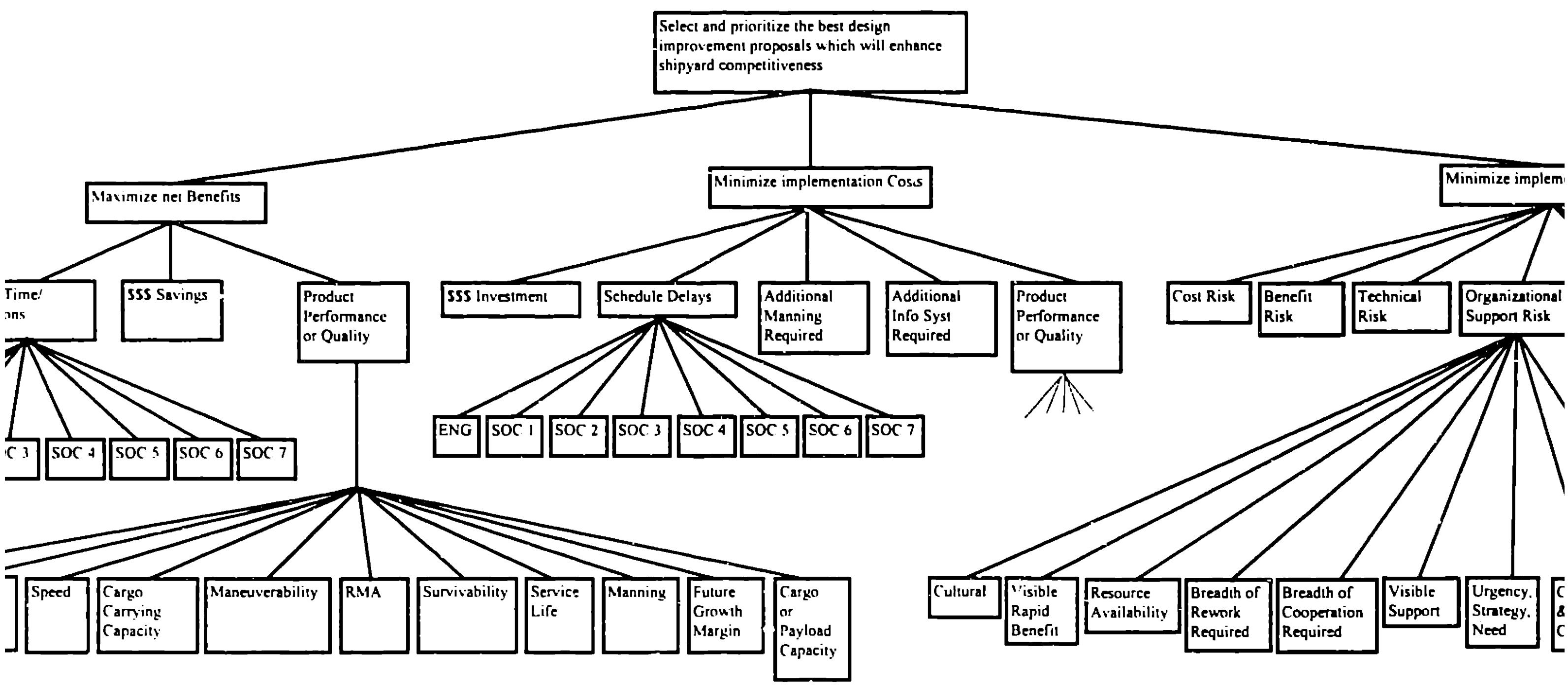
The following questionnaire seeks feedback from you regarding the degree to which different parameters contribute to a design improvement proposal's capacity to enhance shipyard competitiveness. The results of this questionnaire will be used to develop the weights assigned to parameters in a decisionmaking model for use in evaluating, ranking, and weighting design improvement proposals. This is accomplished through a system of pair-wise comparisons known as the Analytic Hierarchy Process. This ranking and weighting can subsequently be used as a basis for decisions regarding which proposals to implement and how to allocate resources to a portfolio of proposals.

The decisionmaking model being proposed operates within the general framework illustrated below. This questionnaire is concerned with the evaluation, prioritization and decisionmaking phases of the framework, particularly as it relates to elective (productivity motivated) changes. These changes are associated with the first row of motivations in the illustration below.



The structured decision system proposed begins with a screening process which quickly evaluates the feasibility and merit of a proposal against a set of key criteria which represent thresholds below which porposals will not be pursued. Those that are not rejected as a result are examined through an evaluation model which ranks and weights the portfolio of feasible proposals to assist in implementation and resource allocation decisions.

ırarchy below illustrates the proposed prioritization model. In examining the model, recall that proposals which aı
ːd by this model have been previously screened to demonstrate that they are feasible and have merit. The goal is to sel
ːsign improvement proposals which have the greatest potential to enhance shipyard competitiveness. This goal is supp(
ːvel objectives, or criteria, which serve as model parameters. These are subsequently supported by additional sub-criteı
and sub-criteria reflect shipyard strategic objectives, and their weighting reflects the relative importance of objectives.
level of the hierarchy are alternative proposals. The most complete description and accounting for each proposal sh
'ith respect to each parameter in the time available, but need not be overly detailed. Proposals will be pair-wise comj
dgments regarding intensity of preference for one over the other with respect to each parameter. This intensity of pr(
based upon both quantitative and qualitative data. Through the Analytic Hierarchy Process, these pairwise comparis
ized into a ranking and weighting of the alternatives. The AHP has advantages over other decisionmaking approaches i
both quantitative and qualitative data to be used, it structures the problem in a natural way, it admits and n
ɜtency (useful in gauging the quality of a decision), and can be used to synthesize the judgments of multiple decisionma



DEFINITIONS

The model parameters are defined as follows.

Benefits, Costs and Risks

The high level criteria in the hierarchy are benefits, costs and risks. Net Benefits of proposals represent the contribution the proposal makes to furthering shipyard strategic objectives, as reflected in the sub-criteria to benefits. Costs refer to the negative impacts which implementing a proposal may have on the organization and the design. Risks are associated with uncertainty. They represent an assessment of both the magnitude of the uncertainty and the likelihood or probability associated with the uncertainty. These high level parameters synthesize the results of their sub-criteria and reflect the intensity with which one proposal contributes to benefits, costs, or risks with respect to another.

