Maritime Product Development Process:   
An Approach from Other Industries

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##### ABSTRACT

*A large body of literature has been written on product development processes over the past decade. This paper provides an overview of some of the common product development processes and provides examples of their application. This paper focuses on four groups of activities that might be improved in maritime product and service development: 1) requirements definition; 2) business case documentation and use; 3) prototyping; and 4) planning for life-cycle and post-sales product involvement. The authors suggest a generic product development process that may be tailored to the business-to-business situations encountered by shipping companies, designers, equipment suppliers, shipyards, ports, and other members of the maritime community. An extensive bibliography is provided to guide further study and act as a roadmap of leading concepts in product development.*

###### INTRODUCTION

A general observation on contemporary life is that the marketplace brings a continual string of new products and services to our homes and offices, often meeting our needs before we are able to verbalize them, and sometimes contributing capabilities that we didn’t even know we needed. In contrast, the US maritime industry is often represented in the press as not agile or innovative, and even people in our industry might agree that innovation takes too long and encounters unreasonable commercial risk. How do other industries quickly and repeatedly develop new products without betting their company on the subsequent market response? What is to be learned about product development from other industries? Are there common techniques for product development that might improve the approach used in the maritime industry?

This paper results from research of the vast and growing body of literature on product development; it is not a report on results of a specific set of maritime projects. A primary purpose of this paper is to provide a bibliography that can assist marine industry managers in understanding the methods used by other industries. Key academic centers of product development research include the Massachusetts Institute of Technology, Harvard Business School, and Stanford University. Industry groups such as the Product Development & Management Association (PDMA)[[1]](#endnote-1) collect and distribute research on this subject, and certify practitioners through testing and required experience. This paper reflects the work of those centers.

Development of new ships and ship equipment often follows an iterative process similar to the well-established design spiral[[2]](#endnote-2), which concentrates on the technical aspects of a new product as it moves from concept and preliminary design to contract design, basic systems engineering, transition design, and development of production information. Over the past decade, there has been an effort by the National Shipbuilding Research Program (NSRP) and its participants to incorporate production engineering methods focused on reduced production costs, shorter cycle times, and fewer quality problems. Much work has also been done in the marine industries on improved CAD/CAM systems, product models, materials requirements programs, and integrated data environments. However, other industries commonly apply a broader view of the product development process, starting with business objectives of both the buyer and seller, and often encompass the entire lifecycle of the product, including manufacturing, customer support, and even disposal. These broad product development processes may have iterative steps, but aim for early and robust decisions that preclude the need for redesign at a later stage, or worse, failure of the product after introduction to the market. By formally mapping the process end-to-end, it is possible to reduce both business and technical risk, so that key information is identified at the appropriate time. Innovation is encouraged by teams working across the entire enterprise to accomplish functional tasks. Speed to market may also be significantly improved.

This paper reviews product development case studies in other industries, and provides examples of methods that may be usefully applied to new maritime goods and services. The topic of product development is very large, so we have applied our own experience to focus on a few key differences between the maritime industry and other industries:

* The overall process for product development
* Definition of requirements for the product
* Documentation and use of a business case
* Prototyping
* Planning for life-cycle and post-sales product involvement

The methods we discuss herein are equally applicable to both products and services, but for purposes of this paper, we restrict ourselves to processes used for physical, engineered products, thereby eliminating software and many services, as well as bulk commodities. Note that this still leaves broad applicability in our industry – ship owners, shipyards, and equipment suppliers develop physical, engineered products as part of their offerings to the marketplace.

###### Product Development Processes

No one product development process fits all companies or all products. Both the external business environment and current technology within a company contribute to selection of an appropriate process. There are two broad general approaches to product development:

* Market-pull processes start with a perception of a market opportunity based in customer needs, and then find a cost-effective set of technologies to meet these needs.
* Technology-push processes begin with discovery of new technical methods, followed by a search for related customer needs.

Often the product development process must consider whether the new product is to be a derivative of an existing product, or a completely new item. Further, the process must sometimes work around significant constraints due to production processes, regulation, risk and liability exposure, or schedule considerations.

Choice of a product development process seems to be strongly related to whether the intended product requires a break-through or not, which in turn sets the need for the degree of innovation, management control, and speed at which the product is developed. **Figure 1** suggests a framework in which “New-to-World” products require a product development process that carefully manages risks and ambiguity (Rosenau, 2000), while new products derived from earlier versions can reasonably arise from faster, less controlled processes. This is almost counter-intuitive, advocating formal, controlled processes where innovation is needed. Doesn’t control stifle creativity? We conclude that the literature shows that control establishes a structure to support innovation, not suppress it. The focus of all industries is attaining innovation at a reasonable level of business risk, not in unbridled creativity that subsequently fails after product introduction.

**Figure 1**

**Extent of innovation versus business concerns**Adapted from (Rosenau, 2000), p. 19

The following sub sections describe three product development process models used by other industries, ordered to illustrate increasing levels of formalization and management control:

Kelley’s concept-centered process

Ulrich and Eppinger’s generic model

Rosenau’s Fuzzy-Front-End and Stage Gate process.

###### Kelley’s Concept-Centered Process

Tom Kelley documents the highly creative and innovative process used by IDEO, a product design consultancy serving a variety of industries, but with strong experience with computer hardware and peripherals (Kelley, 2001). Kelley’s approach emphasizes team efforts within a flexible but formal process, shown in **Figure 2**. Similar to the other processes presented in this paper, Kelley begins with an effort to define the customer’s needs in a market-pull approach, rather than a technology-push. Kelley’s approach also introduces quick and focused benchmarking to identify technology and perceived constraints on meeting the customer’s needs in a specific situation. A strong emphasis is placed on observing potential customers in their environment, grappling with the existing products, and listening to the customers expressing their needs in their own non-technical language. Rapid group brainstorming sessions are advocated to quickly visualize a large set of possible concepts that react to the observations of customers, often generating over 100 ideas in a brainstorming session intentionally restricted to an hour. Kelley uses prototype development and testing to evaluate and refine the most promising concepts. Prototype testing involves both the design team and potential customers, and begins with rough assemblies of on-hand materials to allow assessment of functionality followed by more advanced prototypes that represent the look and feel of the final article. Kelley’s final step involves implementation of the concept design, which involves a multitude of detail design, production, and marketing activities necessary to bring the product to market; Kelley’s book does not attempt to detail these implementation activities. This process may in fact be akin to the “Fuzzy-Front End” described later in this paper.

