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■ *Research Article*

Total Value Management — A Knowledge Management Concept for Integrating TQM into Concurrent Product and Process Development

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Most industrial implementations of total quality management (TQM) are based on *dimensions*, which are 'quality-oriented', goals are 'quality-focused' or efforts are 'quality-driven'. Today manufacturing sectors are much more fiercely competitive and global than before. Consumers are more demanding, competition is more contentious and ruthless, and technology is advancing (and changing) rapidly. The quality-based philosophy inherent in a TQM implementation does not exploit the concurrencies present in today's complex product design, development and delivery (PD^3) environment. The competitors are always finding better and faster ways of designing and developing products. With the TQM process alone, it is difficult to accomplish all aspects of Total Value Management (TVM) such as X-ability, cost, leanness, responsiveness, agility, tools and technology, and organization issues. A new concurrent Knowledge Management process for Total Value Management is proposed here, which accounts for concurrency — paralleling of value characteristics — along with an integrated methodology for their systematic deployment. Copyright © 2001 John Wiley & Sons, Ltd.

INTRODUCTION

Besides achieving steady growth and continued profitability, companies today are facing a variety of new knowledge management (KM) challenges (Bhote, 1996). Persistent among these are global competition, increasing labor costs, rising customer expectations (Bhote, 1997b), shorter product life cycles, and increasing government regulations. The old techniques of coping with 'short-term fixes' in 'reactionary mode' are not enough to sustain declining sales. Companies are slowly realizing the need to focus on 'precautionary measures' (that is, problem prevention versus fighting fires most of the time). There is a need to plan ahead, combine the available talents and KM resources — marketing people, design engineers and manufacturing staff — to work closely together and somehow plan a product that has all the important life-cycle values (Stalk, Evans and Shulman, 1992). Quality was and still is one of the most important life-cycle values in product design and development (Garvin, 1993). In order to implement KM procedures for producing quality products some organizations employ Total Quality Management. TQM is a management approach centered on quality (Evans and Lindsay, 1998) and is based on participation of all its members who aim at attaining long-tem success through satisfaction of the customers (Magrab, 1997). The premise

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is that 'by designing and manufacturing quality products that reflect the customer's desires and tastes, everybody will win' (Besterfield *et al.*, 1995). Customers will see the benefits and will be more willing to buy the products, manufacturers will receive more profits. However, this is not happening today with products developed in a fierce competitive environment (Bhote, 1997b).

Today, many companies are interested in improving their competitive position in the world marketplace. It is important for these companies to frequently bring in KM tools, product innovations and value-added services to the market in a timely fashion (Stalk, Evans and Shulman, 1992). For instance, high-tech companies (e.g. Microsoft and Intel) use an expeditionary marketing approach for moving their products. They compete on the basis on innovation rather than quality. This is because those companies that introduce innovations, new product concepts at high (or even less than high) quality levels often have the largest share of the market. Timely product development (Clark and Fujimoto, 1989) benefits a company in many ways. By early introduction, the company gains the customers' confidence; customers see their needs fulfilled and buy the products. The company gains an easy market share, giving it a competitive advantage. Customers become familiar with the products and thus they may develop a loyalty and be less likely to switch. The company gets on the learning curve ahead of their competitors. It is able to set the price and reap its profits much longer.

What mistakes do most manufacturers make when implementing TQM?

A common mistake a company makes undergoing a 'TQM process' implementation is the latent view of the term 'quality' (Evans and Lindsay, 1998). 'Quality' in the TQM sense does not limit itself to 'product quality', but the reputation of the company as a 'quality provider' (Garvin, 1993).

TQM is about institutionalizing a process of continuous improvement — of building quality in products through individual employees, through work-groups, and through organizational re-engineering (Evans and Lindsay, 1998). What differentiates TQM from other knowledge management techniques is its emphasis on 'CPI' — establishing a change process for improvement (Besterfield *et al.*, 1995). There is also a strong relationship between a product's quality, its market share and the company's return on investment. Irrespective of a product's market share, products with higher quality always yield a higher return on investments (Magrab, 1997). A recent study (*Manufacturing News*, 1996) of 167 automotive companies throughout the world has determined that those companies with poor quality products have an average sales growth of approximately 5.4%, whereas those companies that consistently produce high-quality products experience a sales growth averaging 16%. Also a large percentage of those companies that consistently produce quality products reported that they have used additional KM techniques along with TQM. Some examples of KM techniques employed were quality function deployment, failure mode and effects analysis for products and processes, design for experiments, and poka-yoke (Evans and Lindsay, 1998). There are several books discussing each technique in great detail (Ishikawa, 1985; Feigenbaum, 1990; Juran and Gryna, 1993). Other major quality tools reported used during a TQM process are (Besterfield *et al.*, 1995):

- Benchmarking (Bhote, 1995)
- Quality function deployment (QFD) (Ungvari, 1991; Clausing and Hauser, 1988)
- Operator's process Control (OPC)
- Zero Quality Control (ZQC), Statistical Quality Control (SQC) (also referred to as Total Quality Control (TQC) (Ishikawa, 1985) and Factorial Evolutionary Operation (EVOP))
- Fool-proofing process for production (or the Pokayokal Jidoka concept)
- Tools and technology deployment: Andon, Kanban system (Juran and Gryna, 1993)

Among the seven powerful tools for the twenty-first century, Bhote (1997a) lists three new ones (not mentioned earlier): Multiple Environment Over Stress Test (MEOST), Total Preventive Maintenance, Next Operation as Customer (NOAC) in addition to Benchmarking, DOE, QFD and Poka-Yoke. The definitions of OPC are shown in Figure 1 by a Venn-type diagram. OPC tools, which are based on Statistical Process Control (SPC), include techniques such as Zero Quality Control (ZQC), Source Inspection and Poke-Yoke (Prasad, 1996) More details are contained in Shingo (1986). Many of the quality tools, such as statistical process control, process analysis and simplification, etc., are well established in quality management circles (Ross, 1988). The book *Total Quality Control* by Armand Feigenbaum (1991) addresses the complex nature of quality across the organization. It covers a wide variety of topics, including the basics of statistical process control, how to set up systems to monitor quality, and how to design better quality products. It also discusses the economics of improved quality and how to