BENEFITS:

Cycle Time/Duration:

This parameter is associated with the value which reducing the construction cycle has to the shipyard. It represents the intensity of preference for one proposal over another with respect to their contribution to the strategic objective of reducing cycle time. Reduction of cycle time is a strategic objective which has value independent of cost or quality. It is associated with labor hours, material handling time and any waiting or lost time associated with tasks. Cycle time ultimately impacts market share and impacts on the amount and type of work the shipyard can bid on. Reduced cycle time is generally believed to lead to lower costs, but also has value independent of costs. For example while reducing labor content, and therefore man-hours, will always result in reduced cost it does not necessarily result in reduced cycle time. The reduction of cycle time is dependent on whether the tasks being made easier are actually on the critical path. If they are, a reduction in cycle time will occur in addition to a reduction in costs. A shipyard may choose a strategy which focuses heavily on reducing cycle time without emphasizing dollar savings. Cycle time is being considered here as an independent parameter and reflects the value of reducing the construction cycle even if the dollar costs associated with the labor content remained the same.

Ship production can be described as taking place in a variety of stages. These form sub-criteria to reduced cycle time, as a shipyard may determine that reductions in a particular stage are of greater strategic importance due to facility constraints and the work content of a particular contract.

The sub-criteria to cycle time reduction are defined as follows:

- Engineering
- SOC 1 - Fabrication
- SOC 2 - Sub Assembly
- SOC 3 - Assembly
- SOC 4 - On - Unit Outfitting
- SOC 5 - On - Block Outfitting
- SOC 6 - On - Board
- SOC 7 - Test and Trials

Dollar Savings:

This parameter represents the dollars associated with labor or material content which the proposal will save. It is the intensity of preference for one proposal over another with respect to the total dollar value of man-hour reduction, substitution or reduction of material, and other proposal characteristics. It is independent of dollars which are not due to labor or material content. Those that are associated with reduced cycle time (such as incentives for meeting or beating schedule or costs associated with time in the yard that are not directly linked to labor content or design features) are considered when evaluating alternatives with respect to cycle time and the weight allocated to that parameter. In this way, dollar savings is being defined as a parameter independent of cycle time.

Performance or Quality Improvement:

This parameter is associated with a number of sub-criteria which reflect performance or quality features of importance to the owner. The weights of these sub-criteria should reflect the "voice of the customer" as it relates to their desires. The weight of performance improvement in comparison to cycle time reduction or dollar savings is a function of shipyard strategy and objectives. The parameter reflects the intensity of preference for one proposal over another with respect to improving performance.

<u>COSTS:</u>

Dollars Invested:

This parameter represents the intensity of the decisionmakers aversion to the total cost, in dollars, that is estimated to be required to implement one proposal relative to another. This should include consideration of non-recurring and recurring costs, labor, and material.

Schedule Delay:

This parameter represents the intensity with which one alternative negatively impacts schedule with respect to other alternatives. The dollar value of schedule delay is generally very difficult if not impossible to predict. The interest here is the intensity of the aversion to projects which impact schedule regardless of the estimated dollar investment in the project. This parameter has also been associated with sub-criteria to allow the strategic importance of certain stages to be accounted for.

Additional Manning Required:

The requirement for additional manpower by those involved in the implementation effort represents a cost which is distinct from budget and schedule. Manpower is a resource which contributes to dollar costs, but is also an independent consideration of importance to decisionmakers. Forcing an overtime situation, or addition of people to the team, represents a destabilizing force which management would prefer to avoid but is difficult to evaluate strictly in terms of dollars or schedule. The commitment of manpower means that this resource is now unavailable to handle current workload or unforeseen requirements. The weight associated with this parameter represents an aversion to increased manpower requirements.

Additional Information Systems Resources Required:

The requirement for additional computer equipment or software represents a cost which has significance independent of dollars invested. As was the case with manpower, this requirement contributes to dollars invested, but is generally considered as an additional parameter by management. The parameter represents the intensity with which one proposal ties up (or requires acquisition of additional) information system resources as compared to another resource.

Product Performance or Quality:

This parameter represents the intensity with which one proposal negatively impacts product performance or quality as compared to another proposal. As was the case in the discussion of benefits, it is a function of sub-criteria which are of importance to the customer.

RISKS

Cost Risk:

This parameter represents the intensity with which the costs estimated for a proposal may have been underestimated. It is a measure of cost uncertainty with respect to the combined impact of magnitude and likelihood. It is a representation of the intensity of preference for one proposal over another with respect to their cost uncertainty.

Benefit Risk:

This parameter represents the intensity with which the benefits estimated for a proposal may have been underestimated. It is a measure of benefit uncertainty with respect to the combined impact of magnitude and likelihood. It is a representation of the intensity of preference for one proposal over another with respect to their benefit uncertainty.

Technical Risk:

This parameter represents the intensity with which one proposal is preferable over another with respect to the likelihood that the proposal may fail for technical reasons.

Organizational Support Risk:

This parameter represents the intensity of preference for one proposal over another with respect to the likelihood that one may fail due to a lack of organizational support, despite all other measures of merit being promising. This parameter is a function of a number of sub-criteria as follows.

The "Cultural" parameter represents the intensity with which one proposal requires changes in peoples attitudes or daily work-habits as compared to another proposal. It represents the impact that the change will have on people personally in the way they conduct their daily work.

The "Visible Rapid Benefits" parameter represents the intensity with which a proposal is believed to have highly visible short-term benefits as compared to another proposal.

The "Resource Availability" parameter represents the intensity of the uncertainty associated with the availability of resources to implement one proposal as compared to another.

"Breadth of Rework Required" represents the intensity of preference for one proposal over another with respect to the number of documents and product models which will require rework to implement the proposal.

"Breadth of Cooperation Required" represents the intensity of preference for one proposal over another with respect to the degree of cooperation required by numerous people or groups. It is a measure of the risks associated with the degree of communication and cooperation which is required for a proposal to be successful.

