Towards balancing multiple competitiveness measures for improving business performance in manufacturing

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Abstract: Today, companies are facing tremendous challenges of how to provide the agility that came from 'craft manufacturing' with the cost benefits that were the results of 'mass production.' 'Concurrent Engineering,' coupled with automation efforts, is becoming vital in maintaining a competitive posture in today's marketplace. Competitiveness in this context represents a system's total performance. It is important to note that the performance of an organizational unit is governed largely by the system in which it is contained. It would be a worthless exercise to improve the business performance of a local unit without changing the entire system, if units were interdependent. Business performance is an effective measure of how inputs (people, materials, means, etc.) are utilized in a certain period (measured in terms of operating expenses), in order to realize certain useful outputs in this period. The paper proposes a method for finding a cumulative balancing index for optimising a company's total competitiveness position based on the following eight independently measured factors:

- overall productivity
- time-to-market
- customer satisfaction
- cost-of-quality
- profitability
- inventory
- quality
- unscheduled changes.

Keywords: Balancing manufacturing competitiveness; cost-to-quality; customer satisfaction; time-to-market; business performance; effectiveness; performance efficiency; inventory; unscheduled changes; measures of merits.

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1 Introduction

In an effort to reduce time to market, foster teamwork, cut costs and eliminate late engineering changes [1], managers in many organizations are trying to 'redefine' the role of an employee in the context of a new paradigm. This new paradigm is characterized by recognizing the importance and real value of an employee as part of a cooperative work environment supporting concurrent functionality and by horizontal and vertical integration within the enterprise. It is also characterized by 'empowerment,' or pushing decision making to the lowest ranks, with emphasis on well-rounded experience and expertise. Other items include improving the 'process' (e.g., benchmarking, continuous process improvements, process restructuring, process renovation and process reengineering [2]), considerations of both long-range and short-range goals and a total customer-focus [3]. Today, we are witnessing the demise of the 'control age' and the dawn of a 'flexibility era' - translating into a new breed of customized products. Consumers want finished goods tailored to international (English versus Metric measurement standards; left-handed drive versus right-handed drive automobile vehicle regulations), national (emission requirements, etc.), regional, ethnic and personal tastes. For manufacturers that means producing a great mix of product options at low volumes. The catch is that today's customers want the product features of 'skill-based manufacturing' at the speed, quality and cost of 'information-based mass production.' The factors that demand a significant change in our overall approach to design and manufacturing are [4]:

- Rapid proliferation in the number and variety of products that we manufacture today
- Increasing dependency of product performance on manufacturing process capabilities
- Customer demands for improved quality and better product performance
- Dependence of cost on labour rates resulting from choice of plants to manufacture the product and their locations

- Demand for stronger and lighter materials
- Competitors steadily shortening their time to market
- Availability of World Class quality products at competitive prices in the world market
- Customer demand for producing the part right the first time and every time thereafter
- Declining cost of computing hardware versus the power it offers
- Rising costs of software development versus the hardware costs.

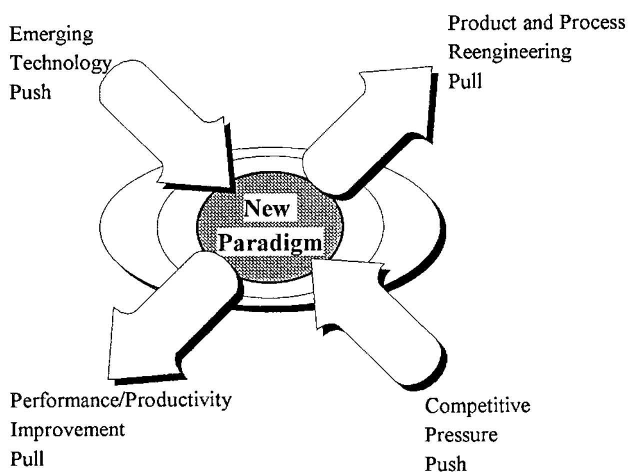
2 Push and pull for new paradigms

Figure 1 describes some of the various ways in which new technology can impact on an organization.

There are two aspects to new paradigms: push and pull. 'Push' is where a new technology or a concept is substituted for or inserted into a new or existing product. 'Pull' is where customers demand an improved product or process irrespective of the current state of technology utilization. The triggering of a pull, from an improved product or process standpoint, happens only when the existing technology is not adequate or at its best. Not at its best means the technology as it is, fails to provide the expected market shares, quality targets, or profit margins. In the 'pull' case, needed productivity can be gained through means other than switching to a new technology. Figure 1 summarizes these pull and push factors into four broad-based categories:

- Competitive pressure push
- Emerging technology push
- Productivity improvement pull and
- Process reengineering pull.

