Developing a Manufacturing Science for Designing and Managing Systems for Total Quality Commitment

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DEVELOPING A MANUFACTURING SCIENCE FOR DESIGNING AND MANAGING SYSTEMS FOR TOTAL QUALITY COMMITMENT

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1. Introduction and Overview

This paper outlines the research required to develop a manufacturing science for designing and managing systems for total quality commitment. Commitment to quality is an important factor in the international competitive successes of the Japanese, the world's preeminent manufacturing practitioners. Much of the methodology used by the Japanese is applicable in the United States. However, for American companies to equal and surpass their international competitors, significant work is required to understand, improve, and refine the Japanese and other methodologies for achieving total quality commitment. As important as adapting these methodologies for use in the United States, is convincing U.S. managers that the benefits returned by these methodologies exceeds the cost of investing in them.

To respond to the challenge of developing a manufacturing science to support total quality commitment in the United States, research must be conducted in three interrelated areas: customer-driven product engineering, concurrent product and process design, and dynamic process improvement. Customer-driven product engineering addresses two processes: (1) defining the product mission, that is, eliciting qualitative customer requirements and translating them into physical product characteristics and features, and (2) designing products that efficiently and effectively meet their product missions. Concurrent product and process design involves subjecting the design process to simultaneous consideration of product requirements and technological manufacturing capabilities to assure that the resulting product-process system achieves high quality production at low cost. Dynamic process improvement is the constant, systematic application of engineering and managerial effort to product and process to achieve continual improvement in product performance and conformance, process quality and capability, and costs.

In each of these three areas, better theory and methods are needed. Research should address classifying firms, industries, products, and processes according to what are the critical management and engineering tasks needed for competitive success. Research is also needed to guide development of technologies for problem solving. Methodological research must develop tools and systems to support efforts to improve product and process quality.

In each of the next three sections, respectively, we elaborate on the type of research we envision for the areas of customer-driven product engineering, concurrent product and process design, and dynamic process improvement. In the fifth section we describe a research strategy to carry out such a program. The final section contains concluding discussion.

2. Customer-Driven Product Engineering

A customer judges product quality by how well the product meets his or her specific requirements. In most industries, customers' precise needs vary by customer and vary over time. In addition, customers often need help in specifying their needs. These factors make collecting and summarizing needs information for product design decisions a challenging task. To begin work in customer-driven product engineering, one must develop a methodology for eliciting and representing customer requirements, and translating these requirements into physical product characteristics and features.

Achieving detailed knowledge about customer needs requires a dialogue among engineers, marketing personnel, and potential users. This dialogue needs to proceed through several phases. The first phase is a structured, but qualitative, set of interviews intended to evoke a complete set of customer needs in their own words. There are a number of research questions to be addressed: How many interviews are needed to obtain a full set of requirements? How broad should the scope of inquiry be? How should the interviews be structured? For most firms, this kind of marketing research is time-consuming and expensive. Therefore, research must address how to elicit this information most efficiently.

In the second phase, customers must be questioned to structure the full set of needs discovered above into a hierarchy that extends from the most general to the most specific requirements. This grouping of needs is important for considering how various competing products meet the set of requirements for total product function.

A third research phase uncovers the relative importance of these needs, and how well each of the competing products or technologies (if there are any) meets these needs. The research must address how to obtain this information from customers, how to represent quantitatively this type of information, and how to aggregate it to enable overall comparisons among products. This analysis will uncover the aspects of customer needs that are met poorly by existing products, and therefore identify new and redesigned product opportunities.

Once the customers' needs are fully and accurately specified, they need to be incorporated into a product design that delivers the desired benefits. This process requires close interaction between the marketing and engineering groups. In many firms, close interaction between these groups rarely occurs, and the resulting product designs suffer as a result. Research is needed to identify, investigate, improve, and test procedures to foster interaction between marketing and engineering, with an aim of better matching product function to customer need.

Quality Function Deployment is one mechanism, used in Japan, to improve the marketing-design interface. Recently, a number of U.S. companies have shown interest in adopting this methodology, but they lack a complete articulation of the approach, and an analysis of how best to implement it in the U.S.