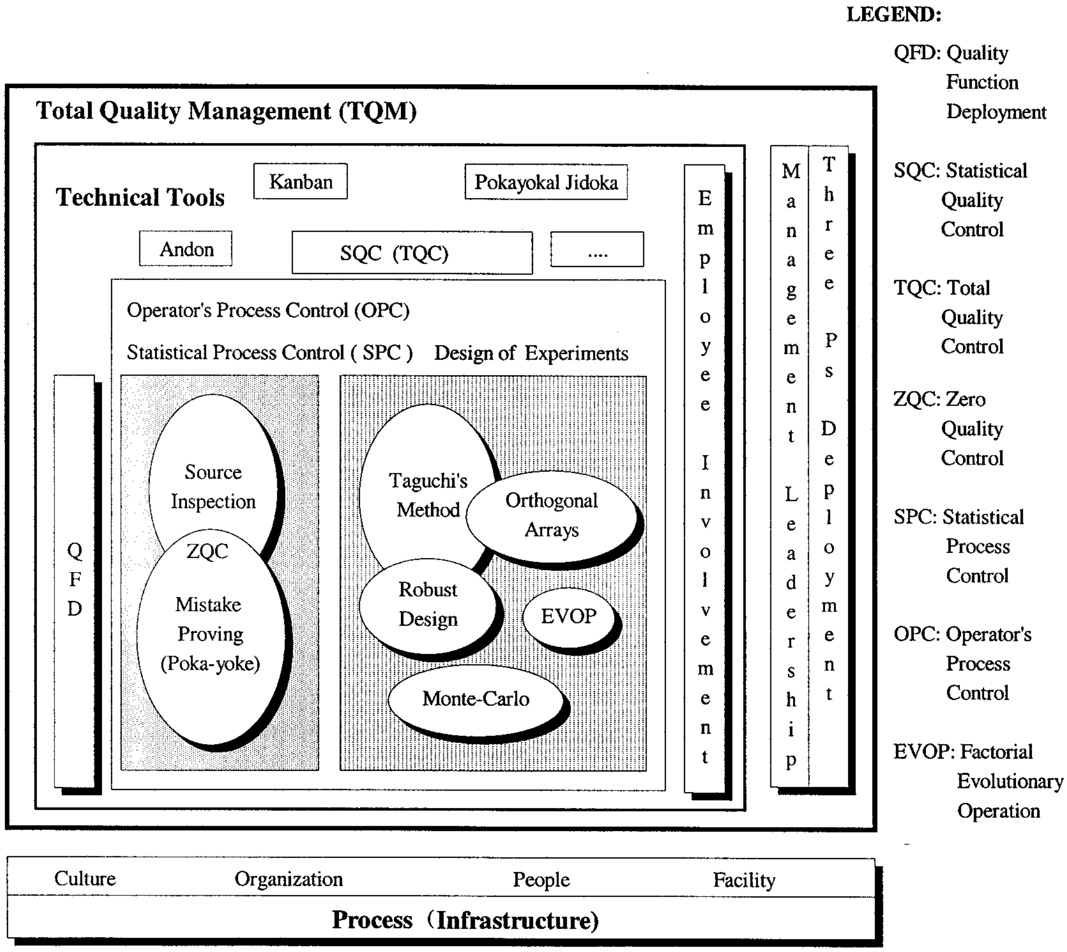

Figure 1 Quality management principles

achieve large savings and profits from a modest investment (Feigenbaum, 1990).

Another common mistake manufacturers make — when considering and implementing modernization initiatives — is a failure to consider the total enterprise or a complete set of objectives as they are developing their TQM-based solutions (Kearney, 1997). They want to rapidly introduce new TQM features, new technology, new quality control fixes into a specific area of a product line, or quickly re-engineer a particular process that has been the cause of unacceptable quality. The tendency is to seek a solution for a specific objective, such as quality. Usually, little or no consideration is given to what impact that would have on other functional areas of the company or how that solution will affect other company objectives (Besterfield *et al.*, 1995). The proposed solution might temporarily satisfy the modernization program and even get the initial problem cured, but this may also adversely affect other areas or other goals of the company. Companies that have already made the mistake of making the quality the first element have only succeeded in frustrating the entire organization (Kearney, 1997). Many of them have abandoned their quality programs after only a few years. Today there is seldom talk about programs like 'make it right the first time', 'zero defects', and 'quality plus'. Even the Baldrige Award has lost some of its appeal (Kearney, 1997). Bhote reports that 'most Fortune 500 companies embracing TQM have registered less than a 10 percent quality improvements per year, which in today's competitive world, is tantamount to standing still' (Bhote, 1997b). According to Bhote (1997b) TQM is the latest in a long line of fads, potions, and nostrums. He adds 'the United States has a strong quality heart, but a soft quality head'. One of the reason for this underperformance, he cites, is due to the selection of poor quality measurements over meaningful metrics (Bhote, 1997b). He gives two examples of such metrics as cost and cycle-time — both were not quality-focused.

CHARACTERISTICS OF A SUCCESSFUL LEARNING COMPANY

The fact is that continued dependence on conventional 3Ps, conventional 4Ms and conventional 7Ts (Prasad, 1997) is likely to yield conventional results (see Figure 2). The result may be an overall reduction of the enterprise's efficiency and it may affect the net profit margin. However, if the dependence is continued with the right knowledge content such as modern 3Ps, modern 4Ms, and modern 7Ts, this will yield more likely correct results (Figure 2) — meaning great products. Great products all share a set of knowledge contents (built into a product) that account for their quality. Wheelwright and Clark (1992) of the Harvard Business School call it product integrity. Integrity is what causes users to describe the quality of a product in words like 'They got it right!' 'This is the best I ever seen!' 'This is cute!' etc.

Studying the Japanese way (Ishikawa, 1985; Arai, 1997, Clark and Fujimoto, 1989, 1991) — particularly Dr Taguchi (1987), QFD (Clausing and Hauser, 1988), and the recent emphasis on quality recognition as in Japanese TQC (Garvin, 1993) and from reading books (Womack and Jones, 1996); Liker, Ettlie and Campbell, 1995; Nishiguchi, 1994) and the reports of the American management visiting Japan (Kamath and Liker, 1994), one can draw the following conclusions.

There are at least five striking characteristics that distinguish a successful learning company from its less successful counterparts. The most successful companies apply KM techniques while using productivity and quality tools. They manufacture products with integrity (Wheelwright and Clark, 1992). Such companies, by virtue of KM techniques, generally exhibit the following five integrity characteristics (Prasad, 1997):

- **Voice of Customer (VOC) at every stage of product development**: Pay strict attention to and focus all efforts on the 'voice of the customer' throughout every stage of the product development, from product definition to delivery cycle. The customers in this case is not limited to those who buy the product but include

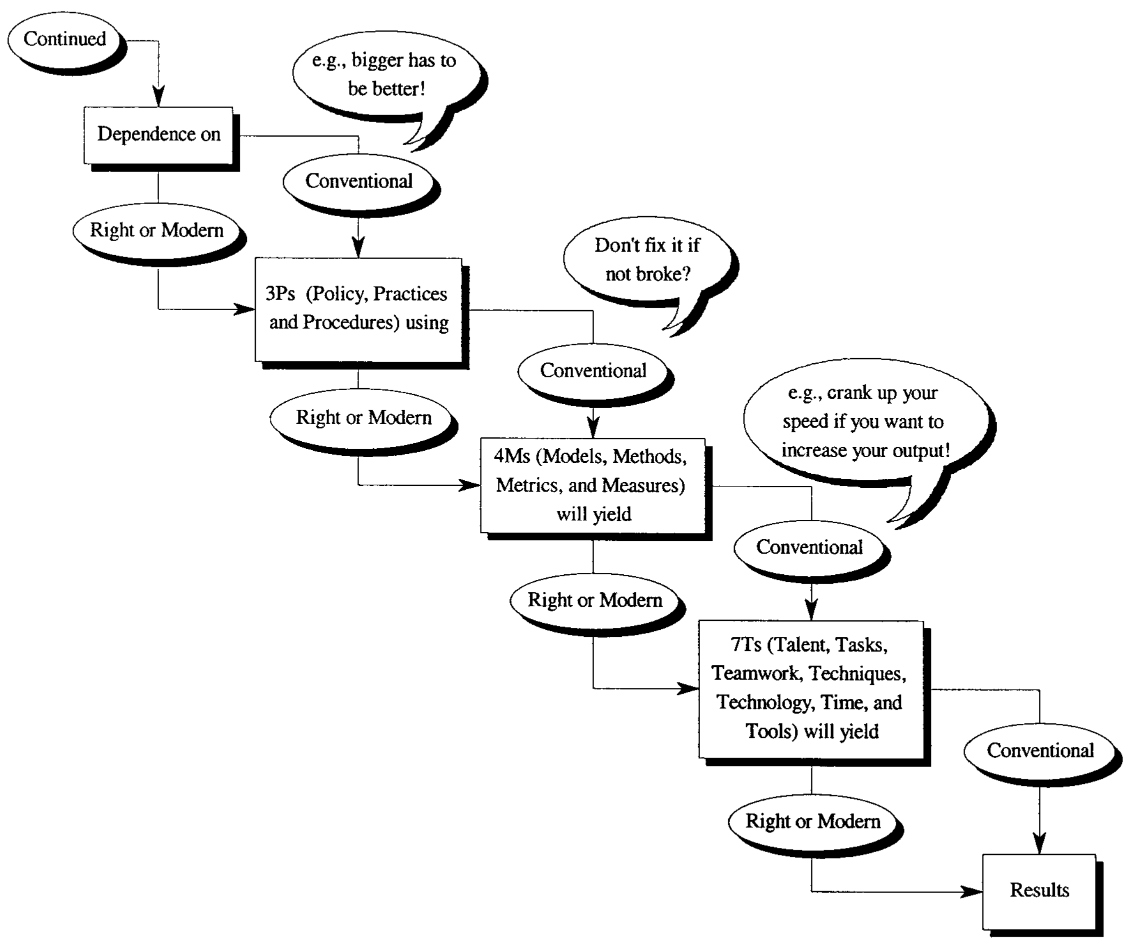

Figure 2 Why are tools and techniques by themselves are not sufficient to produce good results?

internal and external customers (Prasad, 1996, Figure 2.22/Volume I).