**Figure 2**

**Kelley’s Product Development Process**

*Adapted from (Kelley, 2000, pp 6-7)*



This is a people-centered approach that puts little emphasis on documentation, business research or management controls. Surveys and focus groups are replaced by direct observation of customers in their environment, as customers rarely are able to express their needs completely and accurately. Experimentation and hands-on assessment through prototyping take the place of extensive engineering development and verification. Little explicit analysis is given to how the article will be manufactured, or to participation in after-sales aspects of the product’s lifecycle; these considerations are apparently handed off to others after the concept development has concluded. This approach does not choose an existing product or technology as an early basis for meeting the observed customer needs, but allows an open search for best alternatives to meet customer requirements.

Kelley’s process requires attention to organization and team culture to encourage innovation and to reduce or eliminate barriers to creativity by the team. Similar emphasis on team dynamics can be found in many other references in the literature, notably (Kao, 1996), which provides specific guidelines for establishing and nurturing creative teams.

Kelley’s concept-centered process results in break-through articles, New-to-the-World, or New-to-the-Company, at a faster speed of introduction than processes with greater management control. A premium is placed on innovation, creativity, and match to the customer’s observed needs, with risk controlled by progressive prototyping. As such, we observe that this process may be best applied to consumer goods and services, where customer interaction can be readily observed, and where new attributes and capabilities may have a strong role in customer acceptance. This may be an appropriate model for marine products with extensive human interaction, such as seating areas for passenger ferries, integrated bridge systems, interior communications systems or container securing systems.

This approach may not be a good model for development of goods and services in a business-to-business market, or where the product is intended to be an adaptation or upgrade of an existing product.

###### Ulrich & Eppinger’s Generic Model

Ulrich documents a more extensive product development model with moderate levels of management control through their materials for a graduate course at the Sloan School at Massachusetts Institute of Technology (Ulrich 1995). **Figure 3** summarizes this product development model, which cuts across organizations to form multi-disciplinary teams with marketing, technical, purchasing, and production skills.

The Ulrich process starts with a Mission Statement, which is variously described in other sources as a Product Innovation Charter or Product Development Objectives Statement. This document is written by top management, and defines the business expectations, target market, relationship to other products and suppliers, and anticipated development budget and schedule. It both empowers the development team, setting out responsibilities and authorities, and restricts them by setting macro-boundaries in which the development effort will proceed.

Concept development begins in the Ulrich model with the same sort of activities that start the Kelley model: direct observation and interaction with customers to identify customer needs. However, the Ulrich approach results in a documentation set that systematically captures customers’ needs and turns them into prioritized requirements, which are then sorted and quantified by the development team into target specifications, which are refined through benchmarking of competing goods. Ulrich’s approach develops an economic analysis for the product concept – providing an early assurance that the price point and likely market size are worth the investment. Note that Ulrich’s approach does not require less creativity or innovation than Kelley’s method; it adds more structure and business focus to the process. Ulrich also places less emphasis than Kelley on early and intense prototyping.

**Figure 3**

**Ulrich & Eppinger’s Product Development Process**

*Adaptation from (Ulrich, 1995, p 15)*



Ulrich’s process moves to systems-level design using a product work breakdown structure to guide integration of major subsystems and interfaces. This stage also develops industrial design aspects for the look and feel of the article, defines the assembly method and production approach, and performs make-buy analyses and identifies key suppliers. At this stage, Ulrich begins development of a plan for product options, lifecycle management, and relationship to an extended product family.

Detail design in Ulrich’s model bears similarity to the process used in US shipyards to develop Production Information (PI). Part geometry, material, and fabrication and assembly methods are defined in detail. Required tooling is defined, and long-lead tooling procurement is initiated. Quality assurance processes and metrics are established. A detailed marketing plan is prepared and matched to the product attributes.

The testing and refinement stage involves field-testing of prototype systems and components, and reliability and performance testing of the product. Design changes are developed, validated and implemented before the product is released for manufacture, or launched. Supplier capabilities are assessed and manufacturing staff are trained prior to product launch to ensure that the goods or services can be provided at the quantity forecast by the marketing plan.

During production ramp-up, early production units are placed with key customers to identify any latent defects that may arise through the production process. The production system is engaged at the planned level of production following this late-phase prototyping and adjustment of the design, supply chain or manufacturing activities.

At a top level, this product development model is similar to classic systems engineering approaches, which typically include requirements analysis, system definition, production design and construction, followed by system fielding and support[[3]](#endnote-3). However the Ulrich model strengthens the requirements definition through direct customer observation; adds an early analysis of business issues such as cost, price and estimate of market volume; and expands system fielding into a broader testing phase and a production ramp-up phase. The Ulrich model therefore acts to better control business risk compared to classic systems engineering, which focuses on technical aspects of development.

The Ulrich process is highly structured and repeatable. It balances early focus on customer needs with systematic reduction of commercial risk. This model may be appropriate to a large project such as development of a propulsion system or new ship class, where the required degree of innovation varies between systems and the article as a whole, and where significant risk may arise from system integration and production processes. While the Ulrich model uses cross-functional development teams, it puts less emphasis on corporate culture and organizational techniques, and more focus on structure and documentation. These features of the process may tend to make it less agile and slower than the Kelley model, but more certain as to the commercial outcome.

###### FFE-SG-PPS Model

The basis for PDMA certification as a New Product Development Professional (NPDP) is the Fuzzy Front End – Stages and Gates – Pre-Profit Sales (FFE-SG-PPS) process (Rosenau 1996). This is a comprehensive approach that provides a high level of structure and management control. It is commonly used in companies that have extensive research and development activities, and where it is necessary to manage portfolios of products that must compete for investment and talent.

This FFE-SG-PPS model is conceptually organized into three major phases. The first phase is often referred to as the “Fuzzy Front End” because it intentionally allows for uncertainty, creativity and luck, while applying early structure to identify attractive product development concepts.

**Figure 4** shows a technology-push FFE model that collects raw ideas for new products, both through accidental discovery and structured research. This collection effort focuses on “Hunting Grounds – a discontinuity in technology or the market that opens a new product development opportunity” (Belliveau 2002). FFE then applies a strategic planning filter that assesses whether to invest in further development. In general, this strategic filter is centered on business objectives, of which technical feasibility is only one of many considerations. A short list of plausible product ideas advances into formal, structured development. We observe that Kelley’s product development process could reasonably be applied as a market-pull alternative for FFE and the first stage of a formal development process.