Figure 1 Push and pull for a new paradigm



The push type of technology is easier to be copied by a competitor. There are two primary forces driving the technology push: a decrease in cost of automation tools and an increase in availability of automation technology through third parties. In US industries, during 1993-94, more than 30 million reported that they used computers at work! About five years ago, the computer industry and technology were still expanding at a rapid rate. At that time the 286 CPU computer was considered the standard PC in the workplace and in schools. Everyone thought it was very reasonable and it was accepted widely. So that paradigm was set in the customers' minds. Anything less than Intel 286, such as Intel 186 or 88/87, was considered slow or undesirable. Since then, faster computers with new CPUs have been introduced into the market, which means that today customers have new paradigms. A 286/386 computer is considered obsolete and is no longer desirable by almost anyone. In the customer's eyes, the Pentium computer is the new standard (paradigm) (see Table 1).

Table 1 Paradigm shift due to new technology

Paradigm Shift	*A*	*B*	*C*	*D*
Type of CPU/Chips	Intel 286	Intel 386	Intel 486	Pentium
Year of Introduction	1984-85	1988-89	1991-92	1994-95

2.1 Competitive pressure push

Organizational pressure is created by the 'globalisation' of manufacturing and inadequate power of the company to provide a formidable competitive response. A competitive response is the organizational ability to produce a competitive product that ranks equal, or surpasses, quality, speed, cost and similar attributes important to the customers or to the company [1]. For a long time Switzerland was the world leader in precision watches. They had the best craftspeople in the watch industry and skilled employees for making mechanical watches. Switzerland then owned most of the world market in precision watches. When the invention of the quartz watch came into being, the Swiss did not take it seriously - they more or less ignored this new paradigm (discovery and technology) and did not invest in it. Quartz technology was then brought over to Japan and the Japanese decided to invest in it. When Japanese quartz watches came onto the market and competed against the Swiss mechanical watch, the Swiss could not compete with the Japanese. Now, quartz watches are much more popular everywhere and easily affordable and cost less than five US dollars. Japan still owns most of the world's market share in watches today.

Today, customers 'expect the same level' of satisfaction and perfection that initially came from craft manufacturing but 'want to pay' a price achievable only by mass production. Customers want the best of both worlds – 'features' such as - attention to detail and 'quality' that come from craft manufacturing and 'low cost' and 'consistency' that come from mass production. Though the underlying process and teamwork used in 'craft manufacturing' represented a miniature 'replica' of what was desirable for a 'customer-focused' organization, it lacked the 'recipe' for a successful company. The main question is how one would be able to provide customer satisfaction on a 'recurrent basis' if the technology and organization kept on changing. Chain competition has driven engineers to include terms such as time compression, total quality management, teamwork, quality function deployment and *Taguchi* into their vocabulary [5]. 'Concurrent engineering,' coupled with automation efforts, is vital in maintaining a competitive posture in today's market-place. Despite recent advances in computational and communication technology, it is still not an easy task to win competitiveness effectively. Despite all of the above efforts applied in the USA, foreign organizations appear to be gaining ground from the consumers' viewpoint. The 'change' in external conditions adds new competitive pressure to decrease time further and lower costs. Today, companies are facing tremendous challenges of - how to provide the agility that came from 'craft manufacturing' with the cost benefits that were the results of 'mass production.'

2.2 Emerging technology push

Technology is also changing; more and more vendors are opting for 'open' architectures, 'common' window-like user interfaces and 'plug-in' application interfaces. There is a great temptation to use advanced information technology to support widely 'altered' organization forms. The truth is that technology only enables CE, it does not create it. New technologies will continue to emerge. The changes in market conditions are driving the use of emerging technology, which in turn is driven by the changing processes it has to support. The two constantly interact, each pushing the other to an ever-higher limit. Nike used athletic shoe pump technology to break into the medical equipment market. Group technology, for example, is forcing new ways of doing design engineering. In group technology, features common to many parts of a product are identified and classified in groups. This practice not only saves in process planning time for machining but a number of parts can be machined in a batch mode. Another case in point is that of an integrated system. In the mid 1980s, an integrated computer-aided design/computer-aided manufacturing/computer-aided engineering (CAD/CAM/CAE) system was considered to be an ideal choice, but not any more. Many organizations, large and small, are adopting a 'lease and integrate' (open system) philosophy rather than a 'buying a bundled (closed)' system. There are several other factors for this technology push, as described below.

