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THE EVOLUTION OF THE PUMP BUSINESS IN THE INFORMATION AGE

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ABSTRACT

The information age is redefining virtually all aspects of conducting business, including the way pumping systems are designed, evaluated, procured, manufactured, and maintained through their entire lifecycle. These engineered-to-order products will be designed and represented using Internet technologies that have not yet been completely developed. However, it is apparent that the process of selecting and purchasing pumps will be dramatically changed in the context of the way critical information is communicated between pump purchaser and supplier. The emerging information technologies that are contributing to improved quality and cycle time in the overall pump design and procurement process will include selection, configuration, automated bill-of-materials, catalog purchasing, and collaboration technologies. These are described in the context of a highly collaborative, engineered-to-order design environment prevalent in the pumping machinery industry.

INTRODUCTION

Trading partners involved in the buying and selling of pumps and associated mechanical equipment are entering into a period of change that is unprecedented in the industry. This statement is bold and deserves explanation in the context of the past, present, and future of the industry.

Three Socio-Economic Phases

Osashi (Cooper, 2001) observed three phases in the industry, known as the Expansion Phase (Past), the Environmental Phase (Present) and the Globalization Phase (Future). The *Expansion Phase* occurred during the post World War II re-building of major economic centers. During this period, the majority of new pump families were conceptualized and developed. The underlying technologies that led to the fundamental physical understanding of the behavior of pumps also evolved during this period. This included research on rotordynamics, hydraulic instabilities, cavitation, and engineering materials. This phase was subsidized by the economic boom associated with the post WWII expansion, dedicating substantial flow of funds and resources to new pump technology research and development. The *Environmental Phase*, which began in the 1980's, resulted in a convergence of the performance-oriented design and product design technologies of the earlier phase with the environmental and emissions control issues of the period. Sophisticated hydraulic analysis and design software were developed to optimize the basic design embodiments developed earlier. Higher efficiency machines and sealing technology with lower emissions were profiled during this period. In addition, pump installations were evaluated for their total energy costs and retrofitted with equipment that was better suited for the current or changing conditions of service. Now, the pumping industry is evolving into a *Globalization Phase*. This phase is driven by the substantial influence of information technology on the economics of the traditional manufacturing firm and its role in the pumping industry's value-chain.

Information as a Catalyst for Change

Information technology must be viewed as an "enabler" or a "catalyst" for the globalization trend that is taking place in the industry today. Information technology "enables" trading partners located at opposite ends of the globe to collaborate on design projects, to exchange new product designs using CAD/CAM, and to share manufacturing resources based on regional demand. Information technology has also been a "catalyst" to force companies to re-invent themselves by disaggregating and then re-aggregating their firm into new business models (Tabscott, et al., 2000). Consider the *Wall Street Journal*, which was founded in 1889 as an aggregated collection of content (news, advertising, editorials) delivered in the context of a newspaper as a physical product. With the influence of the Internet, the owners of the *Wall Street Journal* disaggregated the product into its constituent parts and re-aggregated the product into the *Wall Street Journal Interactive*

(WSJI), a new on-line version of the traditional product. This product is substantially personalized to meet the customer's needs, including personal stock quotes, news articles directed towards the readers area(s) of interest, on-line discussions, and access to the research libraries. This product addresses the needs of the new and substantially globalized marketplace and may render the old, and profitable product obsolete.

Admittedly, the pump industries end product, a sophisticated piece of machinery built to meet a custom fluid processing application, is substantially different than a newspaper and arguably, is not as "Internet friendly" to change as the new WSJI. However, by disaggregating the pump industry into its constituent elements in the value chain, one quickly concludes that the costs associated with manufacturing and assembling the equipment represents only a small portion of the total value of the equipment. The non-manufacturing related costs included in sales, marketing, engineering, procurement, logistics, inventory, and financing represent areas that will be affected by information technology.

The assertion that the pumping industry is entering a period of change that is unprecedented cannot, and will not, be proven for 5 to 10 years hence. This assertion is based on a number of leading indicators, primarily catalyzed by the impact of emerging information technologies. These indicators will be presented in the following section, and developed in detail throughout the remainder of the paper.