"Visible Support" represents the intensity of preference for one proposal over another with respect to the amount and quality of visible management support for the proposal.

The "Urgency, Strategy, Need" parameter measures the intensity of preference for proposals which clearly are aligned with a communicated and understood strategy or shipyard objective which the people or organizations tasked with implementation support.

"Complexity & Capability" refers to the intensity of preference for proposals which do not require knowledge or workforce capabilities which are scarce or missing, and for which the means and requirements for implementation are readily understood and achievable.

"Stability" refers to the intensity of preference for proposals which require action related to processes or interim products which are standardized and understood, and by people or groups which are not presently stressed by a high degree of change.

Regulatory Risk:

This parameter represents the intensity of preference for proposals which are less likely to be delayed or rejected by regulatory bodies (or the customer).

Schedule Risk:

This parameter represents the intensity of preference for proposals which exhibit less uncertainty with respect the both the magnitude and likelihood of schedule delays beyond those estimated in the consideration of costs.

Thresholds and Goals

When considering the benefits, costs or risks of proposals, please describe the threshold level for each sub-criteria. These threshold levels represent the minimum level of achievement you would accept to consider implementing a proposal. Please also describe the goal level. This represents your "stretch goal" or the best you would expect to see a proposal achieve. These thresholds and goals will be useful in setting the context for the subsequent pair-wise comparisons. They will also aid in the development of the pre-prioritization screening model.

If a criteria is particularly insignificant to you, you may enter a zero for both the threshold and the goal. If you believe that a proposal is worth looking at so long as a particular parameter is positive, you can simply indicate "positive". The purpose of these questions is to gain an understanding of how you would quickly determine if a proposal is worth evaluating further, and to place comparisons of parameters in the context of a scenario which is "reasonable" to you. If the questions below do not reflect the way you think about these issues, please provide a short description of how you consider thresholds and goals for proposals.

Maximizing Benefits:

Cycle Time Reduction:

In establishing the thresholds and goals, assume that the only cycle time reduction a proposal results in is for that particular stage. In setting the threshold and goal for "all stages" consider the reduction you would expect to see for any given proposal with respect to TOTAL construction cycle. Please express these as % improvement over current performance.

STAGE	THRESHOLD	GOAL	STAGE	THRESHOLD	GOAL
Engineering:	______%	______%	SOC 4:	______%	______%
SOC 1:	______%	______%	SOC 5:	______%	______%
SOC 2:	______%	______%	SOC 6:	______%	______%
SOC 3:	______%	______%	SOC 7:	______%	______%
All Stages:	______%	______%			

Dollar Savings:

Please indicate the threshold dollar value you would consider as worth pursuing, and the "stretch goal" which represents the most you would expect the "best" proposal to save. You can also indicate a benefit/cost ratio or return if that is an important consideration to you.

Threshold ______________ $ Goal _________________$

Product Performance or Quality Improvement:

The model being developed is focused upon proposals which enhance competitiveness through productivity improvement. This parameter and its sub-criteria is therefore of secondary importance in evaluating benefits within the context of the purpose of this model. It is included to reflect the fact that given two proposals which provide equal benefits with respect to productivity, one which improves quality would be favored. There is no need to identify threshold values or goals.

Minimizing Implementation Costs:

Dollars Invested:

Please indicate the highest threshold dollar value you would consider as worth pursuing. The "stretch goal" is assumed to be a zero cost change. You can also indicate a benefit/cost ratio or return if that is an important consideration to you.

Threshold ______________ $ Goal ________0________$

Schedule Delays:

Please indicate the most schedule delay you would accept. The goal is assumed to be zero delay.

STAGE	THRESHOLD	GOAL	STAGE	THRESHOLD	GOAL
Engineering:	______%	0 %	SOC 4:	______%	0 %
SOC 1:	______%	0 %	SOC 5:	______%	0 %
SOC 2:	______%	0 %	SOC 6:	______%	0 %
SOC 3:	______%	0 %	SOC 7:	______%	0 %
All Stages:	______%	0 %			

Additional Manning Required:

Please indicate the threshold highest increase in equivalent men you would accept as being required above the baseline workload during the implementation period.

Threshold ________________ equiv. men Goal ____0____ equiv. men

Additional Information Systems Required:

Please indicate the threshold highest increase in number of computer terminals or software licenses you would accept as being required above the baseline workload during the implementation period.

Threshold _____________terminals/licenses Goal ____0____ terminals/licenses

Product Performance or Quality Impact:

It is assumed that for the purposes of this model, the threshold performance level is not explicit, but is some measure that is related to the ship specification, applicable regulations and shipyard standards. It is understood that some negotiation is possible with regard to specifications and standards, but that there is generally an understood threshold performance level for each characteristic. The threshold will be assumed to be understood, and the goal is no negative impact.

Minimizing Risks:

Cost Risk:

Please indicate the threshold uncertainty which you would accept with respect to implementation costs. This can be expressed as a probability distribution. The distribution will be described subjectively here using several points. The interest is only in costs higher than the estimate. The goal is assumed to be zero risk of implementation costs higher than those estimated.

Probability that implementation cost is as estimated: ___________%

Probability that implementation cost is 10% higher: ___________%

Max % increase over estimate you would accept: ___________%

Probability that implementation cost is that much higher: ___________%

Benefit Risk:

Please indicate the threshold uncertainty which you would accept with respect to implementation benefits. This can be expressed as a probability distribution. The distribution will be described subjectively here using several points. The interest is only in benefits lower than the estimate. The goal is assumed to be zero risk of implementation benefits lower than those estimated.

Probability that implementation benefit is as estimated: ___________%

Probability that implementation benefit is 10% lower: ___________%

Max % decrease below estimate you would accept: ___________%

Probability that implementation benefit is that much lower: ___________%

Technical Risk:

What threshold % chance would you accept that the proposal would be proven to be technically unworkable? The goal is assumed to be zero risk.

__________%

Organizational Risk:

What threshold % chance would you accept that the proposal would fail to be implemented because of insufficient organizational support? The goal is assumed to be zero risk.

_________%

Please consider each of the sub-criteria to organizational risk...