**Figure 4**

###### The Fuzzy Front End

*(Rosenau, 1996; Figure 6.1)*

The next phase provides a structured, formal development process: The Stage-GateTM (SG) Process[[4]](#endnote-4), moves from ideas to production with well-defined management review and control points. Each Stage is a prescribed set of activities resulting in a set of required outcomes and deliverables. Activities are cross functional, and include technical experts, manufacturing staff, marketing staff, purchasing staff, and sometimes team members from outside the organization, such as key suppliers. Each Gate is a quality control point and management review to determine whether the product development is sufficiently mature and attractive from a business perspective to proceed to the next Stage. Gates can be thought of as go/no-go decisions, and the Stages and Gates typically are prohibited from being performed in parallel. Often decision-makers at each Gate (“Gate Keepers”) are only as senior as necessary to commit resources required in the next phase. This approach encourages technical and business analysts to participate in decision-making and take ownership of tough decisions that kill mediocre projects and focus money and talent on excellent projects.

**Figure 5** illustrates a typical SG approach. The first gate is the strategic filter previously described as part of the FFE. Stage 1 determines technical and manufacturing feasibility of the product. An initial activity in this stage is to determine required product attributes and specifications. This may involve primary market research through customer surveys, focus groups, and competitor analysis. Stage 1 may incorporate elements of Concept Synthesis, Systems Level Design and Detail Design from Ullrich’s model, to the extent these activities are necessary to demonstrate feasibility. Bench testing, mockups, computer simulation, or simple calculations may be part of this stage as necessary to verify that the product performs as intended. Stage 2 establishes the business case for the product, establishing a price point and expected volume, competitive position through benchmarking, producibility, investment requirements, estimated time-to-market and time-to-profit, required supplier relationships, risk and regulatory compliance issues, and relationship to existing and planned products and product lines. Stage 3 involves full technical, production, and marketing development to define the product for manufacturing and sales. Stage 4 involves sufficient testing and validation to assure management that product is acceptable to the market, free from technical defects, and producible in the selected manufacturing facilities and processes. Presuming successful testing and evaluation, Gate 5 is a final go/no-go decision that governs release for manufacture or launch. Depending on the complexity of the product and size of the investment, additional stages and gates may be necessary.

###### Figure 5

**Typical Stages & Gates**

*(Rosenau, 1996)*



Completion of the SG phase moves a product into the Pre-Profit Sales (PPS) phase in which the product is initially manufactured, marketed, sold and serviced. Initially small lots are manufactured to allow manufacturing facilities to ramp-up to the projected sales volume. Product features are concurrently assessed with a limited set of trusted customers, possibly through beta prototype testing, sales calls, or formal feedback surveys. Any technical problems are captured and analyzed to develop early changes. Complementary services and products are identified and placed in the marketplace, such as after sales of required consumables or field services. The objective of this phase is to minimize risk, shorten the period from introduction of the product to the market to the generation of profits, and to apply formal data gathering about the product to improve sales potential and apply lessons-learned to other projects.

###### Rationale for Formal Product Development Processes

PDMA reports that “nearly 20% of reporting companies either have no formal process or one that is only informally understood (but not documented) within the company. Lack of process hampers involvement and participation and contributes to the poor understanding of effective new product development practices found in some companies.” (Hustad, 1996) Another way to look at this statement is that in other industries, over 80% of companies have some level of formal product development process. Hustad goes on to report that almost 70% of the reporting companies utilize a variant of stages and gates.

The Kelley, Ulrich and FFE-SG-PPS models have one common attribute: they have discrete, well-communicated steps organized into a sequential process. Boike and Staley’s analysis of competing companies found that the most successful product developers were as much as 50% faster to profit than competitors; a key difference between successful and less-successful firms was insufficient planning and direction associated with a poorly defined product development strategy and process (Boike, 1996). Hammer also reports impressive results from formal processes: “We see numerous and weekly examples of the application of formal processes to develop products. For example, in the mid-1990’s Caterpillar introduced a formal, four-stage process for creating and introducing new models. As a result, cycle time for new product development dropped from eight years to as little as three years.” (Hammer, 2002).

We therefore conclude that a necessary (but not sufficient) condition for successful product development is a structured, well-planned and communicated process. The process must facilitate and capture discoveries, but provide enough structure to ensure that a key business activity, development of future products, does not rely on luck. Similarly the process needs to strike a balance between dynamic creativity and management control, supporting innovation, but directing it to an ultimate business goal.

###### Example: Product Development Process

A current US Navy program provides excellent examples of structured product development processes for New-to-the-World systems, balancing innovation and management control. For example, Boeing has outlined a formal product development and systems engineering process for Command, Control, Communication, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) Mission Systems for the Navy’s Joint Command & Control Ship (JCC(X)). This process includes requirements analysis, systems analysis, functional analysis, and concept synthesis. The product is defined in terms of a system-of-systems hierarchy, allowing components, sub-systems and systems to be developed in parallel. Requirements are defined in terms of required product and system attributes. Alternative designs are identified and analyzed both for performance and total life cycle cost. A detailed business case treats Cost as an Independent Variable. Both producibility and lifecycle support issues are defined. Product design and testing are developed in parallel using a progressive prototyping concept. Alternative acquisition strategies are considered, explicitly linking the marketing function to each stage of design. This process is clearly communicated to the customer, suppliers, and the product development team (Guthrie, 2002).

###### REQUIREMENTS DEFINITION

Perhaps one of the thorniest problems in any industry is defining what requirements new products are expected to meet. An equally challenging second step in requirements definition is effectively and efficiently communicating these requirements through the development team and assuring that the resulting product meets these requirements. The long-term success of products, and in many cases the profitability of the developer, rest on this step.

###### Customer Requirements

The maritime industry is one of the few industries that require customers to write out their requirements in a comprehensive, accurate and timely document. Although the marketplace offers us new cars, computers, homes, food and other necessities on a daily basis, we rarely if ever show up at a store with a detailed list of our requirements or a full product specification. Hustad summarizes a view often found in non-maritime industries:

“Sometimes we must know our customer’s needs better than they know themselves. Seldom can a customer describe a new product for us. We have to understand their problems and develop effective solutions.” (Hustad, 1996)

In contrast, new ships arise from outline, performance and/or detailed ship specifications prepared by the customer. New marine equipment most frequently comes from modification of existing product lines in response to a purchase specification or written inquiry from the customer. The experience of the authors is that maritime product development teams do not make a routine practice of observing users or attempting to pro-actively identify customer problems and provide solutions. In general, maritime product development reacts to stated minimum or maximum thresholds established in writing by the customer.