- **Strong fit**: There is a strong fit between the need of the product users and the features of the product itself. Himmelfarb (1992) cites 15 elements to qualify this strong fit A great product fully satisfies those needs (Wheelwright and Clark, 1992) from a number of perspectives. In fact great products go beyond simple satisfaction of stated needs. They often satisfy needs that users never thought of until they used the product, thus, surprising and delighting the users.
- **Global optimization**: Optimize products for a number of value considerations simultaneously: cost, weight, and investment (Dika and Begley, 1991), leanness (Womack and Jones, 1996), responsiveness (Clark and Fujimoto, 1989), innovations and timeliness (Clark and Fujimoto, 1991), design for X-ability (Prasad, 1997) and various other considerations, not just the eight dimensions of quality (Garvin, 1987) alone.
- **Parameter desensitization**: Desensitize the products to a wide range of variations (that is, variation in parts, process variation (Taguchi, 1987) tolerances, manufacturing variations, computing approximations including human factors variation as well) (Prasad, 1997).
- **Function as a unit (coherence)**: Take appropriate steps or precautions so that all components and elements of the product, including those physically outside the product, e.g. supply structures (Sako, 1995), product and process interfaces (Prasad, 1996), plug-in tools, work together seamlessly. The product as a whole functions as a unit. Examples of coherence include integrating workforce, suppliers and the customers — both horizontally as well as vertically — and organizing the concurrent teams cross-functionally (Bralla, 1996).

It is usually more cost effective to have teams consider most of the above integrity characteristics when pursuing a productivity or competitiveness solution even though only one characteristic may be targeted initially (Carroll, 1997). Thus, when the time comes to modernize through other integrity characteristics, one feels assured that previously introduced technologies or new processes will not adversely affect other areas, other objectives, or will not cause any adverse situations. Considering one particular integrity characteristic, one functional area of the company, one product line. or one particular objective for improvement could lead to a sub-optimized solution (Wheelwright and Clark, 1992). TQM by itself is, therefore, an insufficient vehicle for maximizing competitiveness or productivity.

TOTAL VALUE MANAGEMENT (TVM)

Total Value Management (TVM) is proposed here as a new Knowledge Management (KM) concept for balancing the interest of the entire organization — the supply base, the customers, and the company. The KM concept employs some of the basic (underlying) principles of Total Quality Management (TQM) (Garvin, 1987) and the Learning Organization (Garvin, 1993) but it goes well beyond its Quality Management or Learning focus. The process is based on systematically identifying, formulating, and applying a total enterprise-level knowledge management focus — based on total values (Prasad, 1997). However, this is not the first time value has been used in this way. World-class manufacturers frequently employ world-class operational functions (values) to assess their performance by benchmarking themselves against their competitions (Heim and Compton, 1992) Some examples of key values suitable for TVM are Quality (function-wise) (Garvin, 1987), X-ability (performance-wise) (Anderson, 1990), Leanness (Womack and Jones, 1996), Cost (profit-wise) (Dika and Begley, 1991), Tools and Technology (innovation-wise) (Kearney, 1997), Responsiveness (time-wise) (Clark and Fujimoto, 1989) and Infrastructure (organization-wise) (Bralla, 1996). If these functions are a subset of what characterizes a world-class product, clearly Quality in the TQM sense is an important but a basic consideration towards bringing a total optimized product from world-class perspectives (Heim and Compton, 1992). Fundamentals to TVM are the ideas that everyone in the organization has a customer — internal or external. That productivity improvement comes from understanding and improving business processes, procedures and policies (3Ps) and applying a set of governing value principles (Evans and Lindsay, 1998)

- Process of continuous improvement
- Appropriate policy deployment at all process levels: culture, organization, people, facility, etc.
- Employee involvement
- Management leadership
- Measurements of quality deployment
- Deployment of foolproofing

If one is truly ‘customer-oriented’ then the primary ‘value’ should be those attributes or characteristics that are perceived to be *valuable by* *the customers*. In most cases, however, an organization is interested in satisfying the needs of both the customers and the company. They would like to use the knowledge-based supply-channel to support its production process. In that case, 'value' represents KM attributes or characteristics that are perceived to be *valuable* by all involved in the product development process. Building a product that optimizes many key functional values intrinsically, not just on the basis of Quality-based philosophies, ought to be the dream of any forward-thinking company. How effectively, efficiently, and quickly anyone is able to succeed in this endeavor depends upon many KM factors that need to be considered. TVM is designed — *by plan* — to provide a sure path to increase global market share and profitability.

Basis of value management

As discussed earlier, clearly many value-based initiatives has been undertaken during product design and development in the TQM setting to capture other considerations (Stalk, Evans and Shulman, 1992) that are not quality-based. Japanese TQC (the foundation for TQM in the USA) (Ishikawa, 1985) had also focused on one or more aspects beyond quality such as supplier relationships (*Keiretsu*) (Nishiguchi, 1994), CPI (*Kaizan*), waste reduction (*Muda*) (Ohno, 1988), and the learning organization (Garvin, 1993) with TQM. Though there are some side benefits of imposing such quality-based philosophies — such as a product's 'cycle-time' reduction (Clark and Fujimoto, 1989), business growth, and better return on investments (Dika and Begley, 1991), value-based considerations are different from those quality-based tools and techniques. Values are those independent knowledge contents that are considered important to the customers, the suppliers and the company. Quality is only one of its contents. Many organizations have experienced difficulties in accommodating such independent knowledge-based values through quality dimensions (Garvin, 1987) and through a deployment vehicle that is purely TQM-based (Bhote, 1997a) Researchers have noted that many of the pertinent knowledge-based values (see, for example, Stalk, Evans and Shulman, 1992) required during product design and development either could not be directly imposed through TQM (Wheelwright and Clark, 1992) or could not be addressed through a quality-based TQM process.

Value management requires a commitment to incorporate value elements, through KM concepts, at all levels of interactions with product, process, enterprise and the teams. Besides possessing the above-mentioned quality characteristics, products with strong integrity are usually designed and developed around a clear and a core set of four (Knowledge Management) Ms. These four Ms — namely, methods, models, metrics and measures, and discussed by Prasad (1997) — are defined early in the life cycle of the product and are followed religiously throughout the product development. Many books are written on this topic. *Out of the Crisis* by Edward Deming presents a forceful statement on the corporate philosophy needed to make meaningful quality improvements (Deming, 1986) through KM. The emphasis is placed on five fundamental areas (see Figure 3):

- **Teams**: Workgroups are the primary source of value (e.g. quality and productivity) improvement, limited only by their knowledge, what they do on their job and how they do it (Carroll, 1997).
- **Value system**: Everyone must understand what the corporate vision is, what value system we are expected to operate under, the corporate philosophy, etc. For example, the goal should be to minimize the total cost over the lifetime of the product, not just its purchase price (Clark and Fujimoto, 1991).
- **Customer**: How do we determine what customers would like and build a product that the customer would buy? This is very much similar to 'market-in' approach (Freeze and Aaaron, 1990) emphasized in the Japanese TQC (Ishikawa, 1985).
- **Organization**: Most problems arise from the process (e.g. 3Ps), not the people who are executing it. Management can change the process either through empowerment (Luther, 1997) or otherwise. They must support and provide resources, show time commitment, break down barriers between areas, and create a set of consistent goals with 'constancy-of-purpose' in mind.
- **Methods**: Determining how people are led in their skills, their knowledge (such as analytical or statistical knowledge), and the pride they take in their contributions (education and training). Are their decisions formed on a sound or a rational basis? Methods also include setting up the right processes upfront (e.g. establishing a multidisciplinary review team upfront during analysis and design makes it more likely to see defects quickly).