Cultural:

What threshold % chance would you accept that the proposal would fail to be implemented because of insufficient organizational support due to the intensity with which the proposal requires those tasked with implementation to change their attitudes or daily work habits? The goal is assumed to be zero risk.

_________%

Visible Rapid Benefit:

What threshold % chance would you accept that the proposal would fail to be implemented because of insufficient organizational support due to the intensity with which the proposal lacks clearly visible, short term, benefits? The goal is assumed to be zero risk.

_________%

Resource Availability:

What threshold % chance would you accept that the proposal would fail to be implemented because at some point during implementation it is found that there are insufficient resources? The goal is assumed to be zero risk.

_________%

Breadth of rework required:

What threshold % chance would you accept that the proposal would fail to be implemented because those tasked with implementation could not accept the level of rework involved? The goal is assumed to be zero risk.

_________%

Breadth of cooperation required:

What threshold % chance would you accept that the proposal would fail to be implemented because at some point during implementation it is found that communication lines have broken down and that the necessary level of cooperation was not being achieved among those tasked with implementation? The goal is assumed to be zero risk.

_________%

Visible Support:

What threshold % chance would you accept that the proposal would fail to be implemented because of insufficient clearly visible management support? The goal is assumed to be zero risk.

_________%

Urgency, Strategy, Need:

What threshold % chance would you accept that the proposal would fail to be implemented because it is not clear that there is a strategy associated with it, or that it fits into an existing strategy? The goal is assumed to be zero risk.

_________%

Complexity and Capability:

What threshold % chance would you accept that the proposal would fail to be implemented because of its task complexity and/or a lack of the necessary workforce skills? The goal is assumed to be zero risk.

_________%

Stability:

What threshold % chance would you accept that the proposal would fail to be implemented because it is associated with issues for which there is a lack of clearly understood standard processes and products, and those tasked with implementation are already undergoing significant change efforts? The goal is assumed to be zero risk.

_________%

RELATIONSHIP MATRICES

Please identify in the matrices below the degree to which one parameter (on the left) impacts another parameter's (top of matrix) contribution to the goal. Use the following intensity scale. Positive values indicate a parameter assists another in its contribution to the goal. Negative values indicate a parameter hinders another in its contribution to the goal. Please review the parameter definitions when determining relationships. If you believe that there is no dependency, then enter a zero.

INTENSITY	DEFINITION	EXPLANATION
0	None	There is no dependency relationship
1	Equal	Two parameters are identical
2	Weak	One parameter weakly influences the other
3	Moderate	One parameter moderately influences the other
4	Moderate Plus	
5	Strong	Experience and judgment indicate a strong influence
6	Strong Plus	
7	Very Strong	
8	Very, Very Strong	
9	Extreme Importance	The evidence of the impact of one activity over another is of the highest possible order of affirmation

High Level Criteria Relationships

With Respect To Prioritizing Design Improvement Proposals	Maximize Net Benefit	Minimize Implementation Costs	Minimize Implementation Risks
Maximize Net Benefit	1		
Minimize Implementation Costs		1	
Minimize Implementation Risks			1

Mazimize Net Benefits			
With Respect to Maximizing Net Benefits	Cycle Time/Duration Reduction	Dollar Savings	Product Performance Improvement
Cycle Time/Duration Reduction	1		
Dollar Savings		1	
Product Performance Improvement			1

Cycle Time Reduction								
With Respect to Maximizing Benefit by Reducing Cycle Time	Engineering	SOC 1	SOC 2	SOC 3	SOC 4	SOC 5	SOC 6	SOC 7
Engineering	1							
SOC 1		1						
SOC 2			1					
SOC 3				1				
SOC 4					1			
SOC 5						1		
SOC 6							1	
SOC 7								1

Minimize Implementation Costs

With Respect to Minimizing Implementation Costs	Dollars Invested	Schedule Delays	Additional Manning Required	Addtional Info. Syst. Required	Product Performance or Quality Impact
Dollars Invested	1				
Schedule Delays		1			
Additional Manning Required			1		
Addtional Info. Syst. Required				1	
Product Performance or Quality Impact					1

Schedule Delay

With Respect to Minimizing implementation costs by minimizing schedule delay	Engineering	SOC 1	SOC 2	SOC 3	SOC 4	SOC 5	SOC 6	SOC 7
Engineering	1							
SOC 1		1						
SOC 2			1					
SOC 3				1				
SOC 4					1			
SOC 5						1		
SOC 6							1	
SOC 7								1

Minimizing Risks						
With Respect to Minimizing Risks	Cost Risk	Benefit Risk	Technical Risk	Organizational Support Risk	Regulatory Risk	Schedule Risk
Cost Risk	1					
Benefit Risk		1				
Technical Risk			1			
Organizational Support Risk				1		
Regulatory Risk					1	
Schedule Risk						1

Organizational Risks									
With Respect to Minimizing implementation risks associated with organizational support	Cultural	Visible Rapid Benefit	Resource Availability	Breadth of Rework Required	Breadth of Cooperation Required	Visible Support	Urgency, Strategy, Need	Complexity and Capability	Stability
Cultural	1								
Visible Rapid Benefit		1							
Resource Availability			1						
Breadth of Rework Required				1					
Breadth of Cooperation Required					1				
Visible Support						1			
Urgency, Strategy, Need							1		
Complexity and Capability								1	
Stability									1

PAIR-WISE QUESTIONNAIRE

The following questions will relate to pairwise comparisons between model parameters. You will be asked to identify which parameter more intensely supports an objective, and by how much, as compared to another parameter. In answering these questions, the following interpretation should be used for numerical representations of intensity judgments.

INTENSITY	DEFINITION	EXPLANATION
1	Equal Importance	Two activities contribute equally to the objective
2	Weak	
3	Moderate	Experience and judgment slightly favor one
4	Moderate Plus	
5	Strong	Experience and judgment strongly favor one
6	Strong Plus	
7	Very Strong	An activity is favored very strongly over another
8	Very, Very Strong	
9	Extreme Importance	The evidence favoring one activity over another is of the highest possible order of affirmation

Example

Which of the two parameters below has the greatest influence on the value of a proposal's benefits to the shipyard, and with what intensity?