Maritime product development most commonly involves business-to-business transactions rather than consumer marketing, and is therefore fundamentally different than many other industries. However, we observe that all maritime products have some human interaction and use, and ultimately satisfy needs established by people, not machines. So direct observation of users and customers may be a tool to significantly improve the maritime industry product development processes.

The literature abounds with discussion of prescribed methods for harvesting customer needs. Kelley is a forceful advocate for direct contact with users:

“We’re not big fans of focus groups. We don’t much care for traditional market research either. We go to the source. Not the ‘experts’ inside a company, but the actual people who use the product or something similar to what we’re hoping to create. Plenty of well-meaning clients already ‘know’ how people use their products. They’re so familiar with their customers that they can rattle off half a dozen good reasons why an innovation is impractical. Of course, we listen to these concerns. Then we get in the operating room, so to speak, and see for ourselves.” (Kelley, 2001, p 25)

Ulrich also asserts that direct interaction with users through interviews is more effective than focus groups. For consumer products, Ulrich asserts that 30 interviews are generally sufficient to capture 90% of needs. For B-2-B products (most maritime products), it is important to find clusters of key users, whose routine and repeated use of a product makes them excellent targets for observation. Ulrich cautions against questionnaires and written surveys, which do not provide sufficient information about the environment in which customers actually use products. Some of the things to look for during direct observation include:

* Typical uses
* Likes related to current product solutions
* Dislikes related to current product solutions
* Latent uses that are not expressed but are observed
* Lifecycle, service and extended use related to current product solutions
* Suggested improvements in current products. (Ulrich, 1995)

A key benefit of direct observation of users is that it establishes context and importance of each need for the users. This data is crucial for later decisions by the product team, trading off alternative designs, and prioritizing product attributes. One method to capture the importance of expressed needs is through Attribute Categorization and Evaluation (ACE); see (MacMillan, 1996). Following observation or interaction with a user, the product attributes are categorized in a 3x 3 matrix, in which the columns are headed “Basic”, “Discriminator” and “Energizer”, capturing how strongly a user feels about an attribute. The rows of the matrix capture whether the feeling is positive, negative or neutral. For example, a Basic/Positive attribute is non-negotiable, while an Energizer/Negative product attribute can be regarded as an “enrager”, something that must be fixed. Numerous other methods are described in the literature for prioritizing customer needs and product attributes.

###### Corporate Requirements

The requirements of the developing company also need to be explicitly identified and documented early in the product development process. This confronts significant business risks in product development that must be avoided from the outset:

“There are two extreme dangers in the management and execution of new product development efforts: 1) making what you cannot sell, and 2) selling what you cannot make.” (Rosenau, 2000, p. 3)

At a top level, new products should exploit the developer’s strengths and capitalize on competitor’s weaknesses. However, to accomplish this, product development teams need to have a clear understanding of how senior management views strengths and weaknesses. At a minimum, managers should assure a match between company strategy and the product development effort by mapping and communicating the core competencies of the developer (Prahalad, 1990). These core competencies should be explicitly reflected in corporate requirements for new products. Any shortfalls in core competencies required for a new product may require outsiders to be brought into the development team, or may trigger a “no-go” decision in a stage-gate process.

A key step is defining marketing and financial expectations to combat against “making what you cannot sell.” Many companies use Innovation Mission Statements or Product Innovation Charters to communicate corporate business objectives to a product development team. These statements are simple, short, direct, early communications and empowerments. Regardless of whether a product is a market-pull or technology push-type, a Product Innovation Charter typically addresses the following issues, see (Crawford, 1987):

* Product type or class
* End use application (who uses it)
* Targeted customer group (who makes the buying decision)
* Technology boundaries
* Relationship to existing products, products in development, or essential suppliers
* Expected financial returns
* Any special business purposes, such as maintenance or renewal of market share or diversification into new markets
* Expected time to market and time to profit
* Empowerment for budget, schedule and resource allocation decisions.

In the maritime industry, senior managers often hold back from this sort of definition in an attempt to avoid over-constraining product development efforts. However, this same dilemma is confronted in other industries, and the imperative to provide strategic and tactical guidance is described by (Clark, 1997):

“Top managers must descend into the technological black box. They must help scientists and engineers ask searching questions about customers and competitors.”

Yet another step is to define the general schema of producibility requirements and facility constraints to avoid “selling what you cannot make”. Ideally, these requirements are documented as part of ongoing business, and do not need to be part of the product development process. However, if they are not part of the documentation of the core competencies and capability of the business, later success requires them to be available early in the concept development. Producibility requirements should not be identified mid-stream or approaching release for manufacture. These requirements should be maintained as the project proceeds, ensuring that the product technology and attributes are congruent at all times with manufacturing capabilities of the developing company and all key suppliers.

Another group of corporate requirements focuses on risk management. What attributes must the product have that are prudent and diligent to protect the developer from liability? Any materials or design features that are prohibited are defined early in the process, as well as any mandatory or desirable product attributes necessary to protect users and the developing corporation. This category of requirements is fundamentally different from regulatory or legal requirements; we are describing discretionary attributes that a developer voluntarily chooses to incorporate in order to reduce risk.

###### Third Party Requirements

Often product development is constrained or directed by law and regulation on the national, state and/or local level. An early, comprehensive, and accurate search of legal requirements associated with a proposed product is a common practice in both the maritime and other industries. These searches are facilitated by electronic and web-based regulatory codes. In addition to regulatory compliance on technical issues, export/import control requirements must be identified early in the product development process to preclude false starts or delays in time-to-market due to trade restrictions.

Industry and national standards often guide product development efforts, and explicit citations of these requirements are recommended early in the process. Citations of the Uniform Building Code are as important in development of new homes in the construction industry as classification society and US Coast Guard requirements are for the marine industry.

Key suppliers may have corporate requirements similar in scope and nature to the developing company. (Clark, 1997) makes the point that new technology sources are now worldwide, and that fast and accurate communication of supplier capabilities and constraints is necessary for successful product development. The Internet has greatly expedited this sort of interchange of requirements and supplier participation in product development. In a recent example, Microsoft decided that a metal bracket for holding the disk drive in place was too heavy, so it replaced it with a plastic one that was several ounces lighter and stronger. Working with manufacturing partner Flextronics, Microsoft Corp. used an Internet collaboration system to bring its new Xbox video game console to market last Nov. 15. The Internet collaboration helped slice about two months off the original production schedule (Business Week, February 18, 2002).