Pump Industry Poised for Change

Over the last quarter century, change has occurred at a modest pace in the pump industry compared to the electronics and information industries. During that period, the electronics industry developed powerful design tools and new manufacturing technologies that enabled miniaturization of semiconductors and memory chips. In 1965, Gordon Moore made a memorable observation that each new memory chip contained roughly twice as much capacity as its predecessor, and each chip was released within 18-24 months of the previous chip. This observation, known today as Moore's Law, predicted that computing power would rise exponentially for a brief but sustained period of time. Since the invention of the memory chip, the performance has continued to double every 18 months for the last 40 years and is expected to continue for about 10 more years. Corollaries to Moore's law are now applied in other areas of information technology, such as storage devices and communications technology. These are shown in the table below:

Component Technology	Time to Double Performance
Memory Chip (MIPS)	18 months
Storage (Gigabytes)	12 – 15 months
Communications (Bits/sec)	6 months

Unfortunately, productivity improvements in the area of traditional mechanical design for Industrial Product Manufacturers have not been as dramatic. The primary reason is that the product design process is not well understood for many mechanical devices and the diversity in the design process has not readily adapted to deterministic design and analysis methods as compared to electronic design (Wade and Colton, 1990; Chen and Menq, 1992). In addition, manufacturers in the industrial sector are generally associated with mature products and industrial customers. To a great degree, the legacy of products and high investment in facilities often limit their ability to change. They must service obsolete product lines, provide support for a vast array of spare parts and historical product maintenance data, and must often deal with conservative customers also resistant to change.

Just as the information age has fueled globalization, the effects of Moore's law and advances in information technology will bring profound changes to the pump industry over the next decade. The evolution of the pump industry in the information age is described in the following three sections. First, the characteristics of the engineered-to-order design process are introduced as a framework for representing ETO products using emerging information technologies. Second, the existing inefficiencies of the collaborative exchange between trading partners during the pump selection and procurement process is described. Finally, the emerging information technologies that are expected to substantially change the design and collaboration processes in the industry are introduced.

CHARACTERISTICS OF AN ENGINEERED-TO-ORDER DESIGN ENVIRONMENT

The procurement process for pumping equipment is characterized as an Engineered-to-Order (ETO) design environment. By definition (Dahl and Ochs, 1999), an ETO design environment is characterized by products that are adapted using some level of design activity to meet unique requirements, and result in a unique product configuration for virtually every customer order. This is a highly complex process that has not been broadly enabled using information technologies, especially on the Internet. This is in contrast to the "shopping cart" process in the business-to-consumer (B2C) environment where users purchase books, music, toys, and other commodity products. To Internet-enable the ETO design environment, ETO manufacturers must develop a robust design process with the appropriate balance between standardization and flexibility. Then, they must adopt information technologies that effectively represent this design process and support collaboration between buyers and suppliers.

ETO Design Activities

There are three major design activities utilized in the ETO design environment. The first is known as the *Basic (Generic) Product Design Process* in which the designer develops a unique design solution for the specified set of customer

requirements. This might result in a pump design as represented in Figure 1.

Now, suppose a second set of customer requirements are provided such that a new casing, impeller, and shaft design are needed to meet these new requirements. Over time, a third, fourth, and eventually, an N^{th} set of requirements are provided. These designs are executed using the basic product design process resulting in N unique pump configurations of the same embodiment. Unfortunately, this process is not preferred in practice as the total design cycle for the N configurations is too long, requires too many unique parts, and does not take advantage of modular, or size range design concepts appropriate for this type of ETO product.