The above ideas are borrowed from TQM body of knowledge, and it is no surprise that they are

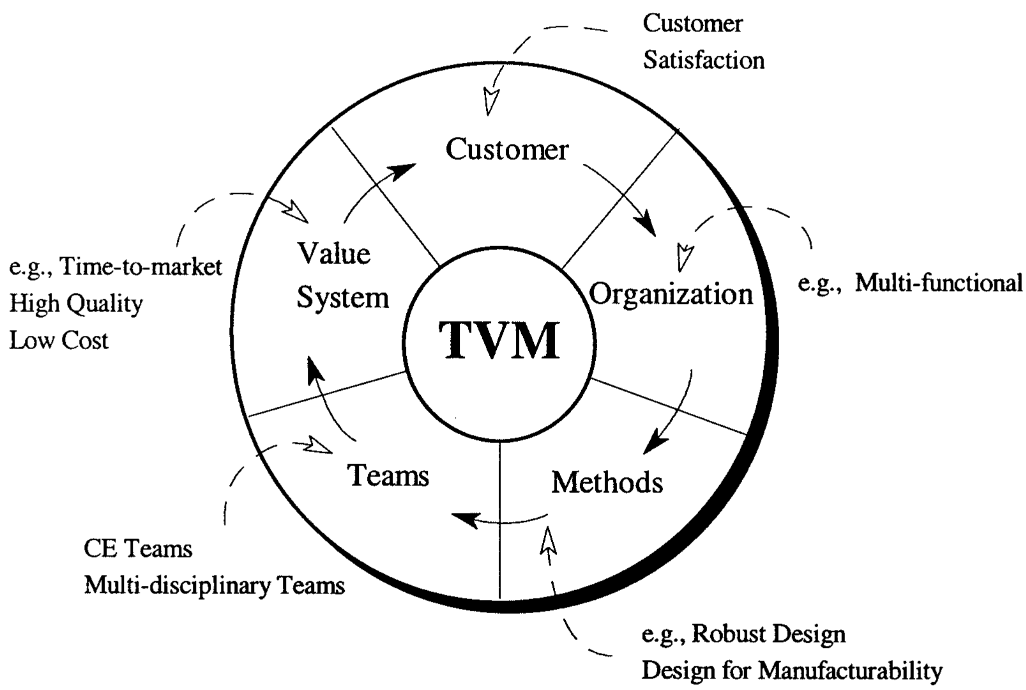

Figure 3 Basis of value management (based on Deming's Philosophy and TQM)

also considered as parts of quality (Garvin, 1987, 1993) or are said to have their origins in the development of so-called Japanese TQC (Ishikawa, 1985). The major differences, however, are in the way they are addressed and implemented in TVM. Both American TQM and Japanese TQC consider those in the context of 'quality management' focus not in the context of 'knowledge management' or 'value management' focus (Magrab, 1997). The Malcolm Baldrige National Quality Award criteria, for instance, focus on the following ten core concepts:

Customer-driven quality
Leadership
Continuous improvement
Full participation
Fast response
Design quality and problem prevention
Long-range outlook
Management by fact
Partnership development
Public responsibility.

Except the fast response, most of the above Baldrige Award criteria are quality-based. Some criteria may appear general on the surface but when the time comes to implementing them during product design, often they are viewed from 'quality' perspectives and are thus grouped together with it. They are never considered as independent value contributors (like quality) or treated concurrently during product development. According to the US Department of Commerce, who presents this award annually, this award recognizes US companies that excel in quality management and quality achievement (Magrab, 1997).

The next section focuses on TVM methodology and its deployment steps (through KM) necessary to yield a world-class product design. World-class design in this case means providing the best class of product values (Stalk, Evans and Shulman, 1992), technology, low product variation, and, at the same time, having the lowest possible variable cost, component weight and manufacturing investment, etc. (Heim and Compton, 1992).

METHODOLOGY FOR TVM

Today, implementing and sustaining an integrated product development process that can create a competitive advantage is much tougher. There are at least three reasons for this. One is that quality tools and techniques are much more widely known and used, thereby lessening the differences between organizations and limiting competitive advantage (Nishiguchi, 1994) based on quality alone (Luther, 1997). The second reason is that in many, if not most, cases, the easy issues and problems that are quality-related has been devised or incorporated. The low-hanging fruit in all but the most protected processes, companies or industries has been gathered and implemented (Luther, 1997). This represents the progress in the implementation of TQM and similar quality-based techniques developed in the 1970s and 1980s (Besterfield *et al*., 1995) and described earlier in the previous section. This has led a manufacturing industry that has now regained a very competitive position in world commerce if it relates to mostly 'quality considerations'. The third reason is that interdependency of other value considerations from knowledge management perspectives (such as cost or responsiveness) on quality is not well understood and therefore these value considerations generally remain untapped or unexplored for breaking new ground.

Implementing a successful quality-based improvement approach today requires much more than deployment of some basic TQM tools (Luther, 1997). TVM is a new knowledge management methodology that uses TQM as a part of its core knowledge. World-class quality is considered the basic entry point for partnership with original equipment manufacturers (OEMs). TVM considers a number of competing values besides quality, and deploys them concurrently throughout a product realization — a PD^3 — process and among all of the identified concurrent teams. The following describes the six essential steps of this new KM methodology:

(1) *Empower cross-functional teams with a constancy-of-purpose management style*: Earlier it was pointed out that quality methods and tools cannot stand alone — other value methods must be considered simultaneously. However, tools and methods — by themselves — cannot transform a company to be a world-class product producer or a world-class service provider (Kearney, 1997). We have learned through the school of hard knocks that unless members of cross-functional teams are working with parallel work-groups, excellence in service and products cannot be attained to its full extent (Bralla, 1996; Carroll, 1997). We have not come to an era where all decisions are automated and all knowledge about the products is electronically captured (in technical memory or knowledge-based systems (KBS)). Prasad (1997, Chapters 6 and 7) discusses KBS and life-cycle intent capture in more detail. Employee or Work-group Involvement is a part of teamwork. The best of the successful companies have found that work-groups in cross-functional teams focused more on the benefits to the total organization than on their individual departments or groups (Carroll, 1997). To succeed we need both a cross-functional team and a team-oriented consistency-of-purpose management style.

(2) *Transform what customers say they want into a build*. This is the key to building a world-class product at competitive prices (Bhote, 1997b) This step can further be broken into the following:
   - Listen carefully to the voice of the customers — what the customers tell us, <u>*expressible*</u> in their language
   - Translate it into the language that is <u>*actionable*</u> by all different workgroups involved in the PD^3 process
   - Make it <u>*understandable*</u> by the workgroup members in every related part of the multi-functional organization
   - Find ways to make it <u>*executable*</u> into the product. For example, in the process of translation, we must ensure that in an attempt to satisfy customer requirements we have not inadvertently created any secondary effects or have lost a part of the original customer's intent.

The incorporation of customer wants and needs into successful products and services is the essential activity of a successful learning organization (Bhote, 1997b) and is a recipe for winning customer loyalty. Along the way, employees and stockholders require that the company stay in business and make an acceptable profit (Bhote, 1996):

(3) *Prioritize activities within the product development process*: in view of what makes the most sense to customer, employees and the business. The concept is similar to focus on priorities — commonly referred as Hoshin Planning (Magrab, 1997). The activities that are prioritized should be based on principles of classifications that are not ambiguous but are also based on discriminating facts. Managers involved in product development know that it is no longer enough to improve product quality (Bhote, 1997a), increase responsiveness to customers (Kearney, 1997), or take steps to eliminate waste or rework and to reduce labor costs. They must also continuously improve their KM concepts, methods, processes and tools based on discriminating facts, not just hearsay, to drive the costs down.