Quality function deployment uses a multifunctional team to develop a series of analyses used to direct new product development or product redesign efforts. The first analysis, called the "house of quality," relates customer needs with product functions for a given product design. Qualitatively expressed customer needs or wants, grouped into related hierarchies, are translated into measurable engineering attributes. The degree to which each engineering attribute affects each customer need is qualitatively recorded, as are interactions among engineering attributes. Also recorded are evaluations of competing products for each customer need and engineering attribute, along with targets for the product being designed.

In a second type of analysis, the engineering attributes are deployed into parts specifications. These parts are value-engineered and compared to the parts of competitors' products. Cost, quality, and function are optimized at the parts level, understanding that these functions all translate directly back to customer requirements.

In a third analysis, part characteristics are deployed into key process operations, which are translated into manufacturing system requirements. Quality function deployment thus concurrently translates customer needs through all product development steps into manufacturing requirements.

Research is needed to investigate quality function deployment as a model for improving product quality and the product development process. To begin such research, one could employ both quantitative and qualitative methods aimed at understanding and documenting how quality function deployment works when implemented in U.S. companies. Project team leaders and members of all current and past projects should be interviewed to learn their perspective about how the process works and what benefits flow from it. Researchers should attend some team meetings to observe the process at work. Upper management, particularly those responsible for new product development, should be interviewed on their perspectives on quality function deployment. The data from these interviews can be used to generate specific testable hypotheses about the benefits and shortcomings of the methodology.

The effectiveness of quality function deployment as a methodology for managing the development process, should become evident from collecting data on the cost, quality, and time to commercialization of the resulting products. Using the data collected from U.S. firms, one can measure product success with standard marketing techniques for testing customer preference and satisfaction. To date, the only published data on development process improvements using the approach are for a Toyota project. Therefore, such data should be of interest to any firm considering adopting the method.

The ultimate objective of the research is to understand the needs and methods for product development well enough to codify a process that firms can use to optimize their marketing and engineering activities in this area. Once such a development methodology is at hand, one could propose its introduction into additional sites to get data to validate the usefulness of the process.

3. Concurrent Product and Process Design for Improved Manufacturability

Equal in importance to incorporating the needs of the customer into product designs, is the need to consider simultaneously the product design and the production system to be used for its manufacture. Effective management of product and process design activities are a crucial component for achieving rapid development and launch of high quality products. In most manufacturing firms, product design drives process design; manufacturing engineers begin their work only after design engineers have finished theirs. This pattern is widely recognized as suboptimal, because product manufacturability, costs, and quality can be affected significantly if the product design is compatible with the manufacturing environment in which it will be produced. However, little systematic knowledge and few tools exist to guide firms in designing manufacturing processes and systems concurrently with their product design efforts. There is a significant need for research to help rectify this situation by developing tools, procedures, and theory for concurrent product and process design. Efforts in this area could focus on two types of research projects: system modelling and study of current and best practice.

In the modelling effort, one could develop a set of manufacturing process models to help identify promising product or process redesign opportunities. Such models would include components for evaluating cost and revenue tradeoffs for design decisions. Optimal leverage could be achieved by structuring this research around work on the manufacturing systems of several firms. The first step would be to develop a mathematical model that describes well the physical flow of work in the manufacturing facility. At a minimum, the model should capture directly work-in-process inventories, some measures of quality, production lead times, and direct manufacturing costs. The model will identify targets of opportunity for product and process redesign efforts. Each interaction between a step in the production process and a component of the product being manufactured provides a potential redesign opportunity. The objective is to identify characteristics that suggest high potential return to redesign. The ultimate goal of the work would be to deduce general principles, rules, and procedures for identification of high-yield opportunities. Such tools should prove useful to those responsible for managing design and manufacturing activities.

In addition to modelling efforts, one should study current and best practice in concurrent product and process design in a sample of firms in Europe, Asia, and the United States. As in the customer-driven product design area outlined above, the aim would be to identify the approaches that seem to be sucessful in this area. In particular, there seems to be an opportunity to extend and apply Taguchi methods for product and process design. Taguchi's four methods for product planning (product parameter design, tolerance design, process parameter design, and on-line quality control) and the quality loss function seem to be used very successfully in Japan. Experience in implementing these methods in the United States suggests that the opportunities to adapt these methods are great. Work with a number of U.S. industrial firms would help them learn to implement these methods quickly and effectively, and generate a quality engineering technology transferable to other U.S. firms. The ultimate objective would be to synthesize a demonstratably successful methodology that firms can adapt and optimize for their own use.