###### Requirements versus Specifications

Observed customer needs are not statements of requirements, nor are they specifications; the literature on product development makes a clear differentiation of these statements, progressively tightening definitions from capturing needs in the voice of the customer to stating specifications as concise metrics. (Ulrich, 1995) provides clues on how to differentiate customer needs, requirements and specifications:

* Observed customer statements start with “I like, or I want…”
* Product team members interpret these statements into a performance format of customer needs starting with “The product will …”
* Grouping related customer needs allows a generalized customer need statement, “The product will …”
* The product team translates the customer needs into metrics, of the form, “Attribute + logical operator + numeric value” where possible; some metrics must by their nature remain qualitative and general.
* Benchmarking of competitor metrics provides early choices of where and how the new product will improve on existing products in the marketplace.
* The product team develops target specifications that represent their choices on how to respond to observed customer needs within the framework of competitor’s offerings.

**Figure 6** illustrates the general steps recommended by Ulrich for translating observed customer needs into specifications. We suggest that similar steps apply to translation of corporate and third party requirements into specifications.



### Figure 6

###### Requirements definition from customer observation

Management and communication of the full set of requirements (customer, corporate and third party) and resulting specifications become major tasks of their own. The goal is to ensure that the product development team has a current and complete fact base to support design decisions. Other industries have tackled this problem head-on, using techniques as simple as relational databases that can be linked and queried easily to more elaborate and complex methods such as Quality Functional Deployment (QFD) to methodically ensure the requirements are driven into the end product[[5]](#endnote-5). These methods can result in compliance tools that assure both the buyer and seller that all requirements are met in the resulting product. In contrast, the marine industry continues to issue specifications as text documents, with metrics often buried in language intended to establish legal boundaries in the transaction between buyers and sellers. These specifications are difficult to flow down to team members or to translate into quality assurance tools, and QFD and other requirements communication methods have not been widely adopted in the marine industry due to the perceived complexity of these techniques.

###### Example: Requirements Definition for T-AKE Cargo Stanchions

An example of a maritime product development that incorporated direct observation is the cargo constraint system for the new flight of T-AKE Dry Cargo Ammunition Ships awarded to NASSCO. Design engineers observed shipboard operations and discovered that the current cargo constraint system used in the fleet is not easily handled and not efficient in use. A clear and compelling need was documented from these direct observations. Further, NASSCO’s experience with installation of this cargo constraint system was that it required extensive skill and hand work, and interrupted other production work while deck leveling compounds cured. Through a series of brainstorming sessions and Lean DesignTM Workshops led by Munroe Associates, alternative designs were identified and evaluated for technical feasibility. A supplier with expertise in lightweight composite structures was identified and added to the product development team, and a new constraint system was designed utilizing lightweight materials for the cargo stanchions, commercial cargo-securing gear and a more efficient grid system connecting the cargo stanchions and gear to the ship. Prototype development demonstrated the significant reduction in weight, allowing more efficient and safer crew operations in the cargo holds. Cost/benefit studies established both first cost and lifecycle cost savings. This system is now in detail development, therefore the final results of this effort are not yet known.

###### THE BUSINESS CASE

Many other industries focus on an early model of the business case for the new product, in order to ensure that the product meets the price point and volume targets needed to support rational investment in the product. Jolly makes the point that there are lots of new concepts, and that many of these are pure speculation early in the product development cycle. Sorting through these concepts requires a dual insight of technical and market feasibility as a precursor to commercialization; see (Jolly, 1997). The business case is the set of activities in the product development process that creates this dual technical and marketing insight.

Both the Ulrich model and the FFE-SG-PPS model include early business cases. The Ulrich model includes typical business case steps in Concept Development, while the FFE-SG-PPS has two iterations of the business case, first as a screening activity in the FFE, and second as an explicit Stage and Gate in the formal development process.

###### Market Scoping

Early sketches of the market can guide top management in deciding how much money and key talent to invest in new products. Questions that can be answered by early market scoping include:

* What is the estimated size of the potential market, the available market and the likely market?
* Is the size of the market large enough to make this product an attractive investment?
* How is the potential market segmented?
* Who are the key target customers, and how do you know this?
* Who are “lead users”, and are they available to participate in requirements definition and prototyping?

###### Price Point and Value

As a concept design is developed, it becomes possible and desirable to have a simple and robust model of product cost to guide selection of design alternatives. This cost model can be developed as a spreadsheet tool, but should have sufficient detail to reflect the estimated number of production units forecast in the marketing sketch, and include all the steps in the development process. Time-related costs should be explicitly modeled in order to gauge proposed modifications to the product development schedule, and external factors such as time value of money or oil prices may need to be considered to allow the product development team to understand the effect of macro-economic factors on the viability of their proposed concepts. A bottoms-up price can be developed based on this cost model, applying overhead, financing and profit targets established by senior management.

In parallel with the cost model, a marketing study may be able to establish a price point in an open market place by looking at comparable current products or precursor products that may have similar price structures. By comparing the market-based price to the cost-based price, the product development team may gain insight into how the product must be configured to compete successfully.

Some products have large life cycle costs, and the customer’s perception of value is related to the total ownership cost. In such cases, product development teams need a lifecycle cost model in addition to the price models. Customer costs for consumables, maintenance and repair, technology refreshment and insertion, and labor are possible considerations.

###### Competitive Position

Top management must be involved in establishing the competitive position of the firm through strategic planning, which is then implemented by the product development team. Relative to competitors, how does the developer intend to time its entry into the market? Will the developing company be a pioneer, an early leader, or a follower? Studies of other industries suggest “many pioneers fail, while most current leaders are not pioneers” (Tellis, 1996, p. 65). Tellis continues by showing “five factors are common to current leaders, including vision, persistence, commitment, innovation and asset leverage”. All of these factors are ultimately the responsibility of top management: the first four factors are implemented by choosing team members with these personal attributes, while asset leverage can only come from the financial structure of the developer. If initial concept development shows that it is necessary to become a pioneer, the product development team and financial commitment will probably require adjustment before proceeding to later steps in the development process. The speed and effectiveness of the product development will be improved to the extent that this issue can be identified and considered at the beginning rather than toward the end.

Another dimension of competitive position is whether the product development involves sustaining or disruptive technologies. Sustaining technologies improve the performance of current products, as such performance is perceived by the customer. Disruptive technologies degrade performance while offering cheaper price or more convenient use. Christensen argues that adoption of disruptive technologies is a risky course from the outset, and almost invariably undercuts market leaders (Christensen, 1997). If a firm is already a market leader, its senior managers may reasonably shy away from developing new products that rely on disruptive technologies. These issues may need to be an explicit part of a business case to preclude later failure.