(4) *Deploy parallel tracks of value characteristics*: deploy parallel tracks of quality, X-ability

(Anderson, 1990), responsiveness, productivity (Arai, 1997), tools and technology, etc. Stalk, Evans and Shulman (1992) consider values as a KM ability to outperform the competition along the following five knowledge dimensions: speed, consistency, acuity (ability to see the competitive environment clearly), agility and innovation. The knowledge dimensions are very similar to the value characteristics described above. Speed is analogous to responsiveness. The goal is to bring technologically superior quality products at competitive prices to the market before anyone else (Prasad, 1996, Figure 8.8, Chapter 8). Many have believed that values — like quality, cost, X-ability, and responsiveness — are conflicting KM issues (Stalk, Evans and Shulman, 1992), which may be true. However, the following two presumptions that: (1) they cannot be traded against each other, and (2) they cannot be achieved simultaneously are not true at all. The degree to which one can overcome these two depends on what state of product development one is in. The natural conflicts among these factors demand that they all be considered in a systematic and scientific manner as early in the process as possible. The chances that one can achieve a best product value early in the life cycle are more likely than during a later (such as during the detailed design) stage. For example, the Japanese have constantly shown that they can produce cars of far better quality and in much less time than their US competitors (Bralla, 1996, Clark and Fujimoto, 1991). In a recent study of Automobile 'clean sheet' development projects reaching the market between 1990 and 1995, Clark *et al*. (1995) found that a totally new Japanese car required 1.3 million engineering hours from their initial concept to building the first car. By contrast, the USA took over 2.3 million hours and the Europeans over 3.4 million hours.

(5) *Desensitize the parameter to variation*: Apply knowledge-based design, manufacturing and production principles that emphasize reduction of variations around target values. This is similar to an agility dimension described by Stalk, Evans and Shulman (1992) as one of their five competing capabilities. The goal is to insulate parts from all types of variations so that each part is consistently excellent. This is accomplished by KM techniques — desensitizing the product to variation in parts, manufacturing variation and customer use; and desensitizing the manufacturing processes to variation in equipment, operators and material (Taguchi, 1987). This can be accomplished by finding the range of variation in parameter values for which the response function is insensitive. Insensitivity indicates that variations in functional values are very small. Figure 4 shows a plot of several response functions when a concerned parameter value is changed. There are portions on each curve that are marked 'insensitive range'. Clearly one can then choose the respective parameters which fall within this range. This KM techniques assures that the corresponding function value will not change significantly even if one cannot hold the parameter strictly at its nominal value. What we want to design are products that satisfy the customer, perform well under a wide range of usage conditions beyond our control and which are difficult to manufacture and/or assemble improperly (Freeze and Aaron, 1990).

(6) *Function as a unit (coherence)*: The product-realization process (Prasad, 1996) is the foundation to building a coherent system the first time and every time thereafter. Because the process is iterative, a KM concept is used to make sure that we are not reinventing the wheel with each new product line program or annual model releases. The KM process allows us to draw upon technical memory including historical data and digital models, apply what makes sense and redesign what does not, thus repeating past successes, not past failures (Bralla, 1996). Toyota achieved success with its famous vehicle development process called 'Kozokeikaku' or K-4 because the employees were trained to review structures of recent similar Toyota models and identify the features that applied whenever they had to come up with a new design (Martin, Sawyer, and Sorge, 1995). The Toyota development process in conjunction with the trained workforce in the K-4 culture, in reality, provided 'a culturally prescribed method of looking at the vehicle engineering relationships and how the whole structure goes together'. It worked well because employees were trained in the Toyota Vehicle Development Process (VDP) and had a full understanding of vehicle histories. The product-realization process discussed by Prasad (1996) as a concurrent loop-based taxonomy does the same thing but it does it more systematically and consistently. The burden on the part of the K-4 employees to follow a prescribed KM procedure is shifted to the product-realization process (taxonomy) itself. The taxonomy accounts for all needed

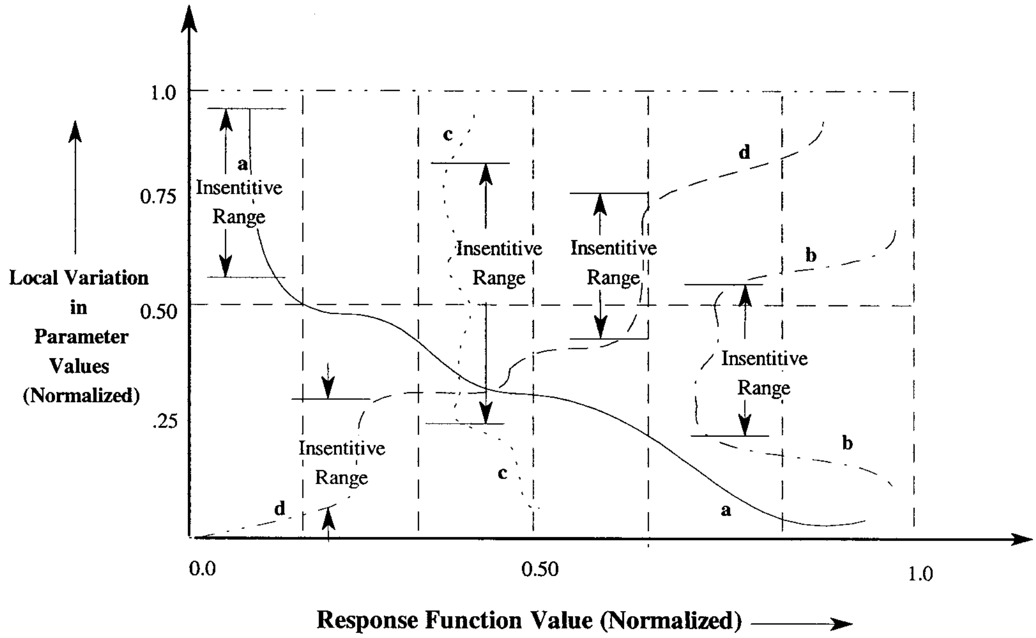

Figure 4 Response function insensitivity to local variation in selected parameters

KM checks. It draws upon technical memory (knowledge bases) to support the infrequent decision-making process.

Concurrent Function Deployment (CFD) is a knowledge-based deployment methodology for TVM — to deploy several values concurrently. TVM is a knowledge management methodology to manage or infuse total value into the entire system. This means considering upfront all relevant values concurrently and ensuring world-class performance in each value class. There are other popular KM tools or methods that can be part of this management group, namely, QFD, SPC, Value Engineering, FMEA, Taguchi Methods, Parameter design, Design for Experiments (Taguchi, 1987), etc. In those contexts, it may be argued that 'cross-functional management' 'focus on priorities' and 'desensitizing parameters' are part of knowledge management movement and thus part of TVM. It is difficult, however, to argue that the 'concurrency' and 'coherence' were also the focus of TQM originally. Deploying 'parallel tracks of values' is the key KM concept of this TVM philosophy. This goes well beyond the 'life-cycle reduction' 'ideas — enforced through CPI and other waste management techniques — employed in TQM.

KNOWLEDGE CONTENTS OF TVM

Total Value Management is a concatenation of the following knowledge elements:

(a) Concurrent Function Deployment (CFD)
(b) Seven Ts (Talents, Tasks, Teamwork, Techniques, Technology, Time, Tools)
(c) Four Ms (Methods, Models, Metrics and Measures)
(d) Three Ps (Policies, Practices and Procedures)

It is crucial to have all four of these knowledge elements in place to successfully manage and renovate a company. Such knowledge content of TVM can be thought of as the four legs of a stool (Prasad, 1997). The 'Seven Ts' are referred as the employee involvement leg. The 'Four Ms' are the management leadership leg, and the 'three Ps' the business process leg. Without any one of these legs the stool tips over — meaning they provide stability.

Although concurrent function deployment focuses on values, it does so under the assumption that these may not have to come at the expense of business process (3Ps). Improvements in the product content that deliver a limited set of values (such as quality, cost, etc.) cannot be expected to provide improvements in all other remaining knowledge management aspects such as business processes (3Ps), culture, human factors, Four Ms, Seven Ts, etc. Team members must view other members of the team as internal customers. There is a definite need to manage the business process. The requirements of the internal customers must be met, at the same time they must work together to rethink continually or re-engineer the process in which they have become so accustomed to working. TVM provides the needed knowledge management process infrastructure — the missing link of this value-chain continuum. They are discussed in greater detail in the following section.