Cycle Time Reduction $$$ Savings

9.....8.....(7).....6.....5.....4.....3.....2.....1.....2.....3.....4.....5.....6.....7.....8.....9

In the example above, cycle time reduction is considered to be very strongly favored over dollar savings with respect to the value of a proposal's benefits to the shipyard.

Scenario

Please consider the following:

- The alternatives being evaluated by the model described have already been screened to determine that they meet minimum feasibility criteria and are believed to have merit (net positive benefit). Proposals being evaluated will have been estimated to meet threshold requirements.

- The criteria weights reflect shipyard strategy, and are a function of the conditions at the shipyard and even a particular contract. In answering these questions, please consider the conditions that existed at the start of the Sealift New Construction contract. The alternatives being evaluated have generally been motivated by lessons learned on Sealift Conversion 1 and identification of technology which has not yet been taken advantage of. Please assume that this prioritization addresses the decision to implement on SLNC or not, and that Functional and Transition design are essentially complete. Detail Structural design is well underway and outfitting detail design has begun.

- In answering the pair-wise comparisons on the following pages, please indicate which parameter contributes more intensely to the goal of selecting and prioritizing design improvement proposals to enhance shipyard competitiveness. Assume that the comparison is between achieving the threshold in the lesser vs. the goal in the greater as defined earlier.

HIGH LEVEL CRITERIA

Please identify which of the parameters in the pairs on the following page more intensely contributes to the goal of selecting and prioritizing design improvement proposals to enhance shipyard competitiveness. Assume that the comparison is between achieving the threshold in the lesser vs. the goal in the greater as defined earlier.

BENEFITS

Please identify which of the parameters in the pairs on the following page more intensely contributes to the goal of maximizing the benefit of design improvement proposals. Assume that the comparison is between achieving the threshold in the lesser vs. the goal in the greater as defined earlier.

BENEFITS - Cycle Time Reduction

Please identify which of the parameters in the pairs on the following pages more intensely contributes to the goal of maximizing the benefit of design improvement proposals by reducing cycle time. Assume that the comparison is between achieving the threshold in the lesser vs. the goal in the greater as defined earlier.

BENEFITS - Performance Improvement

Please identify which of the parameters in the pairs on the following pages more intensely contributes to the goal of maximizing the benefit of design improvement proposals by improving product performance or quality. Assume that the comparison is between achieving the threshold in the lesser vs. the goal in the greater as defined earlier.

COSTS

Please identify which of the parameters in the pairs on the following page more intensely contributes to the goal of minimizing the cost of implementation of design improvement proposals. Assume that the comparison is between achieving the threshold in the lesser vs. the goal in the greater as defined earlier.

COSTS - Schedule Delay

Please identify which of the parameters in the pairs on the following pages more intensely contributes to the goal of minimizing the cost of implementation of design improvement proposals by minimizing schedule delays. Assume that the comparison is between achieving the threshold in the lesser vs. the goal in the greater as defined earlier.

COSTS - Product Performance

Please identify which of the parameters in the pairs on the following pages more intensely contributes to the goal of minimizing the cost of implementation of design improvement proposals by minimizing negative impacts upon product performance or quality. Assume that the comparison is between achieving the threshold in the lesser vs. the goal in the greater as defined earlier.

RISKS

Please identify which of the parameters in the pairs on the following page more intensely contributes to the goal of minimizing the risks of implementation failure of design improvement proposals. Assume that the comparison is between achieving the threshold in the lesser vs. the goal in the greater as defined earlier.

RISKS - Organizational

Please identify which of the parameters in the pairs on the following pages more intensely contributes to the goal of minimizing the risks of implementation failure due to a lack of organizational support for design improvement proposals. Assume that the comparison is between achieving the threshold in the lesser vs. the goal in the greater as defined earlier.

TEST OF THE MODEL

REV '-' Alternatives Evaluation

Your name: ______________________________

Case studies are being used to "test" the model which has been developed based upon the feedback you previously provided. A short description of the case projects is provided with some of the "backup" material which had been generated at the time the project was being considered. This material is provided after the pair-wise comparison questions. Please review it to refresh your memory regarding the case studies as necessary. The intent is to evaluate the projects as though you were looking at them for the first time, based upon the knowledge that was available to you at the time the projects were initially being proposed.

In answering the questions, please consider the conditions that existed at the start of the SLNC. The alternatives being evaluated have generally been motivated by lessons learned on the SLC1. Functional and Transition design for the SLNC are essentially complete, detail design in Structural is well underway and Outfitting detail design has begun.

These projects will be pair-wise compared against the model criteria to result in a ranking and weighting of the projects based on the information that was available at the time (in the past). These cases have been selected because I believe that they will be familiar to you, and because we have knowledge today regarding how successful they were. In addition to pair-wise comparing the alternatives with respect to the criteria to evaluate them via the model, I am also asking you to pair-wise compare them DIRECTLY as to the intensity with which you believe they were successful in enhancing the shipyard's productivity. This should be based on everything you know today.

CASE STUDY SUMMARIES

Eight case studies were selected to test the decision model developed in this research. Summaries of the cases were developed, complete with supporting documentation, to refresh the memory of those participating in the research. They were asked to pairwise compare the cases relative to the model criteria based upon the information that was available at the time the case was originally being considered. Later the participants were asked to pairwise compare the cases with respect to the contribution they were thought to have actually made to improved competitiveness. The following summaries are provided to give additional background to the reader, but do not include the quantitative data which is considered to be business sensitive.

CASE 1 - Deck Socket Cups

It has been proposed by production to reduce the thickness of deck socket cups for lashing tie-downs from 1/2" to 1/4" for an existing and upcoming sealift contract. Implementing the change would mean modifying an existing standard to include the new cups and to change any existing bills of material and find numbers on drawings as required for follow on work for contracts in progress. It is proposed to use the thinner cups everywhere except the weather deck and in way of tanks. The ships under consideration are estimated to have 14,000 to 22,000 per vessel that would be candidates for the change.