The extent to which a product concept or key technology is defensible is often a consideration in the business case. Can the concepts embodied in a new technology be restricted to the developer, possibly through patents or other barriers, or are product attributes easily duplicated by competitors?

###### Best Alternatives

Product teams may be good at identifying and designing alternatives; however choosing between these alternatives is often difficult when technical attributes fail to result in clear-cut winners. Business concerns should dominate, and this is where formal trade-off studies, using the acquisition price models and total ownership cost models are particularly useful. The business case should clearly layout the key macro-economic assumptions, analysis methods, and decision criteria to be applied to trade studies. For example, the Analytic Hierarchy Process (AHP) is a decision analysis tool that assesses preferences of customers and product development teams for competing product attributes. AHP allows quantitative performance and qualitative features to be combined to rank alternative design concepts. (Saaty, 1996)

Trade-off studies are part of the concept design, but the business case should provide direction to the product development team at an early stage:

* A list of key alternative design opportunities to be investigated by the team
* Design objective
* Analysis methods
* Decision criteria
* Authority to make decisions or requirements for senior management participation.

###### Example: Business Cases for the Energy Industry

Over the past five years, we have developed cost and price models for: crude and product tankers; gas carriers; floating production, storage and offloading vessels; and very large deepwater production barges. All of these cost and price models provided early insight into the cost of vessel design alternatives at the concept design stage. Expansion of the level of detail within a fixed cost estimating framework allowed project developers to focus on significant cost drivers as the project progressed into detail design. These models considered labor, material, schedule, overhead, profit, number of units and learning, time-related costs and escalation, and owner’s costs as necessary. Using these models, we have:

* Demonstrated early viability of projects in a stage-gate process
* Assisted product developers in choosing the best size and speed of vessels
* Helped choose best machinery alternatives, considering acquisition cost, total ownership cost, and non-financial technical factors
* Scoped the impact of shifting work scope from topside contractors to shipyards
* Assessed the impact of moving cargo-handling equipment from ship to shore.

###### PROTOTYPING

Other industries often use prototyping from the earliest stages of product development, combining design and testing:

“Conceptually, any development project can be thought of as a sequence of design-build-test cycles. Within each cycle, the prototype serves as a focal point for problem solving, communications, and conflict resolution. Furthermore, it forces specificity in design, provides feedback about the choices made thus far, and highlights remaining unresolved issues.” (Wheelwright, 1992, p. 259)

Prototyping demonstrates at an early stage whether the design works as required and how well it actually meets customer needs. Prototyping can improve communication within product development team, to key customers and partners, and to third parties such as regulators and financers. Physical prototyping can detect unanticipated phenomena from the environment of use, man-machine interfaces, and interaction of technologies. Prototyping can (and should) be a design tool, not just a validation and verification tool.

The maritime industry has used physical testing extensively for many years, as a tool to verify satisfactory design and testing. For example, most ships undergo an extensive test and trials program following construction and prior to delivery; this is not strictly prototyping, as it is not intended to be a design tool. Model testing programs are often classic prototyping activities, developing alternatives early in the design process, discovering the interaction of technologies (between hull, propeller and rudder), and frequently involving the customer as an active observer. Successful prototyping has the three attributes in this example: early use, design ramifications and customer interaction.

Early definition of product architecture supports early start of a prototyping effort. A product breakdown structure allows the development team to focus on new systems, subsystems and components, and identify other elements that may appropriately be adapted from earlier (or competing) products. Early prototyping assists both in design of these new elements, and by assuring low-risk integration of existing technologies.

Just as observation of the customer using *existing* products is usually part of product development in other industries, prototyping offers the opportunity to observe key customers as they interact with interim designs for the proposed *new* product. Note that the “customer” that participates in prototyping may be an actual intended buyer, or a small group of trusted users that have agreed to put in the time and effort required. However, “customers” are not industry experts or technical staff acting as proxies for real users.

The main dimensions of prototyping are the extent to which the product is modeled, and the form of modeling used, as shown in **Figure 7**. Early prototypes are often assembled from spare parts in a laboratory or workshop, accurately representing fit and function, but not modeling form or aesthetics. Prototyping may be either a physical representation or a simulation; however it should accurately represent both the proposed product design and the environments in which it will be used. Periodic prototyping can match stage-gate process, adding detail and reality to the product models as it enters each new stage.



### Figure 7

###### Prototyping Dimensions, Scope and Approach

*Adapted from (Ullrich, 1995, page 219)*

###### Proof of Concept

Provides a physical or computer-simulated embodiment of the product, system, sub-system, or component. Allows early and rapid comparison of design alternatives as measured by primarily by key performance attributes and secondarily by look and feel. This is usually a bench test or gross simulation model. Proof-of-concept prototypes focus on systems, sub-systems or components that introduce a new technology, integration of technologies, or new use. Proof-of-concept prototypes are primary design and screening tools. Customers participate with the development team in a laboratory environment.

###### Alpha Prototypes

Alpha prototypes represent “production intent” but do not attempt to replicate an actual production article. While identical materials and configuration are used, the alpha prototype is not fabricated in the actual processes or facilities to be used in production. This step determines if a product will work as designed, and whether the product satisfies key customer needs. Alpha prototypes are design discovery and risk reduction tools. Customers participate with the development team in a realistic approximation of the environment in which the product will be used.

###### Beta Prototypes

Beta prototypes are built with parts supplied by the proposed production processes, verifying the performance and reliability of actual product from real facilities and processes. Extensive use testing and assessment is performed both by customers and the development team. Beta testing reduces rework and cycle time during the pre-profit stage (PPS). Beta testing is both a quality assurance and commercial risk reduction tool. Beta testing is often conducted in the customer’s actual environment of use.

###### Gamma Prototypes

Gamma testing is a relatively new introduction to prototyping. It is a form of test marketing that proves that a product and related services fully meets market needs before full introduction. Gamma testing extends beta testing to include the consumable items and services needed to support the product. Like beta testing, it is often conducted in the customer’s actual environment of use.

**Prototype Program Management**

Advances in prototyping technology through computer simulation and modeling make earlier and more extensive prototype programs affordable compared to several decades ago. While prototyping may be more affordable, it continues to represent a significant commitment of time and resources in many product development efforts. As shown in **Figure 8**, Thomke points to four major issues in management of experimentation, which is a subset of prototype programs. Like many others in the literature, Thomke emphasizes early prototyping to attain the greatest benefit in design and screening of new concepts, however he also points out that planning a sequence of prototypes, with application of learning between prototype events, leads to more effective results. Thomke also advises that the integration of new and old technologies must be carefully planned in experimentation programs, ensuring that old technologies are as effectively applied and testing in the environment of use as are new concepts.