Concurrent function deployment

The first step in creating a great product is an understanding of what exactly makes a product great. Earlier we described five pertinent characteristics of a successful learning company. Generally, development of a new artifact does include consideration of several life-cycle values that are pertinent to meeting the customers' requirements. From the KM point of view, many of these values are independent, i.e. there is very little or no interaction between them. Through the course of investigations and study, the author has found that the deployment of many artifact functions (values) can proceed in parallel with what we know toady as '*quality FD*.' Examples are: X-ability (performance), tools and technology, cost, responsiveness and infrastructure. Generally, these functions or values are independently specified or estimated in KM. The results of experience can be used to specify the requirements and expectation for each of the values in parallel without having to wait until a deployment of '*quality FD*' is complete.

The CFD concept expands the original definition of QFD, discussed at length in Clausing and Hauser (1988), to include parallel deployments. This provides a method to consider the deployment of competing values simultaneously. We have called this KM approach *Concurrent Function Deployment (CFD)*. The intent of CFD is to incorporate 'Voice of the Customer' into all nine phases of the product development cycle, through Mission Definition, Concept Definition, Engineering and Analysis, Product Design, Prototyping, Production Engineering and Planning, Production Operations and Control, Manufacturing and finally into Continuous Improvement, Support and Delivery (see Prasad, 1997). In other words, CFD is customer-driven KM methodology.

CFD is a knowledge management methodology the enforces the notion of concurrency and deploys simultaneously a number of competing artifact values, not just the 'Quality as found in QFD'. The artifact value deployment is through all its life-cycle phases. If a specification chart is being developed for the product, the taxonomy for requirements and constraints (RCs) must reflect all value considerations. RCs thus include customer requirements (CRs), VOCs and all types of WHATs that one may encounter. There are many value characteristics (VCs) for artifacts, such as quality, X-ability, tools and technology, costs, responsiveness, infrastructure, etc. Such a taxonomy will ensure that all-important aspects for product and process design knowledge have been identified and included. The focus of CFD is on systematically capturing product information (knowledge), such as market competitive analysis and customer satisfaction rating, analyzing these ratings to improve product functionality (say, an X-ability part) and then adding an array of values that are important to the customers and to the company. CFD thus ensures knowledge-based concurrent product development. CFD breaks the multi-year QFD ordeal by allowing workgroups to work concurrently on a number of conflicting values and compare their notes at common checkpoints. CFD is a simple and powerful KM tool that leads to long-range thinking and better communication across several value functions.

Prasad (1997, Chapter 1) has described a concurrent function deployment (CFD) architecture. Key KM aspects for preparing an environment for such architecture were discussed, including types of workgroups, monitoring, refining, and measuring the CFD process elements; and extending its effectiveness to the company's principal trade partners (Prasad, 1997). The relationships between QFD to CFD were discussed with particular emphasis on continuous process improvement (CPI) and KM.

Seven Ts and employee involvement

The first management challenge is to energize the workforce so that they buy into the concept of value improvement (not just the quality improvement) in every aspect of the businesses. The second challenge is to organize the teams so that employee efforts are aligned with the company goals. The way to meet these two challenges is cooperative teamwork. Teamwork consists of four elements: virtual teams, technology teams, personnel teams and logical teams. One part of teamwork is familiarizing the workgroups with the proper use of technical tools, the other part is employee involvement. With all sorts of empowered tools, it would be of little use if employees are not motivated (Carroll, 1997). The third challenge is to bring the right kind of talent to the right kind of tasks. We can reorganize the tasks in the best possible way but it will do little good if the right talents are not available to work on them. Furthermore employees, no matter how motivated they are, may not be able to function well until the right KM techniques are in place and are supported by the right set of KM technologies. Figure 5 shows the relationship between these seven CE enablers (7Ts) and their influencing agents.

Four Ms and management leadership

The four Ms (Methods, Models, Metrics and Measures) of Knowledge Management play a crucial role in defining TVM goals. Methods provide cost-effective, value-driven solutions that are on time for managing large manufacturing projects and also for product development. Dauch further breaks down the methods for managing complex manufacturing projects into an additional set of Four Ms (Dauch, 1993). Dauch's four Ms of project management are: Materials, Machinery, Methods and Manpower. Metrics and Measures help define the goals and performance expectations for the organization. World-class manufacturers adopt or develop appropriate KM metrics to interpret and describe quantitatively the criterion used to measure the effectiveness of the manufacturing system (Magrab, 1997). For example, if management is not actively involved then possible value thrusts that have been developed so far can be preempted by other 'programs of the month' where management does spend its time. Management leadership plays a key role in 'policy deployment'. It must provide clarity in leadership through mission statements, standards, incentives, and adjustments to the reward system. In the context of KM, management leadership in addition to other job functions must provide the following three TVM-related functions:

- *Concurrent function deployment (CFD)*: This involves deployment of a particular specification of a target value, which addresses the