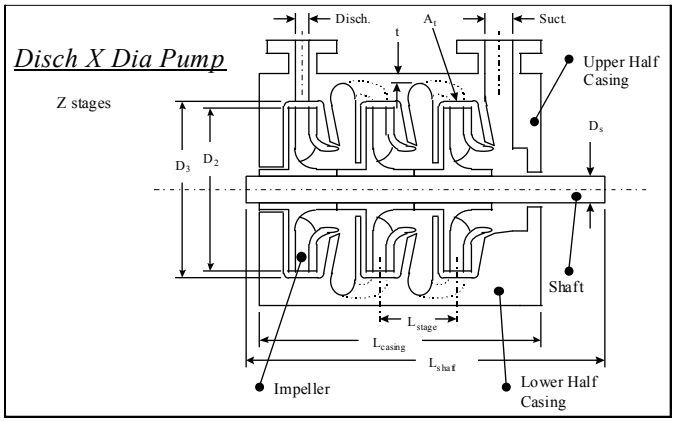

Figure 1. Simplified Centrifugal Pump Embodiment

Alternatively, an ETO manufacturer will execute a more robust *Product Range Design Process* involving the simultaneous design of individual variants to meet a broad range of anticipated customer requirements. An important decision during the product range design process is the level of design abstraction to build into the product definition. The following four levels of design abstraction: *pre-conceived, pre-configured, pre-designed,* and *pre-manufactured* are shown in Figure 2 and described below.

A *pre-conceived* product line has a fully developed and predefined embodiment design. At this level of abstraction, fixed physical dimensions for the design variables for the casing, impeller, and shaft depicted in Figure 1 do not yet exist. A pre-conceived product line is often used when the demand or definition of various customer requirements is not well known.

A *pre-configured* product line is used when a bounded set of customer requirements is predefined. This set of customer requirements is sufficient to allow the designers to pre-configure a defined set of physical design variables to satisfy the defined range of customer requirements. Fixed values for each of the design variables (i.e. D_2, L_{shaft}, etc.) are defined, describing a single, unique configuration design. A complete set of N individual configurations describes the pre-configured product line.

A *pre-designed* product line has fully developed part designs and manufacturing instructions for each pre-configured part variant described in the product line configuration. In the pump example, each impeller, casing, and shaft includes not only the configuration design variables in Figure 1, but also the previously undefined dimensions, tolerances, and manufacturing processes found in a fully defined manufacturing plan. A pre-designed product line is intended to eliminate all design activity required for each unique customer order.

Finally, a *pre-manufactured* product line includes parts or entire assemblies of designs manufactured to the pre-designed product line definition. In this example, various configurations of pump designs might be pre-manufactured and available for stock purchases from a pump services catalog. Alternatively, individual components might be stocked and assembled in a configure-to-order mode to meet a unique set of requirements. The pre-manufactured product line does not involve new design activity for each customer order.

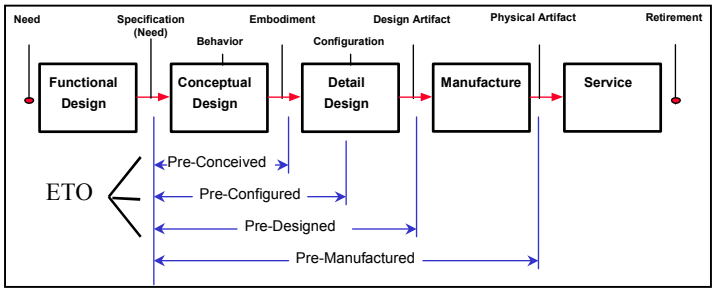

Figure 2. Levels of Design Abstraction for Product Range Designs

Specialized design methods are available to rigorously execute the various levels of the product range design. Examples include size range and modular design concepts (Pahl and Beitz, 1998), graph theoretic methods (Dahl, 1997), product range design evaluations using information content metrics (Dahl, 1997), (Suh, 1990).

The third process executed in the ETO environment is the *Engineered-to-Order Design Process* itself. This process starts with *Selection Design,* or the choice of the most appropriate design embodiment that satisfies the customer's requirements. The *Configuration Design* involves the specific choice of pump configuration required to meet the customer's requirements. A pre-configured product range design simplifies the configuration design to a simple selection from a range of pre-configured alternatives. The final step in the ETO process is the *Order Design*. This is the execution of the specific manufacturing plan to deliver the desired physical product. The degree of design activity required in the Order Design phase depends on whether the product is a pre-conceived, pre-configured, pre-designed, or pre-manufactured product range.

The effectiveness of the ETO Design process is substantially improved with automated design systems. Manufacturers have utilized CAD/CAM technology to automate

the detail design process. However, the "front-end" selection and configuration design process, often performed collaboratively between buyer and supplier, is less prevalent and a strong candidate for deployment on the Internet.