###### Figure 8

###### Management of Experimentation

*(Thomke, 2001, page 69)*

|  |
| --- |
| The Essentials for Enlightened Experimentation Innovation requires the right R&D systems for performing experiments that will generate the information needed to develop and refine products quickly. The challenges are managerial as well as technical: Organize for rapid experimentation  * + Examine and revamp entrenched routines, organizational boundaries, and incentives to encourage rapid experimentation   + Consider using small development groups of the people with the knowledge   + Experiment in parallel instead of sequentially  Fail early and often, but avoid mistakes  * + Embrace failures that occur early in the process and advance knowledge   + Well-designed tests have clear objectives; mistakes often occur when variables are not controlled   + Allow for multiple, repeated trials  Anticipate and exploit early information  * Front load: identify problems upstream where they are easier and cheaper to solve * Acknowledge the trade-off between cost and fidelity   Combine new and traditional technologies   * Do not assume that a new technology will replace an established one * New technologies emerge and evolve continually |

###### Example: Ballast Water Bio-Treatment System Prototyping

International regulations [IMO Resolution A.868 (20), 40th MEPC, 1997] adopted guidelines for control and management of ship’s ballast water systems to minimize the transfer of harmful aquatic organisms from one region to another. A conventional method of compliance is to exchange ballast water at sea, which complicates ship operation and incurs both added overtime and maintenance costs. A non-marine specialist in high-flow water separation technology, Velox Technology, Inc. teamed with specialists in ultraviolet water treatment to develop a new ballast water system that renders ballast water safe for discharge in port. Following concept development, an alpha prototype was developed in a standard 40 foot container and evaluated in Vancouver harbor. This prototype demonstrated performance of the system to Canadian government officials. Vancouver Port Authority was one of the first in North America to introduce mandatory ballast exchange, and was therefore selected to participate in prototyping. A beta prototype was installed aboard Princess Cruises’ *m/v Regal Princess*, in April 2000, and two more systems were installed in Princess Cruise ships in late 2001. This product is now marketed under the OptiMar TMname, and was the winner of a 2001 SeaTrade Award for innovation.[[6]](#endnote-6)

###### LIFECYCLE AND POST-SALES SUPPORT

Lifecycle costs for many products significantly exceed the first cost of the product or service. For example, the post-delivery cost of ship operation, including fuel, manning, spare parts, consumables, insurance, drydocking, and port fees may be several multiples of the purchase price of the ship itself. This after market may represent a major sales opportunity that is often under-exploited. Additionally, failure to consider post-delivery support during the design of a product or service can also prevent a new product from succeeding in the marketplace. Lifecycle support is therefore a consideration at the beginning of product design, not just after the product has been sold.

Rosenau describes a Continued Sales Interval (CSI) in which a developer can actively offer related products or services, improve and extend the product, passively ignore the product, or quit the market without investing in product improvement or sales. The authors’ observe that many sectors of the marine industry often either passively ignore the product or quit the market after the initial sale; this strategy is often inherent in the underlying product development process.

(Ulrich, 1996) discusses a product development activity in which early brainstorming identifies likely product changes in service. The product team then considers how these likely changes can be anticipated in the product architecture. **Figure 9** provides a rough schematic of this approach. This method allows a product developer to build-in future participation in revenue from the product while ensuring better customer support in service.



**Figure 9**

**Product Lifecycle Considerations**

*(Author’s adaptation of concepts by Ulrich, 1996)*

We suggest a framework that considers four lifecycle support aspects:

* + - Guarantee service
    - Technology refreshment and insertion
    - After sales and support
    - Disposal.

###### Guarantee

All products come with some warranty, whether expressed or implied, that the product is suitable for intended use. Many other industries systematically collect and review warranty, guarantee, service and liability issues from prior, related products as part of the product development process. Can early choice of materials or configuration reduce future guarantee problems? This is an important question for many product development teams, which may also result in more extensive prototyping, or need to be considered in setting the price point for the product. Guarantee problems may dramatically impact the time-to-profit, pushing returns out from the first units to much later in a product series. Insight into guarantee concerns can be obtained in the early stages of product development through benchmarking of the developer’s own prior products as well as from the experience of suppliers and competitors.

###### Technology Refreshment & Insertion

Advancements in information technology have changed product lifecycles dramatically over the past decade. The well-known Moore’s Law states that the speed of computer chips doubles every 18 months, and market pressures for faster and more capable computers extends this observation to an 18 month cycle time for new generations of computers. In the marine industry, expectations for domestic ship life have increased from 25 years to over 40 years, while new onboard computer systems may become obsolete twice during the time it takes to design and construct a ship. This leads to the need for designing technology refreshment and insertion into new products from early in the product development process.

Technology refreshment maintains a products’ technological currency, whereas technology insertion introduces new functionality. Considerations include: commonality, modularity, application of corporate and industry standards, design for supportability, flexible and adaptable configurations, and reliability and maintainability.

**Figure 10** illustrates how technology refreshment and insertion might work in a five ship design and construction program for integration of a new computer-based technology. By necessity, the equipment must be purchased with sufficient lead time to allow installation during ship construction; commercial pricing issues usually lead to purchasing multiple ship sets at the same time. As shown in Figure 10, flexibility in specification of ship sets 1-3 needs to be retained as late as possible. Even so, it’s likely that technology refreshment (TR1) will be required to introduce enhanced features shortly after the first ship enters service. Later ship sets 4 and 5 should be specified as late as possible for construction of ship 4, and will be delivered with technology refreshments incorporated in the first three ship sets. A second round of technology refreshment may be necessary to extend the life of all equipment in the fleet, and this TR2 may coincide with delivery of the last ship. As TR2 is installed, development of engineering modifications may result in technology insertion (TI1) to provide new functionality for equipment throughout the whole fleet.

Figure 10  
Technology insertion and refreshment in ship series construction

An early plan such as **Figure 10** is necessary to fully anticipate how the computer-based system, related support systems, and the ship as a whole must be configured to support efficient and effective change. The US Navy’s Joint Command & Control Ship, JCC(X), is currently considering technology refreshment and insertion as an explicit part of product development for the ship and its constituent systems. Note that the pervasive use of microprocessors makes this issue a concern for many hull, mechanical and electrical systems as well as electronics.