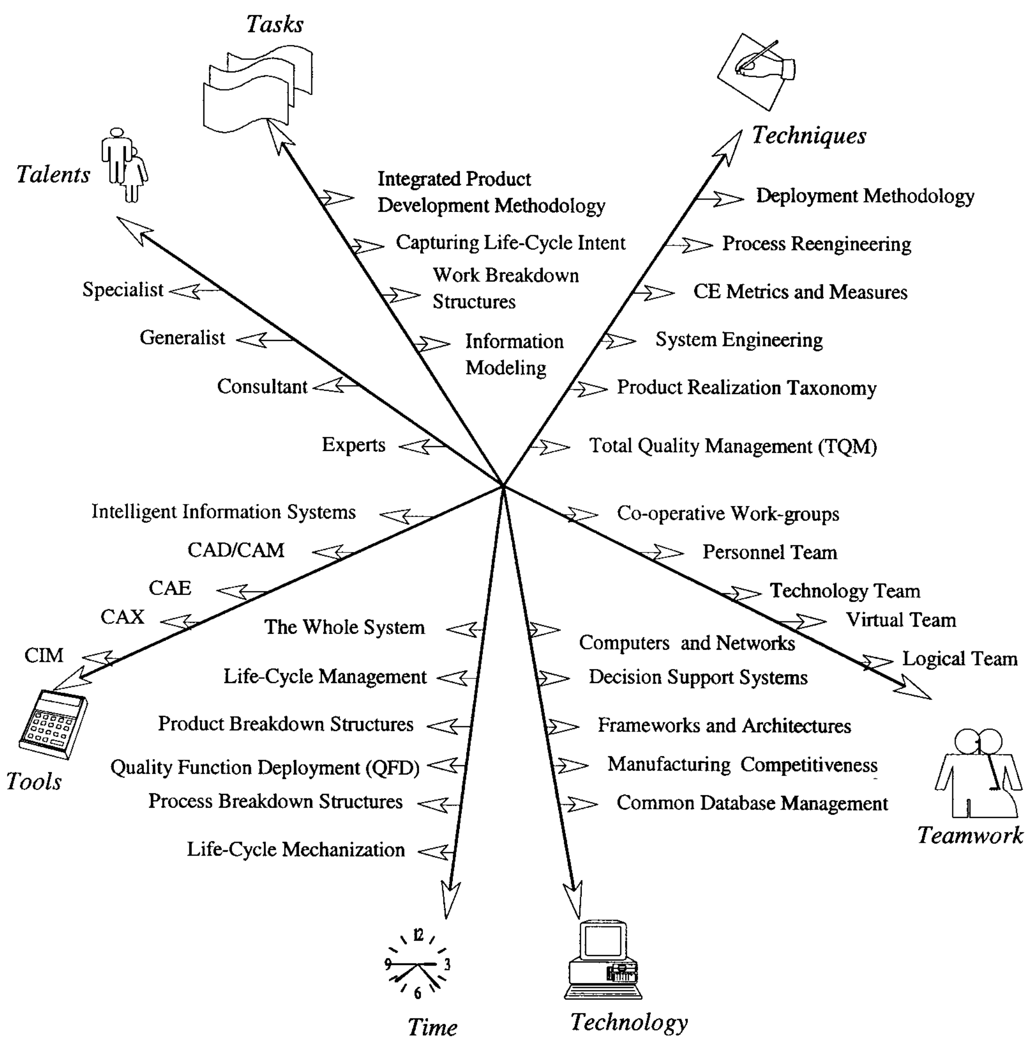

Figure 5 Relationship between CE enablers (7Ts) and the influencing agents

voice of the customer. The Kano Model, the requirements prioritization process and its integration into product strategic planning is a part of the CFD deployment. One of the requirements in developing world-class products is to keep the voice of the customers in focus. To accomplish this without a methodology or systematic process is a formidable task. We use CFD methodology to do the following:
  - Deploy the voice of the customer *throughout* each step of the PD^3 process,
  - Continue making the right decisions or setting priorities based on '*total value*' as we develop the product and
  - Reflect the voice of the customer in *every* part of the products or services that any workgroup provides.
- *Management style*: The major part of management style is encouraging employee involvement in the entire process. When management teams subscribe to the right management style they create a climate that supports employee involvement and aims at employee discretionary effort.
- *Culture*: Culture is deep-rooted. The general belief is that one cannot simply change a company's culture by just focusing on culture *per se*. It may be a formidable task to change culture, but it is not at all difficult to change the processes that created it. Set-based methods provide many such mechanisms to easily change the process. Taxonomy is a part of set-based methods. It shifts the pressure from the employees who are culturally traditional to a loop-based product-realization process that the workgroups need to follow. As highlighted in this paper, part of the change is an altering management style, another part is providing leadership by establishing a direction, enforcing standards, set-based methods, policy deployment goals, and an action plan.

Three Ps — Policies, Practices and Procedures

TVM — at a minimum — is an extension of TQM to the product-realization process, since its quality basis is rooted in TQM. The concept of TVM extends not only to other values of the product besides quality (such as design for X-ability (DFX), cost, responsiveness, agility, etc.), but also includes the knowledge contents of the TVM process — the 7Ts, 3Ps, and 4Ms that created the product in the first place such as infrastructure, internal and external customer satisfaction, workgroup cooperation, supplier rationaliztion, culture, etc. CFD operates best within a TVM environment since TVM fosters a favorable KM culture that provides harmony between customers, workgroups (employees), suppliers (vendors) and the business (stakeholders). TVM thus preserves the KM and TQM's philosophy — that the best way to expand sales and to increase profit potential (for the stakeholders) is to provide customer loyalty (Bhote, 1997b) through superb products and services (Bralla, 1996).

CONCURRENT PROCESS FOR TVM

A four-step concurrent process for TVM is shown in Figure 6. The knowledge management process for TVM consists of four steps:

(1) Reduce the variable
(2) Control the product
(3) Control the process and
(4) Control the operation.

Taguchi's five-stage process (Taguchi, 1987; Prasad, 1997) may be applied at each knowledge step of this four-step concurrent process. The types of activities that one can perform during each step are shown in Figure 6. Having applied this KM process to a current state, one is likely to achieve an increased probability for success (repeatability and consistency) and a significantly reduced margin of error. The following describes some measures to be used during TVM implementations.

Measuring Total Value

There are many ways to quantify or measure a value associated with an activity. It is, however, very difficult to define a single overall measure that is appropriate for all life-cycle considerations. In the evolving, highly competitive global marketplace, consistent customer satisfaction is essential for long-term survival. Competitive products, whether they are consumer goods or for the defense industry, largely depend upon satisfying customer expectations. Customer satisfaction is achieved not through a single act, but a coordinated array of KM actions, each contributing a useful and interesting dimension toward an artifact's overall performance. For example, the off and on-line methods of quality are a supplement to, but not a substitute for, sound engineering and manufacturing KM practices. Other contributors of customer satisfaction are attributed to efficiency gain and a reduction in the total resource require-

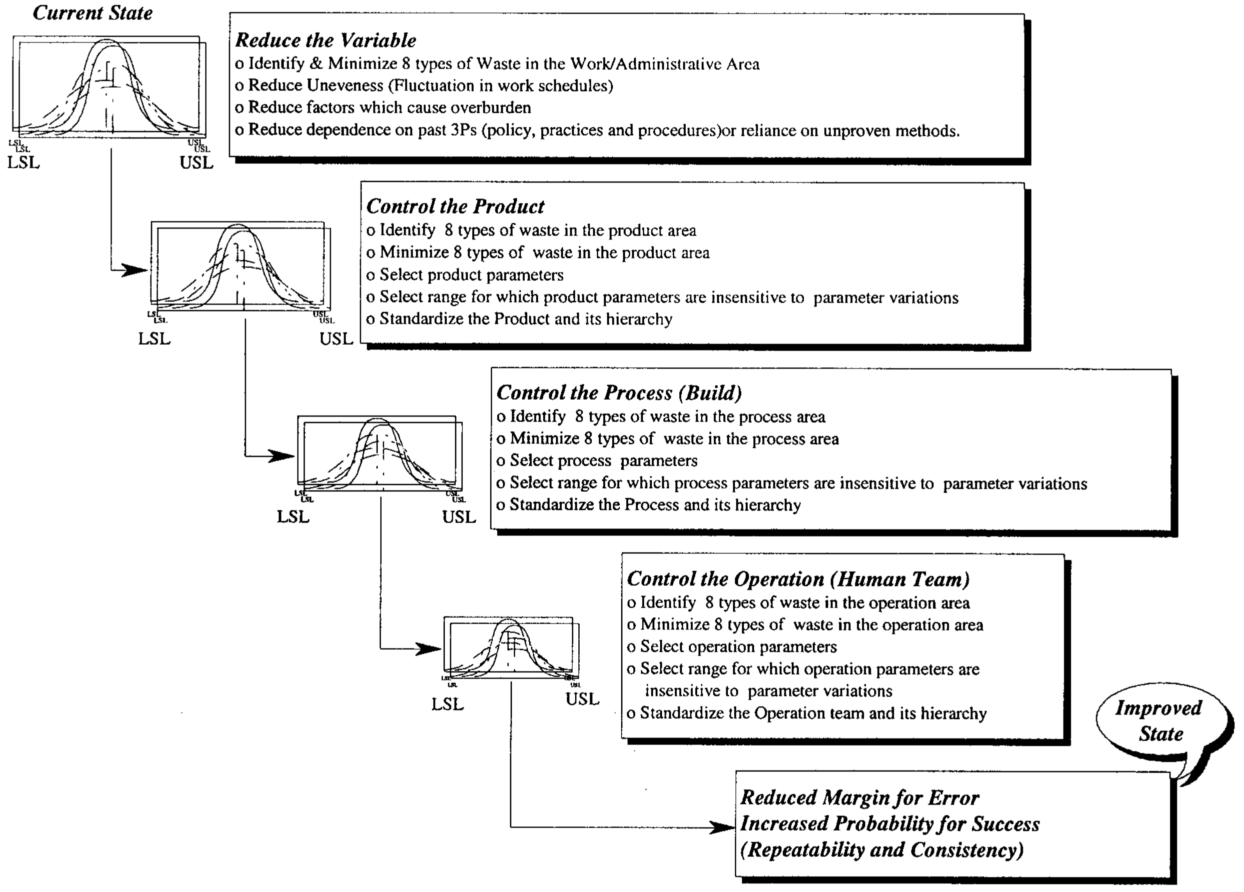

Figure 6 A four-step concurrent process for TVM

ments for the life-cycle support of the product. There is a difference between 'what is important to the customer' and 'what is considered important by the customer' for life-cycle support. For example, cost cutting may not be an important attribute to the customer but the end-cost of the product is. There are five measures of savings associated with value engineering:

(1) **Quality**: Quality to the customer means improved fits and clearances, no defective parts, reduced numbers of parts, improved quality and superb performance. What product manufacturers do to come up with a design and build parts that perform in a quality way has very little significance.
(2) **Functional worth**: Functional worth is a measure for defining the product's worth to the company and/or the customer. It measures the consumer utility in terms of functional-to-cost worth. Very often, functional worth is defined as the value per unit cost of the product. The savings due to functional worth is affected by work-in-progress (WIP) inventory, machine utilization, floor space, superior product design, finished goods inventory, materials overhead, etc. Benchmarking is a method for assigning values to the 3Ps (practices, procedures and policies), and processes associated with developing a product. One of the purposes of benchmarking is to increase a product's functional worth. Benchmarking is also used to:
   - measure the subject's part performance against that of the best-in-class companies
   - determine the best-in-class features or functions and
   - achieve best-in-class performance levels

   Many use information obtained from benchmark studies for setting their own company targets. Benchmark studies are also useful for strategic planning (to be used in QFD), determining product or process implementation plans, and performing value analysis/engineering.
(3) **End cost**: This defines a set of cost measures based on the end product's competitiveness.