This design change would:

- Modestly reduce the weight of a ship
- Result in savings in material dollars
- Result in labor savings
- Result in facilities savings by cutting use of weld robots in half, subsequently extending availability.
- Layout and welding of the cups is on the critical path for the assembly Stage of Construction, but durations and impact upon durations are not known
- Result in improved quality of the weld connection of the cup to the deck (100% weld vs. partial) which has ABS and MSC support
- Reduce the corrosion resistance of the cup itself, but this is not anticipated to be a problem so long as the proposal is limited to decks other than the weather and tanks. In this case the cup thickness meets ABS corrosion allowance.

Initial review of the proposal has shown it to be reasonably feasible, but that ABS and customer approval are subject to a series of physical tests. Hull systems experts believe that the proposal would be acceptable structurally, but ABS and the customer would like to see a demonstration that the thinner cups would not adversely effect the performance of the tie down. The requested test is similar to one performed previously. The test would involve pulling the sockets to the breaking strength/proof load of the tie down to demonstrate that no significant deformation occurs. The physical tests would require the design and construction of a 20 foot by 9 foot steel replication of a deck with cloverleaf cuts and three deep beams and four longitudinal stiffeners. Both thick and thin cups would need to be made for use on this test fixture. Additional test equipment for use in this test is pre-existing from the earlier, similar, test that was performed. The general test methods are understood because of earlier experience in getting approval for the current configuration.

An additional savings which may result is during the test and trials period. If the test is successful, ABS has suggested that they would reduce or eliminate the existing requirement to production test 2% of the on-board cup installations. On-board testing involves a crew of two test engineers moving a test apparatus from tie-down to tie-down throughout the ship to pull test them. Furthermore, paperwork must be maintained and submitted regarding the tests.

Cost data for this proposal is incomplete. The costs in engineering include updating the standard, anticipated to require the addition of details and part numbers to an existing standard. The cost for constructing the test deck section is not clear, but feedback from production is that they have remnant material available which can be used and that it would require about two weeks to build (duration, not man-hours). It is possible that construction might involve the weld school. Performing the tests is anticipated to require one week in duration with three people (a production engineer, and two test engineers) required full time during the test. Furthermore, the test must be developed and approved by ABS. This will require a production engineer full time and a test engineer part time for approx. three weeks. The cost to incorporate the change will depend on how quickly approval can be obtained. In addition to the engineering effort, some re-planning may be required to support the change.

The decision point is whether or not to proceed with the tests, and to develop the new standard in preparation for the change. In addition, in order to meet schedules, it would be prudent to perform preliminary engineering work to identify the changes and Engineering Change Notices in advance of approval to be ready to issue immediately upon approval. Production fully supports the move. Engineering had initially given production's request a lukewarm reception, but has recently shown support for the idea as visibility and upper management support have strengthened. Additionally, there are presently concerns regarding ship weight and any effort which reduces weight is appreciated by Systems Engineering.

CASE 2 - VanStone Flanges

An analysis of the critical path for On Block Outfitting has demonstrated that pipe installation is a key driver. Furthermore, make-up of pipe at block breaks after erection is also a key driver On Board. It has been suggested by Pipe Shop Management that Manufacturing Engineering examine the use of mechanical fittings versus welded fittings. Welded joints require the use of skilled labor which is a scarce commodity which could be put to better use. Cost returns suggest that pipe fabrication and installation is the second largest cost driver for the Sealift Ships next to steel.

In response to Production's request, Manufacturing Engineering has benchmarked other leaders in the shipbuilding industry such as a Japanese yard as well as the civil engineering and petrochem industries. This research has demonstrated that a number of alternative mechanical joints exist. One intriguing example is the VanStone Flange. Traditional flanging is already an option for the yard, but requires flanges to be welded in place and also requires alignment from one flange to the next at installation. The proposed approach utilizes a VanStone flared expansion of the pipe, with a slip on flange that is held on the pipe by the expanded end. Two flanges can be rotated about the pipe to be aligned to one another at installation and the bolted connection holds the flared ends of the pipe tightly in place. Pressurization of the pipe actually increases the tightness of the joint. This approach has been used successfully in civil engineering with no reports of undue leakage. Shipboard applications have been reported, but these have been limited and have had mixed results. Some owners have reported that the connections leak in service. Due to the anticipated savings potential, Manufacturing Engineering performed a study to determine the relative savings in hours and dollars per joint for a variety of alternative schemes. This has demonstrated that the VanStone Flange represents an order of magnitude savings over the current approach of welded sleeves or welded flanges.

To implement this proposal, the acquisition of a VanStone machine will be required. In addition, pipe-fitting standards will require revision. Additional benchmarking and research is required to develop demonstrable technical confidence in the approach. Testing has been performed to date that indicates that the proposal is sound, but the Customer is still wary and requires additional testing. Furthermore, Systems Engineering has expressed similar concerns. It is not yet clear under what conditions the proposal would be approved and what the guarantee terms would be. It is anticipated that an additional combination of physical testing and engineering analysis will be required to demonstrate that the joints will not leak in a dynamic shipboard environment over time. The cost to implement the change on the first ship will be a function of how quickly approval can be obtained. It is estimated that a significant engineering effort would be required to modify the bills of material and pipe spool sheets, as well as to issue ECN's. This approach is being considered for piping sizes from 2 1/2" to 16" IPS. Since these flanges are larger than existing joints, penetrations through beams and bulkheads must be increased to accommodate them. This represents an additional cost in penetration control, ECN's, and requires a significant amount of cooperation between the Deck O/F department and the Structural Department. Furthermore, use of this approach on larger piping is predicated on some additional work being done to get approval for penetrations through beams which are larger than those our current standard would allow. Even if this were not done, Production is convinced that the savings, if approved for the piping that can currently be accommodated, is overwhelming. It is proposed to have this joint be the preferred shop joint to replace socket and butt weld joints to the greatest extent possible. It is also proposed that this joint be the standard for field joints for applicable size ranges. A restriction would be that mechanical joints would only be used in tanks when similar fluids are in the pipe and tank. Thus this is anticipated to be the joint of choice for most systems such as the Fire Main, Foam Main, Bilge and Oily Waste, Sea Water Cooling, Ballast, Lube Oil, Tank Vents and Sounding Tubes, and Vehicle Washdown.