COLLABORATION BETWEEN TRADING PARTNERS IN AN ENGINEERED-TO-ORDER ENVIRONMENT

The collaborative process between trading partners (i.e. buyers and suppliers) in the procurement of pumping equipment and services is known as the Inquiry / Quotation (or RFP / Proposal) process. In the case of complete (new) pumping equipment, the process involves the following six major steps: (1) engineering the pumping system, (2) selecting the pump and driver type, (3) pump specification and data sheet preparation, (4) inquiry and quotation (proposal), (5) evaluate of bids and negotiation, and (6) purchase the selected pump and driver (Patel and Dahl, 2000). The entire process is information intensive, consisting of both technical and commercial information. The first three steps of the process (steps 1 – 3) are technical in nature, involving the exchange of system design, pump specifications, and performance and construction details of the pump. The last three steps of the process (steps 4 – 6) transition toward the commercial elements of the purchasing decision such as equipment costs, life cycle cost evaluations, terms and conditions, and delivery lead-times.

This Inquiry – Quotation information exchange is not limited to only one purchaser-supplier interaction. With each new procurement opportunity, this information exchange affects every trading partner participating in the entire supply chain (Figure 3). Unfortunately, only a fraction of the total inquiry / quotation effort exerted by buyers and suppliers is used in the downstream order engineering effort (Dahl and Ochs, 1997). To reduce costs, purchasers are seeking ways to reduce the engineering resources required to process this information without compromising the quality of the competitive evaluation. Similarly, suppliers are developing methods for responding to inquiries (or requests-for-proposal (RFP)) with less resources and effort while striving to still provide high quality quotations to their customers. Simplifying the inquiry-quotation process is an attractive proposition for both buyer and supplier.

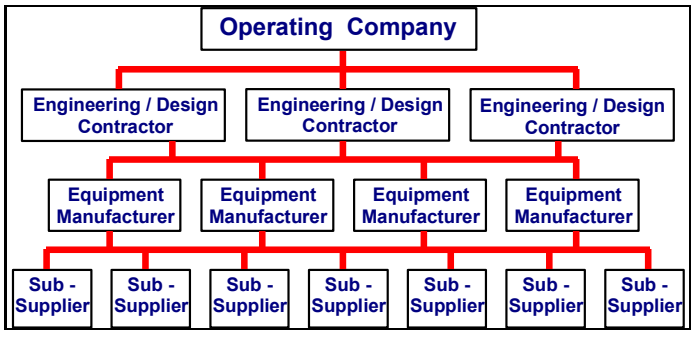

Figure 3. Multi-Firm Information Flow

Each of the interactions between buyer and supplier represents one or more information *transactions*. Savings are obtained by either eliminating a transaction, or substantially reducing the time or effort involved in performing that transaction. One approach is to structure the flow of information between companies to reduce information ambiguity and enhance common work practices. The Internet provides a ubiquitous technology infrastructure allowing globally dispersed trading partners a means for reducing transaction costs. The next section describes the information technologies that are particularly important in improving design and collaborative processes in the selection and purchasing process for pumping equipment.

EMERGING INFORMATION TECHNOLOGIES

The rate of change in the pumping equipment market will be widely affected by the evolution of business-to-business (B2B) e-commerce conducted over the Internet. This Internet technology is relatively new, even as measured in "Internet Years"[1]. Yet, the basic marketing forces and strategies needed to implement B2B e-commerce for engineered equipment providers is only now starting to be discussed in open industry forums. Suppliers have commonly thought that engineered equipment is too complex to be sold over the Internet. Unlike commodities, there are many variables that affect the application, selection, configuration, and maintenance of pumps. Presently, Internet exchanges do not integrate the engineering and product knowledge required to effectively meet the needs of the buyer, or seller. They treat pumps as a catalog item, which is a gross simplification. Ironically, it is this complexity that makes the pump industry a prime candidate for process improvements through Internet commerce. The successful exploitation of the Internet by the pump industry will require the strong integration of pump domain knowledge and Internet knowledge. This will not be an easy task.

The following sections describe three major categories of emerging technologies of the information age that will drive change in the pump industry: (i) the digital foundation, (ii) design process oriented technologies, and (iii) collaboration oriented technologies.