###### After Sales Support

As consumers, most of us are aware of the concept of planned obsolescence, in which manufacturers appear to make conscious choices between cost and product life. The result of these choices may require replacement of the product, but more commonly require replacement of some component. Product development teams commonly consider and prototype issues such as:

* Inspection, maintenance and repair
* Wear
* Consumables and consumption rates

The product design may also consider other products of the developer or its competitors that are collaborative complements. For example, third party software may add functionality without the need for a computer system developer to invest in a new custom application. Help desks and user problem solving services should also be considered, as well as ties to the supplier community. As an example, help desks for marine engines can be accessed by satellite/internet links to manufacturers, who assist in diagnoses of problems, recommend fixes, and provide access to spare parts by drop-shipment from worldwide jobbers.

###### Disposal

Some customers, notably Government customers, face large environmental challenges in ultimate disposal of expired products. Scientific understanding of material hazards continues to expand rapidly; what is deemed safe and acceptable today may not be acceptable a decade from now. Considerations in product development are twofold: 1) avoid product liability and 2) create customer value by assisting in responsible and efficient disposal. A first step in product development is to explicitly list and restrict use of hazardous materials and configurations. Mapping and configuration management programs can provide visibility as to any hazards that are essential to the product. The business case can also consider business arrangements that retain the developer’s involvement throughout the product lifecycle and control of disposal. For example, it may be appropriate to offer material return policies, such as we see with laser printer toner cartridges, or lease arrangements that return the product to the manufacturer for disposal. These ideas must be an explicit part of the product development process to be effective.

###### Example: FRACTRAC and Life Cycle Product Management

Tankers operating under US Coast Guard or the American Bureau of Shipping Alternative Compliance Program undergo an annual inspection of the cargo block to identify cracks and structural problems, hopefully before serious failure occurs. Ship operators develop Critical Area Inspection Plans (CAIP) to focus these inspections on likely problem areas and ensure consistent and thorough documentation of any flaws. MCA Engineers, Inc. has developed a relational database application that allows text, AutoCADTM drawing data and photos to be captured as an inspection is planned and performed. Use of relational databases allows operators, surveyors and regulatory bodies to run queries to find common patterns by structural element type or location. These databases can also incorporate design data developed before the ships enter service, including structural scantlings and identification of predicted high stress locations from finite element or spectral fatigue analyses. FRACTRAC assists owners in assessing the need for timing of corrective action, and by efficiently generating accurate reports for regulatory compliance.

###### CONCLUSION

How can we practically apply these lessons from other industries to development of new shipping services, equipment, systems, and ships? We observe that the US marine industry generally engages in adaptive rather than break-through developments of complex, highly integrated products, arguing for a process that has elements similar to the Ulrich and FFS-SG-PPS models. Kelley’s process can be used as a fuzzy-front end for break-through products, but this innovation-focused process will be the exception rather than the rule in most marine companies.

**Figure 11** shows our suggestion of a generic process for marine product development, which is a hybrid of the Ulrich and FFS-SG-PPS models. It starts with a Product Innovation Charter to clearly layout corporate objectives for investment in a new product. The suggested process strengthens the front and back ends of product development and supports it through better business cases and prototyping. Management reviews provide appropriate oversight without forcing the sequential stop-and-go of a formal stages and gates process; this is sometimes referred to in other industries as overlapping stages and gates. Note that contract award, the buyer’s decision to go forward, is typically the first but not the last management review.

### Figure 11 MMC Generic Process for Maritime Product Development

The US marine industry is largely a business-to-business (B-2-B) market, in which customers traditionally have defined their own requirements and negotiated specifications with the seller during a price setting exercise. Often the requirements definitions are based on past programs, are overtaken by the passage of time, are imprecise, and are not reflective of actual customer use. Corporate competencies and internal requirements are often poorly stated in specifications. Tools may not be in place to explicitly communicate requirements downstream into the product development process. We therefore observe that improved marine products development processes will incorporate systematic requirements definitions linked to a strong business case.

We also observe that the marine industry lags others in adoption of formal prototyping techniques, using experimentation and testing as verification tools rather than design processes, and often fails to take the opportunity to observe the customer’s reaction to physical or virtual design representations at an early stage. Lifecycle support should also be considered as an explicit activity in the marine product development process, in order to create added revenue opportunities for the developer, increase value to the customer, and limit both profit and liability risk.

We note that the buyer’s primary decision criterion in the marine industry is often price, and therefore the need to contain costs has been a focus of US marine product development processes. It is therefore appropriate to continue strong emphasis on the integration of design and manufacturing through techniques such as Integrated Product and Process Development (IPPD), Lean DesignTM, and Design for Manufacturing (DFM). However, these efforts need to be reflected in the business case at an early stage.

Finally, we observe that adoption of a formal product development process with a work instruction, plan, schedule and budget is necessary to ensure that the process is actually implemented as intended. The marine industry examples demonstrate that many of the methods applied in other industries are also practices in the marine industry, however we note that these methods are often applied piecemeal. A key improvement will be to map out all of the steps in the process, end-to-end, and clearly communicate the process to all participants, including internal team members, suppliers and customers. Non-marine companies have clearly benefited from formal product development processes, reducing cost and risk, decreasing time to profit, and increasing returns and competitiveness.

Frank Popoff, Chairman of the Board of Dow Chemical Company, sums up the expected results of good product development, which may be reasonably expected for the marine industry as well:

“The secret to success is a continuous flow of new products, processes and services that bring value to our customers. … America’s best and most admired companies recognize the value of innovation.” (Rosenau, 2000, p. 9)

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2. See Storch et.al. page 237 [↑](#endnote-ref-2)
3. Readers are referred to the website of the International Council on Systems Engineering, [www.incose.org](http://www.incose.org), for links to articles on the systems engineering process [↑](#endnote-ref-3)
4. Stage-GateTM is a registered trademark of Dr. Robert G. Cooper and the Product Development Institute, Inc.; see <http://www.prod-dev.com/>. The general concepts of structured development activities followed by strict management reviews are well represented throughout the literature on product development, including PDMA articles and books. [↑](#endnote-ref-4)
5. QFD is described in a series of National Shipbuilding Research Program reports and training materials. See also (Clark, 1997, pp. 299-315) for a concise example of how QFD works. [↑](#endnote-ref-5)
6. See Hyde Products website, [www.hydeweb.com/ballast/ballast.htm](http://www.hydeweb.com/ballast/ballast.htm) and also the OptiMarin A/S website at [www.ballastwater.com](http://www.ballastwater.com). [↑](#endnote-ref-6)