The current decision point is whether to continue research on this proposal and to perform the required testing and analysis, and to develop the proposed standard in preparation for approval. Actual changes would not commence until after approval, at which point a decision would be made regarding hull applicability.

CASE 3 - Foundation/Method Mount Standard

Experience on the Sealift Conversion contract demonstrated that the identification, design, procurement and installation of equipment foundations was very costly and caused extensive rework. Confusion and lateness of VFI resulted in late identification of the need for a foundation, and therefore the design and procurement processes did not support Assembly and Outfitting Stages of Construction. This lead to extensive rework on board. A lack of resources resulted in subcontract of foundation designs resulting in additional management costs and subsequent rework due to miscommunication. Production has suggested that the foundations appear to follow no consistent design practice and are not utilizing the most producible details. Foundation fabrication is subcontracted, and the lack of standardization of materials and construction practices has increased costs and resulted in poor accuracy control.

This resulted in the formation of a PAT team with upper management support to investigate the root causes of the problems and suggest process and organizational improvements. The PAT team focused on the identification, management and procurement processes. It was suggested that Manufacturing Engineering work with Engineering to focus on the design process and improve the product itself to reduce costs and cycle time.

It is proposed to reduce the costs and cycle time associated with design, fabrication, and installation of foundations by:

- Developing standards eliminating the need to design, draw, fabricate and ship a foundation
- Increase foundation availability by utilizing standard parts
- Install in On Block and Assembly vs. On Board Stages of Construction due to increased availability
- Develop design guidance for typical but non-standard foundations and train designers to reduce fab and installation costs

The proposed standard would provide guidance and part numbers for "method mounts" to cover a wide range of circumstances. These would take advantage of stud technology and mechanical fastening to the greatest extent possible. Additional standards would be developed such as "pedestal" type foundations and standard angle bar grillages for use on decks and bulkheads. Design guidance for minimizing costly backup structure would be provided.

To implement the proposal requires significant development effort. Engineering analysis must be performed for the method mounts to determine their range of applicability. In addition a number of physical tests would be performed to demonstrate the feasibility of different options. MSC has shown great interest in foundations and has reservations about reducing backup structure and shows a preference for uniquely designed foundations due to concerns regarding vibration and corrosion. To obtain savings on the first New Construction ship, the project must be funded and started quickly. The cost savings projected are a result of

- Reduced design time in engineering due to callout of standards rather than unique design
- Reduced cycle time in purchasing due to reduced number of uniquely fabricated foundations
- Reduced cycle time in production control due to fewer foundations to be received and checked
- Reduced material/fab costs
- Reduced installation cycle time and costs

The costs associated with implementation include engineering analysis. It is anticipated that this cost will be at least partially recouped by using the analysis for a subsequent NSRP deliverable if we are awarded that project. In addition, some physical "prototyping" will be required. These costs have not been estimated. Engineering will need to perform significant revision to an existing standard, essentially a rewrite. This is expected to be a major undertaking which will tie up one person in standards at close to full time for one and a half months after the analysis is complete and require their part time participation prior to that. The analysis is expected to require three months. During this time a Manufacturing Engineer will be assigned to the project full time. Once the standard is developed, its success will require significant training in Engineering regarding the availability and selection of standards. Outfitting design engineers are currently working in a mode where the foundation is "Structural's problem" and will resist this change. The PAT team has suggested moving the foundation design group to Deck Outfitting which would reduce this risk, but that suggestion has not been approved yet.

The decision point is whether to begin development of the standard and to start the analysis. Training would be begun regarding foundation producibility concurrently with the analysis.

CASE 4 - Round Spiral Duct

Next to piping, ventilation represents the next cycle time driver for On Block Outfitting. Pipe is currently the cycle time driver, but if pipe installation time is reduced, ventilation will become part of the critical path. Ventilation also represents a significant fabrication and installation cost.

The Sheetmetal department suggested that Manufacturing Engineering examine potential savings for ventilation fabrication and installation. M.E. performed a study and determined that the current approach which utilizes rectangular duct passed through beams using heavy spool pieces is very costly by comparison to alternatives. The least costly approach is to use round spiral duct passed through beams with no spool pieces and attached with studs.

Use of Round Spiral Duct on sealift will require larger penetrations than can presently be cut in the beams per existing standards if it is to be used in all applications. Preliminary investigation indicates that it is possible to get approval for larger openings if additional engineering effort is undertaken. Absent of this, round spiral would be used where possible with flat oval spiral duct (fabricated from round spiral) used in other cases.

The decision being considered is whether to modify the ventilation standards in preparation for the New Construction contracr, and to backfix part of the lower deck composite drawings which had already been started to reflect round spiral duct. In addition, it is desired to rework parts of the Conversion contract.

CASE 5 - Penetration Standard

Traditional standards for allowable penetration sizes and compensation resulted in significant costs on the Sealift Conversion contract associated with:

- Greater numbers of distributive system runs required due to smaller allowable penetrations

- Many unique penetration sizes resulting in a penetration control nightmare and rework in the field
- Use of expensive steel compensating rings and doublers throughout the ship

It is estimated that there will be 4,000 penetrations in the cargo hold beams of the New Construction contract and that half of these require compensation. Penetrations are currently burned manually at Assembly or On Block.

An initial engineering analysis demonstrated that in many cases the penetration standards were conservative, but was not at a detailed enough level or thought through well enough to get ABS approval. The indication is that half the compensation can be eliminated. On Block management suggested installation of compensation is on the critical path, and that elimination could represent a cycle time reduction per block. By undertaking additional analysis, seeking ABS approval and issuing a Contract Particular Standard, reinforcement could be reduced. In addition, the standardization on the larger openings would improve design stability. This in turn would facilitate NC burning of penetrations in the early Steel Fabrication Stage of Construction and installation of compensating parts in Sub-Assembly and Assembly representing an elimination of this work content entirely from the later On Block stage. Larger openings would also facilitate proposals associated with mechanical pipe fittings and round spiral duct.