The Digital Foundation

The Internet is rapidly becoming the digital foundation through which business-to-business electronic commerce will be conducted between trading partners. The pump design and collaboration processes described in the following sections will be substantially performed across the Internet in the future. Purchasers and suppliers will team up by either contacting each other through their own Web sites or by meeting through special "portals" or "marketplaces" specifically established on the Internet for pumping equipment. According to estimates by Morgan Stanley Dean Witter Internet Research, B2B e-

[1] An *Internet year* is often quoted and generally represented as one-third of a calendar year.

commerce will approximately double every year through 2002, capping at about $1.4 trillion. Bear, Stearns, & Co. and Forrester Research predict that the major beneficiaries of e-commerce include industries such as Energy, Chemicals, and Food and Agriculture, which are large users of pumping equipment (see Figure 4).

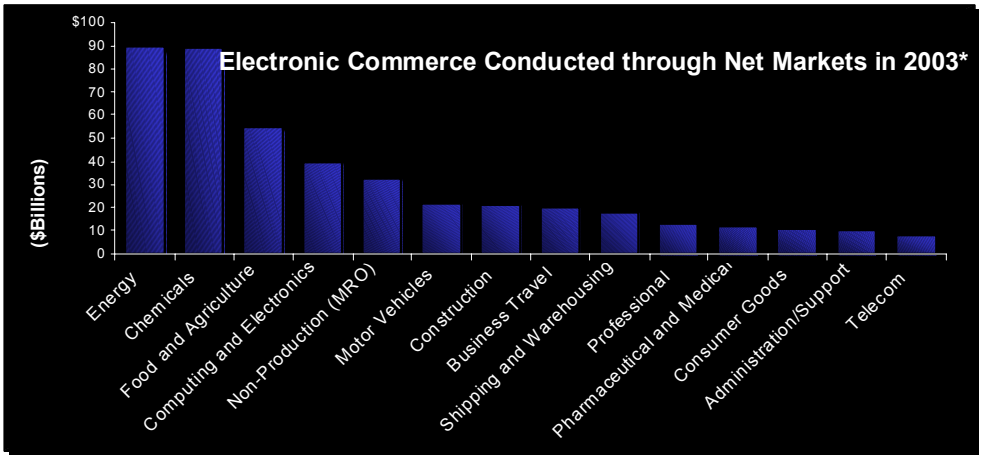

Figure 4. Estimated Electronic Commerce by Market

Design Process Technologies

Complex design processes such as pump system design, pump selection and configuration are ideal candidates for design process Internet solutions. Actual business transactions involving inquiry, quotation, purchase order, and invoicing will also utilize the Internet. These design processes will evolve, starting with commodity type pumps and will eventually support more sophisticated types of pumping equipment. Interactions during the order fulfillment cycle will be available such as order status information.

Pump System and Selection

Designing the piping network and sizing the components for pumping systems are performed early in the overall pump selection and purchasing process. The piping system design involves numerous components that introduce friction losses in the system. These must be calculated in order to estimate the system resistance curve to properly size the pumps needed in the system. An important element of this design process is an optimized pump selection. Pump selection programs are being used to aid in this endeavor. These programs can be reasonably sophisticated, using specialized mathematical algorithms to predict pump performance under varying operating conditions of speed, temperature, NPSHA, pressure, and viscosity. Some are even capable of adjusting performance based on alternative mechanical seal design, wearing ring design and clearance, bearing design, materials of construction, or other mechanical design features. There are dozens of pump selection programs used in the industry today (Cotter, 1996). With few exceptions, these pump selection programs were specially developed by each pump manufacturer using proprietary selection and searching methods. Pump system and selection programs have improved the ability to evaluate large numbers of alternative design alternatives in a short period of time. In the future, Internet enabled pump selection programs will provide greater value to buyers and suppliers alike by providing real-time access to the latest versions of the program and performance data. Similarly, integration between other applications, such as piping or process design programs becomes more practical.