4. Dynamic Process Improvement

Even after optimizing customer needs, product design, and manufacturing system design, a firm cannot expect to be able to sit back and reduce vigilance for opportunities for process improvement. Numerous studies have demonstrated that the cumulative effect of minor technical improvements on productivity is often at least as important as the effect of major technological changes. Therefore we perceive a need to increase the U.S. industrial knowledge base with respect to managing process improvement. In particular, there is a need to develop tools to aid management in decisions of where to invest resources dedicated to process improvement, as well as how to best use the resources invested.

Very little systematic knowledge and very few tools exist to aid management decisions that involve economic tradeoffs related to quality improvement. The traditional cost-of-quality model, the most widely-available tool for monitoring and analyzing quality economics, is primarily an accounting tool for reporting historical results. Because it records historical costs rather than projecting future cash flows, the cost-of-quality model is woefully inadequate for supporting management decisions to invest in the technology, human resources, and management systems required to enable manufacturing firms to compete in a global economy.

The cost-of-quality model calculates the "economical" number of defects to produce. Equivalently, the model derives the point at which additional investment in process improvement, to reduce defect rates further, cannot be justified economically. The calculation requires trading off failure costs, the costs related to producing a certain level of defectives, with appraisal and prevention costs, the costs required to monitor quality and prevent defects. This model, which is seriously flawed on two counts, is the best-known (and for most firms the only-known) model for calculating economic tradeoffs for investments in quality improvement. The flaws in this model arise from the facts that: (1) the model focuses on cost minimization rather than on profit maximization, and (2) the model is static and does not capture future effects of quality investment decisions. Many managers intuitively recognize the shortcomings of the cost of quality model, but use it anyway because the only alternative "model" claims that zero defects should be the target, regardless of the cost of achieving that target

Responding to the second criticism above, one can introduce and model formally a dynamic theory of quality-based learning. This theory holds that firms' quality improvement investments will affect their rates of learning about productivity improvement. More specifically, firms investing in high quality will learn faster or go down a steeper experience curve than those investing less. Therefore, although investing in quality improvement raises costs in the short run, the faster productivity improvements can lead to lower overall costs in the long run. In the formal model, firms invest the optimal amount in quality improvement each period, taking into account the future productivity gains from the investments. The "economical" quality target continually moves towards zero defects, reconciling the zero defects concept with the standard cost-of-quality analysis.

Such a quality-based learning model serves as an improved decision tool for investments in quality improvement, because it takes into account some of the long-term effects of investing more in quality improvement.

We perceive a pressing need for new, and even more sophisticated economic decision tools for managing quality improvement. In Japan, firms summon up the will to invest continually in quality improvement without the use of sophisticated models for economic justification. The Japanese accept on faith that investments in quality improvement will always yield adequate dividends in growth, market share, and profit. In most U.S. firms, faith alone is not enough; managers must demonstrate that projects for quality improvement will secure an adequate return on investment. Because we do not believe that American managers will abandon the fundamental modes of financial analysis to which they are wed, we conclude that a better quality evaluation technology, a technology that captures the heretofore unquantified costs and benefits in the quality equation, are crucial for driving the decision processes needed to restore American competitiveness.

These research objectives could be approached through systematic modelling and an active partnership with industrial firms. Discussions with quality management practitioners have led us to believe that there are two areas of great need: (1) to develop tools that account for the revenue effects of quality decisions, and (2) to develop a cost-of-quality accounting methodology that can serve as a forward-looking decision support tool, rather than just as a historical record of expenditures. With respect to (1), most managers understand that the quality improvement investment decisions they make have significant implications for the sales-generating potential of the firm. With higher quality products, firms can charge higher prices, can win larger market shares, and can deter potential competitors from challenging their markets. Unfortunately, these effects are notoriously difficult to quantify. Even more unfortunate is the common practice of abandoning all hope of quantifying these effects, and therefore effectively assigning them a value of zero for quality investment decisionmaking purposes. The aim of research in this area must be to develop straightforward methods to develop crude estimates and upper and lower bounds on the magnitudes of revenue effects of quality changes. Such techniques have been used successfully to quantify the revenue impacts of product improvement in the consumer packaged goods industries. Work is needed to adapt and improve these techniques for other industrial sectors of the economy. One would not expect to achieve the same precision for the revenue-side effects as is possible for cost estimating; however ballpark figures for these effects, derived in part from game-theoretic models, will reduce the bias toward underinvesting in quality improvement.