The engineering analysis is anticipated to take two months, with program management required from the ME department. The cost is uncertain because the workscope will be defined as we go based upon what we learn and what ABS requires as proof of concept. MSC is wary of the approach but will accept whatever ABS approves. Development of the CPS standard is expected to require significant effort. It will require one Standards Engineer full time for two months, and additional assistance as required. The standard represents a significant departure from the way that engineering does business and will require a great deal of training for it to be successful, as the acceptable sizes of penetrations is anticipated to be a function of location in the ship. The standard will therefore be more complex than that which is currently in use. Training in production will also be required, as they have learned to compensate openings even in situations where engineering mistakenly (or not) neglected to add parts to the drawings. Production will be required to "trust" the drawing because their instincts will not reflect the standard. To maximize the benefits attributable to this initiative, it is proposed to concurrently develop a more streamlined penetration control process leading to NC cutting of penetrations in early Stages of Construction. Cooperation will be required between Deck O/F and Structural Engineering to maximize the benefits of the proposal. The current decision point is whether to continue research on this proposal and to perform the required analysis, and to develop the proposed standard in preparation for approval..

CASE 6 - Loro

This proposal is similar to the VanStone Flange proposal. Research has identified a pipe fitting which requires no hot work or mechanical fastening for non-pressurized systems. It is a simple system consisting of a flared and unflared end. The unflared end is pushed into the flared end and a gasket seals the joint.

The customer is wary of the joint due to potential leakage problems, but is willing to consider limited use as a pilot project. The dollar savings from using Loro-X and Loro-Vac is similar to that for use of VanStone Flanges, but the installation cycle time is significantly lower. In addition, this approach requires a smaller opening through structure and can be used on smaller pipe.

Some physical testing will be required to get approval for the pilot use on deck drains (the application that negotiations to date with MSC has suggested). It is hoped that additional demonstration and negotiation may yield additional application approval.

Once the testing is complete, and approval is obtained, pipe standards will require revision. It is anticipated that this process will take some time and that rework to engineering drawings will be required to take advantage of this application on the first Sealift New Construction hull. It is believed that the upper decks will not require rework, but that lower decks may.

CASE 7 - Shifting Work from On Block O/F to Steel Assembly Stages of Construction

It is appreciated that both cost and cycle time can be reduced if work can be performed in the earliest appropriate stage of construction. It has been suggested that installation of pipe, hangers and other metal outfit that requires hot work be performed in steel Stages of Construction rather than On Block O/F. Recent improvements in steel production have resulted in reduced cycle times in early steel Stages of Construction but cycle time reduction in SOC 5 has not been as dramatic. Steel production supports the effort, believing that with recent improvements in their processes they can achieve the new workscope without impacting their cycle time dramatically. They do require a significant replanning effort to be accomplished along with production information to be added to steel drawings rather than outfit drawings.

A formal benefit analysis has not been performed, but there is high level visibility and support for this project. It is believed by most experts that it will result in a dramatic decrease in cycle time and overall costs. There is risk. If the required information is not provided, is incomplete, or is wrong, then the result could be confusion and rework in both steel and outfit stages.

Proper implementation will require significant effort with regard to changes to planning processes, as well as training and changes to engineering processes in Outfitting and Structural. Since steel stages of construction are earlier, and many Structural Engineering products have already been issued for the first hull, significant replanning and rework will be required. In addition, the O/F design is not stable at the time of issue of Structural products. For this reason, it has been proposed that O/F continue to issue their drawings as they are and that planning perform work to annotate the Structural products. This represents a continuing function, and therefore additional workscope for the planning function. The trade-off is between cycle time reduction and cost reduction in production at the expense of ongoing additional workscope in engineering and planning. No formal cost/benefit analysis has been done, but it is generally agreed that the savings are significant provided schedules are not missed.

CASE 8 - Stud Mounted Padeyes

Throughout the ship, padeyes are welded in place to provide lifting points for equipment maintenance. ABS requires testing of these padeyes, and each must be labeled to indicate its allowable load. Metal O/F Production suggested that Manufacturing Engineering develop and perform tests on a stud mounted padeye to see if it could be used as an alternative. The use of studs has been very successful for hangers and other outfit. The hope is to reduce material costs by not providing as many padeyes and to reduce m/h's associated with installation and testing of padeyes.

The installation and testing of padeyes is not believed to be on the critical path, but was a highly "annoying" process for production on the previous contract which resulted in significant m/h's expended on rework. This was the result of two problems. The first is that testing often required mounting additional padeyes for the sole purpose of facilitating testing. The second was that identification of the need for padeyes was too late to support the first of the class in a timely manner, as the drawing was ship-wide rather than by block.

The proposal is to utilize stud mounted padeyes and to seek approval to eliminate production on-board testing by getting approval that the stud welding process is "in control". ABS and MSC has suggested that they would accept this. Furthermore Engineering is to identify padeyes to the appropriate block to facilitate installation. Engineering has agreed to do this regardless of the type of padeye. Shifting the work to the earlier stage of construction will reduce the labor cost associated with the traditional padeye.

It has been proposed by production personnel there is a savings in m/h in using the stud mounted padeye, but insufficient data is available to confirm the extent of the savings. While it is generally agreed that some savings may result in installation m/h's, it is not believed to be significant based on a follow-on study. The material costs of the stud mounted padeye are higher than those for the standard padeye, but this would be offset by reducing the number provided.

Engineering supports the change if it results in elimination of the need to provide a padeye for every location. The proposal is to provide a box of padeyes, and merely shoot the studs in the overhead as required. In addition, Engineering would only support the change if it eliminated the need for labelplates in the vicinity of the padeye locations. Absent these savings, program management does not believe the proposal is justified. Other improvements to the process which are already in place will result in savings over past practices even with traditional padeyes.

A test program has been suggested by Manufacturing Engineering which would require approximately one month to complete and a Manufacturing Engineer working full time on the project. In addition, the proposal would require a change to an existing standard. MSC has suggested that they like the approach because they believe it will provide them with some operational benefits. They have not approved the idea of not providing a single padeye for each location or the idea of eliminating the need to label the padeyes. It is not clear that they can be convinced on these points.

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