Pump Configuration

The primary tool that pump manufacturers traditionally use during the Inquiry / Quotation process is commonly known as the *Pricebook*. The Pricebook is an engineering design, specification, and pricing manual used by a trained pump applications engineer to convert a customer's inquiry into a customized quotation. The diverse array of information, expertise, and resources needed to generate a customized proposal has prompted the need to systematize the selection and configuration process on the Internet.

Some manufacturers have responded by developing computerized product configurators. Product configurators aid the applications engineer in developing a pump quotation according to a prescribed product configuration model. These configurators use *design rules* to guide configuration choices. Examples of design rules are maximum casing pressure, maximum pump torque for a given shaft design, or the allowable temperature range for a given material. Using these design rules, a configurator can automatically upgrade a flange rating on a casing based on casing pressure or restrict the use of a gasket material as a function of temperature. The adoption of Internet enabled product configurators is essential in bringing buyers and suppliers together to optimize the product design. Buyers benefit by understanding design and cost tradeoffs at a detailed level, while suppliers are assured of a robust implementation of their design rules from configuration through order design.

Automated Bill of Materials

A natural by-product of the configuration process is the development of a high level bill of materials (BOM). The robust scope of supply developed by the configurator provides an unambiguous BOM definition. This high level BOM, when integrated with an existing inventory control / MRP / BOM system, can produce an error-free detailed BOM representing the exact scope-of-supply specified in the customer's quotation.

Catalog Purchasing

Finally, some design situations require only a product search based on simple selection criteria. These are often referred to as catalog search / purchase systems. In the pump

industry, these methods apply to spare parts or sub-assemblies. These searches are usually based on part number or part type, but often reference the parent pump by either pump serial number or model number.

Collaborative Technologies

Collaboration technologies involve both structured and unstructured documents or communications exchanged between trading partners. In addition, a rich knowledgebase of reference information, technical data, and discussion areas further enhance the Internet enabled collaborative environment between buyers and suppliers.

Structured Documents

Structured documents involve fields of information that are important in defining customer's requirements as well as communicating design details between trading partners. The communication of structured inquiry and quotation information is still predominately managed through paper-based documents such as specifications or datasheets. Since both purchaser and manufacturer typically use their own datasheet formats, communication requires a laborious translation and interpretation of information from one datasheet format to another. With the implementation of computerized selection programs and bid-tab programs, this manual translation between these systems is a non-value added task and represents a lost opportunity to streamline the data communication process.

A new standard known as Extensible Mark-up Language (XML) has been developed to provide a standard method for communicating structured business documents across the Internet (see www.xml.com for more information on XML). One recommended application of XML is the translation of datasheet information using the API 610 8th edition Neutral Data Exchange format (Dahl, 1995). This approach would allow disparate buyer and seller Internet applications to seamlessly transfer pump data defined by API 610 via an XML document.

Unstructured Documents

Many unstructured documents are exchanged between buyers and sellers as well. Unstructured documents include drawings, instruction manuals, specification manuals, technical references, and correspondence. While the contents of these documents are not structured at the field level (suitable for relational databases), they are necessary elements in the complex collaboration process for ETO products.

While the documents are unstructured, buyer and seller collaboration requires highly structured methods of posting, accessing, and managing these documents. These are supported using document management and knowledge management technologies. Document management provides a framework for storing unstructured quotation and order related information that is readily accessed by joint buyer and seller project teams. Similarly, knowledge management offers a framework for storing and accessing documents that are referenced across multiple projects. This includes technical literature on pump applications (like ASME papers), discussions on technical problems, or access to other expert resources via on-line chat or discussion forums.

Summary

The basic activities involved in the selection and purchasing of pumps are substantially the same now as in the past, and will be in the future. However, the processes and technologies employed in performing these activities are changing rapidly as a consequence of the Information age. The motivations surrounding these changes are driven by the desire for shorter cycle times, higher quality, and lower costs in the selection and purchasing process. These objectives are driven by the availability of new and emerging information technologies that offer a more seamless and structured flow of information between the purchaser's and the supplier's sales, applications, engineering, and manufacturing functions. The availability of computer systems guarantees only that the infrastructure is in place to achieve the anticipated benefits. However, common work practices between buyers and suppliers must be adopted and adapted to these new technologies. These process changes, not the availability of new information technologies, will govern the speed in which the pump industry changes in the future.