The second thrust of work needed is to develop a forward-looking cost-of-quality accounting methodology for management decisionmaking. Such a methodology would provide a structure for data collection and organization, as well as models for data analysis and decisionmaking. Quality management practitioners cite this as a great need. An important factor for the success of such work is the availability of industrial sites with interest in serving as laboratories for the work.

Research is also needed on development of better methods for improving individual (unit) manufacturing processes. Much industrial advance proceeds by one increment of improvement at a time, rather than by radical jumps. Tools to aid this slow, steady advance are required. The need is to develop and test methods to pursue the ever-repeated improvement cycle of experimentation, response, learning, and adaptation in product and process designs. Statistical methods in the design of experiments for system improvement must be applied to manufacturing problems to aid development and refinement of tools for this purpose.

5. Research Strategy

Initial research must address agenda setting and problem finding. The need for research to support design strategies and quality improvement is well known. However, this broad mandate must be refined into projects that address the most critical problems, are manageable, and will yield high payoffs to industry. For example, there is little systematic knowledge on how optimal strategies for total quality commitment should vary depending on whether the industrial setting exhibits high or low production volumes, commercial or military applications, long or short product life cycles, domestic or foreign manufacturing, durable or nondurable products, etc. In order to focus research efforts, we need to understand better how factors such as these affect efforts to achieve quality preeminence.

To conduct the problem finding and agenda setting stage of the research requires investigation across a broad spectrum of domestic, multinational, and international manufacturing firms to discern current and best practice in quality engineering and quality management. A great deal of this type of information has appeared, primarily in anecdotal form, in journals and the popular press over the past decade. However, only a small fraction of this information has been organized and channeled usefully for driving research.

To begin this stage of the work, one must first organize and synthesize the available written work on quality engineering and quality management practices. This synthesis would then be used to drive the field research needed to identify industrial needs and important firm similarities and differences relevant to achieving total quality commitment. To conduct the field research requires access to a spectrum of manufacturing companies. Programs such as MIT's Leaders for Manufacturing or MIT's Industrial Liaison Program would be very useful for this work. The former program consists of a partnership between MIT and ten large U.S. industrial corporations (e.g., Boeing, Digital Equipment, Kodak, Alcoa, Motorola) committed to providing leadership for improving manufacturing competitiveness. The latter program consists of over 300 domestic and international firms (including many Japanese and European firms) who maintain close ties to the research programs at MIT. The field research will provide guidance for the research to develop a quality technology for customer-driven product engineering, concurrent product and process design, and dynamic process improvement.

After the first stage is complete, research projects must be designed to develop the tools and technology to support the identified objectives. Collaboration with industrial firms is crucial to the success of this effort. We envision the outcomes of this stage to be firm-specific tools, models, software, and procedures that support quality management and engineering.

The final stage of this program would synthesize the knowledge accumulated in the project stage. The objective would be to develop methodologies that are transferable to and adaptable by a wide spectrum of U.S. companies. We expect that this synthesized knowledge would contribute to the quality technology component of a manufacturing science. This scientific and technological knowledge would then be useful to manufacturing firms for both designing and implementing their quality and manufacturing strategies.

6. Concluding Discussion

A firm's quality strategy and technology are the lynchpins upon which competitiveness hangs. Market share and profitability are highly dependent on the quality of a firm's products. Productivity of a firm's assets are just as dependent on the quality of a firm's production processes. Consistent, uniform, in-control processes make Just-in-Time and automation relatively easy to implement; out-of-control processes makes it virtually impossible to implement these other strategies.

Achieving total quality commitment and world-class quality products and processes requires a dedicated, sophisticated team of managers, engineers, and workers who are equipped with the best quality tools and technology possible. The Japanese have invested significant time and resources to develop a quality technology that has worked very well for them. For the United States to compete, it must develop its own quality technology that builds on and then surpasses the best available. To do this requires research to adapt, develop, test, and refine methodologies to continuously design and improve the products and processes of U.S.

manufacturing firms.

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