Two common cost measures are:
(a) How much the product costs to deliver as compared to its predicted (and sometimes contracted) cost and
(b) How this cost compares to what the customer judges its fair market value to be.

Accurate cost estimation is neither essential nor feasible during the early design stages. For example, for early design improvement purposes, it may be enough to know which of the two alternatives leads to lower cost of production than their actual costs. It is, therefore, quite helpful to develop relative measures based on preliminary design descriptions that can predict the associated degree of X-ability. End-cost is affected by direct and indirect costs, assembly cost, part-fabrication cost, fixture cost, etc. The design options (such as design configurations, material properties, manufacturing processes) also affect costs. It is unnecessary to spend time and effort to obtain an accurate cost estimate for each design option in order to suggest a design change. It is more appropriate to identify relative cost drivers to predict improvements from among the possible design options. Early use of end-cost estimations can eliminate unwanted design changes commonly encountered in the later stages of product realization.

(4) **Time-to-market**: There are many definitions of time-to-market (TTM). Some consider TTM a measure of competitiveness, others a measure of customer satisfaction — how close this comes compared to the customer's realistic desires. TTM is the length of time it takes to deliver a product to the customer from the time the decision is made to launch it.

(5) **Active use**: Active use of product implies one of the following two situations: (a) what portion of the purchase price that is charged to the customer relates to maintaining the product in working condition, and (b) what percentage of time the product is available in such working condition for the customer's use as a function of the time it is kept in his or her possession.

Clearly, all these KM factors are focused directly on the customers' end cost, delivery, and usefulness of the manufactured product. They are not concerned with the details of how a company got there. Measurements involving effectiveness of the teaming concepts or of the cross-functional department interactions on product values are not evident. Such measurements are usually in the form of the number of engineering change orders, mean time between failures, remaining time for ramp-up to part production, etc. It does not make any difference to the customers whether engineering releases the design on time or not. The intermediate PD^3 process does not produce and capture happy customers. What most customers are interested in is getting the best-valued product at the lowest price. The best-valued product ensures a continuation of the company's current share in the marketplace. The other most common measure that is important to a company is through TVM importance ratings. This is discussed next.

TVM importance rating (TIR)

Let us assume a_k represents a candidate alternative in a set of alternatives A:

$$A = \{a_1, a_2, a_3, \cdots\cdots a_i, \cdots, a_n\} \quad (1)$$

and the q_j represents an associated quality characteristic element in a set of characteristics Q:

$$Q = \{q_1, q_2, q_3, \cdots, q_j, \cdots, q_m\} \quad (2)$$

Let us assume alternative set A contains most of the quality characteristics. Depending upon how the quality characteristics are incorporated in to the set A, ranking of the set A may be determined in several ways. Let us assume r_{ij} represents the rating for each a_i with respect to an attribute q_j.

If W is a weight vector consisting of weighting factors or preferences of the quality characteristic elements, where:

$$W = \{w_1, w_2, w_3, \cdots, w_j, \cdots, w_m\} \quad (3)$$

then a basis can be formed for determining the importance ranking of the candidate designs as follows:

$$(\mathrm{TIR}_i) \equiv \{w_j\} * [r_{ij}] \quad (4)$$

Note that the higher the TIR (TVM Importance Rating) value is, the better i^{th} design alternative it represents.

Normalized TVM Importance Rating (NTIR)

Normalized rating is similar to a weighted TVM importance rating. The numbers in the TIR are normalized such that none of the values exceed 1. NTIR is a relative measure of the quality of the alternatives with two extremes: 0 representing most unfavorable end of the spectrum and 1 the most favorable end. If NTIR is written as:

$$\mathrm{NTIR}_j = \mathrm{TIR}_j / \mathrm{RMS} \quad (5)$$

where RMS denotes Root Mean Square Value.

$$\mathrm{RMS} = \left[\sum_{j=1}^{m} \mathrm{TIR}_j^2 \right]^{1/2}$$

$$\mathrm{TIR} = \{t_1, t_2, t_3, \cdots, t_j, \cdots, t_m\} \tag{6}$$

where $[0 \le t_j \le 1]$. Instead of subjective ratings, quantitative rating r_{ij} can also be used.

There are several techniques of conceptually presenting the results. Prasad (1996, Chapter 7, Volume 1) describes several of these techniques. The Amoeba Chart (also referred to as a polygon graph or spider chart) is often used to represent these ratings in a compact form. The spider chart graphically displays multivariate scores of various characteristics radially along the circumference of a unit circle.

CONCLUSIONS

The first step in creating a great product is an understanding of what exactly makes a product great. Kim Clark defines a great product as one that meets all pertinent KM characteristics that are required to ensure product integrity (Wheelwright and Clark, 1992). Generally, development of a new artifact does include consideration of several life-cycle values that are pertinent to meeting the customers' and the company's requirements. Many of these values are independent, i.e. there is very little or no interaction between them. Through the course of investigations and study (Prasad, 1997), the author has found that the deployment of many artifact functions (values) can proceed in parallel with what we know today as '*Quality*' in the TQM sense. Since the quality basis of TQM is rooted in TVM, TVM provides at a minimum a useful application of TQM to product development and realization. Examples of other values rooted in TVM for product development (besides quality) are: X-ability (performance), tools and technology, cost, responsiveness, agility, and infrastructure. Generally, these functions or values are independently specified or estimated. The results of experience can be used to specify the requirements and expectation for each of the values in parallel without having to wait until a deployment of '*quality*' is complete.

TVM methodology offers a systematic way of developing a product from its inception to completion. TVM techniques can be applied at several steps during a product development process, such as Concept Development, Engineering, Piloting, Manufacturing and Product Support. Each product development stage ties together with the corresponding deployment (for example, QFD, CFD, SPC, OPC, etc.) and knowledge management planning tools. This results in the selection of the best application of design, process and production capabilities that is possible at each step. TVM supports this selection with sound numerical targets for quality, cost, weight, investment and process capability at each point in the product development process. TVM is based on the principles of concurrent engineering and employs cross-functional teams. It is a KM process for incrementally developing a product from art to part. At each step TVM simultaneously considers many of the parallel states of product development. As we move from step to step, the governing attributes are refined, while TVM deploys the corresponding state value functions leading the design to be the best. The staged deployments discussed in Prasad, (1997, Chapter 1) are a snapshot of what someone can view them to be the best-practice methods. It can aid a product development team with well-thought-out alternatives in support of the overall program. The best design should not only stand up to benchmarks of each step, but also be optimized for all value functions.

As concurrent teams become more experienced in utilizing the KM process, teams will naturally take less time to complete the steps. Since many of the key concerns or conflicts will be identified earlier, unexpected problems during production design and development will not occur. CE teams will be able to document a shortening of the overall PD^3 cycle using this TVM methodology.

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APPENDIX: NOMENCLATURE

3Ps: Policies, Practices and Procedures
4Ms: Methods, Models, Metrics and Measures
7Ts: Talents, Tasks, Teamwork, Techniques, Technology, Time, Tools
CE: Concurrent Engineering
CFD: Concurrent Function Deployment
CPI: Continuous Process Improvement
DFX: Design for X-Ability
EVOP: Factorial Evolutionary Operation

FMEA: Failure Modes and Effects Analysis
K-4: 'Kozokeikaku'
KBS: Knowledge-Based Systems
OPC: Operator's Process Contro
PD^3: Product Design, Development and Delivery
QFD: Quality Function Deployment
SPC: Statistical Process Control
TQM: Total Quality Management
TVM: Total Value Management
VDP: Vehicle Development Process
VOC: Voice of Customer
ZQC: Zero Quality Control

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