Level of Product Range Design Abstraction	Selection	Configuration and Pricing	Automated BOM	Catalog Purchase	Description
Pre-Conceived	√				Optimum pump design embodiment chosen by selection program.
Pre-Configured	√	√			Pump configured and priced according to defined guidelines.
Pre-Designed	√	√	√		Complete pump BOM generated based on configuration rules.
Pre-Manufactured	√	√	√	√	Design process represented by a simple catalog purchase.

Figure 5. ETO Design Process Methodologies

ETO manufacturers will benefit by structuring their ETO product designs into either pre-conceived, pre-configured, pre-designed, or pre-manufactured product ranges. Then, the development of appropriate Internet enabled design process tools will result in robust on-line selling systems that assures a high quality selection, configuration, order design processes

(Figure 5). Pre-conceived product lines have design embodiments that are represented in a pump selection program, but are not yet configurable. Pre-configured products are suitably deployed with a product configurator. Pre-designed ETO products benefit from selection, configuration, and automated BOM technologies while pre-manufactured products are most readily represented using product catalog technologies.

New information technologies utilizing the digital foundation of the Internet combined with emerging design process and collaboration methodologies customized for the pump industry were described. Some of these technologies are in use today, but will be "re-invented" on the Internet in the future in ways that cannot be fully anticipated. However, the rapid changes brought on by the Information age must be recognized for what they are -- as a support process in the collaborative interaction between buyers and suppliers. The Information age will support, but not replace, the basic requirement to design, select, configure, and manufacture high quality and reliable pumps that support a substantial part of our modern life and industry today.

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REFERENCES

Bradley, S. R., and Agogino, A. M., 1993, "Computer-Assisted Catalog Selection with Multiple Objectives", *Design Theory and Methodology*, DE-Vol. 53, ASME.

Chen, B. and Menq, C. H., 1992, "Initial Attempts on the Characterization of Functional Requirements of Mechanical Products", ASME Annual Symposium on Concurrent Engineering, Anaheim California, November 8-12, PED-Vol. 59, pp. 315-329.

Cooper, P., 2001, "Pumps – 2000 and Beyond", Welcoming address at the 17th International Pump Users Symposium, March 2000. To be published in the *Proceedings of the 18th International Pump Users Symposium*, Texas A&M University, College Station, TX, March 2001.

Cotter, Michael, August 1996, "Pumps on the Internet", *World Pump* (359).

Dahl, T., ed., August 1995, "Appendix Q -- Standardized Electronic Data Exchange File Specification", Centrifugal Pumps for Petroleum, Heavy Duty Chemical, and Gas Industry Services, *API Standard 610, 8th Edition*, American Petroleum Institute, Washington, D.C.

Dahl, T., 1997, "Development of a Design System for an Engineered-to-Order Product Line", Ph.D. Dissertation, Lehigh University.

Dahl, T. and Ochs, J., 1997, "Preliminary Pump Selection and Configuration in an Engineered-to-Order Environment", ASME Fluids Engineering Division Summer Meeting, FEDSM'97.

Dahl, T. and Ochs, J., 1999, "Characteristics of an Engineered-to-Order Design Environment", International Conference on Engineering Design, ICED 99 Munich.

Patel, V. and Dahl, T., 2000, "Chapter 11: Selecting and Purchasing Pumps", edited by Karassik, I. J., Messina, J. P., Cooper, P., and Heald, C.C., , *Pump Handbook, 3rd Edition*, Mc-Graw Hill Book Co., New York.

Pahl, G. and Beitz, W., 1988, *Engineering Design: A Systematic Approach*, Springer-Verlag.

Pugh, S., 1991, *Total Design*, Addison-Wesley Publishing Co., Workingham UK.

Suh, N. P., 1990, *Principles of Design*, Oxford University Press, New York.

Tabscott, D., Ticoll, D., and Lowy, A., 2000, *Digital Capital: Harnessing the Power of Business Webs*, Harvard Business School Press, Boston.

Wade J. and Colton, J. S., 1990, "A Framework for Feature-Based Representation of the Design Process", *Engineering with Computers*, Vol. 6, pp. 185-192.