2.2.1 Design technology

Recently, some of the newer generation CAD/CAM packages like Concentra/ICAD, Parametric Technology's Pro/Engineer, SDRC's I-DEAS Master Series, CADDS 5, I/EMS, Anvil-5000, Intellicorp/Pro-Kappa, are adding some form of variable-driven modelling and design functions to their systems, as opposed to the pure explicit modelling system used in the past. For example, most of these systems now have the capacity to constrain the shape using parameters (or variable dimensions) or geometric relationships between the elements, such as parallelism, perpendicularity, or tangency. Some have the capability to record the interactive manual steps into a batch script file. Later, this script can be replayed when master values are changed. Many now have some high level programming capabilities to manipulate geometry. They do not just provide the ability to capture the geometry of the design as in conventional CAD/CAM systems, but also include various variable-driven features and positioning relationships of their parts to each other. Compared to a few years ago, interactive design technology is now here to stay and the products we see in the market-place have a lot to offer. The market-place is getting more and more competitive. Popular CAD/CAM products such as EDS/Unigraphics, Catia Solutions and HP PE/SolidDesigner, have now many built-in design linking and modification facilities which are changing the way CAD/CAMs are now applied to product design. Earlier, during modelling of parts, 'explicit' values were independently assigned. Primitives were positioned using specific coordinate and spatial orientations. If product information was changed, users did not have much option except to recreate the design from the beginning. This is not true with some of the newer generations of CAD/CAM systems. Now we can link 2-D part's dimensions (coordinates and spatial orientations) with 3-D 'master and slave' modes. Engineers can use simple shapes, developed with parametrically-driven 2-D profiles, to build 3-D solid primitives. Appropriate 'mating' constraints and relationships can be defined as a part of a product database. Three-dimensional solid parts can be recreated by altering the 2-D shapes through its 2-D profile parameters. This eliminates many time-consuming manual steps such as 'record and play-back.' Variable-modelling is quite useful if products have 'similar' parts or features such as 'family of parts.' Besides product design, there are other areas where such 'variable-driven' techniques are being applied:

- Product and Part Geometry Creation
- Library of Parts
- Preliminary Design
- Detail Design
- Design/Build Automation
- Product and Process Costing Structure
- Process Planning
- Numerical Control
- Engineering Modelling and Computation
- Generic or Regenerative Modelling
- Operation Analysis/Simulation
- Finite Element Analysis
- Assembly Engineering
- Cost Estimation
- Market Trends Analysis

The ability to 'network' and gather information from around the globe has led to increasingly effective configuration management system (CMS). Due to many of the above reasons, version control or multiple teams or user's access are not considered a major chore. With careful 'variable-driven' modelling and CMS, practically any user—in fact, anyone in the 'entire' organization—can access data from 'any' system, network, or application 'simultaneously.' The result is the ability for the teams to make better and more time-critical decisions.

2.3 Productivity improvement pull

In most design and manufacturing organizations today, there is often a great disparity in the use of computer tools. The software and hardware they have acquired over the years can at best be described as firmwares - 'stand-alone compute islands.' There are pockets in the organizations that are quite traditional – 'firmware-like,' while some other parts are maths-based. The levels of integration across departments are very poor. Usually the problem is more severe with bigger organizations, since, over time, the needs of the work groups have been different. Considering the project needs and the work group's familiarity with requisite tools, companies have acquired a multitude of 'firmwares' that do not communicate with each other. Smaller organizations are lucky not to be constrained by such problems of size. Often they cannot afford a variety of software and hardware systems and thus tend to be more integrated in their approach. Apart from the degree of integration, both types of organizations do, however, encounter the following basic challenges:

- *Computers*: organizations have a multitude of workstations, personal computers, both mini- and mainframes, all of different makes and models acquired over time.
- *Applications and Tools*: they work well when used alone but present a lot of problems when they are required to work together. Perhaps the biggest and most common problem someone experiences is in making an analysis program, such as Finite Element Analysis (FEA), an integral part of a CAD system. Most name brand CAD systems can interface with an FEA program, but CAD and FEA models (geometry-wise) are not interchangeable. It thus presents a problem for the designers when they want to modify the geometry of the CAD design based on results of FEA.
- *Analysis Tools*: a variety of analysis tools exists - some are commercial tools, others are home-grown (developed in-house).
- *Synthesis Tools*: the workers have developed programs for solving specific product design problems, a large percentage of which are home-grown (in-house developed) and proprietary.
- *CAD/CAM Applications*: CAD/CAM applications are vendor supported - bigger organizations have a variety of CAD/CAM systems depending upon the particular inclinations of a group or a department.
- *Office Automation Tools*: office automation tools such as word processors and spreadsheets are most diverse and loose.
- *Productivity Tools:* tools such as these required to solve engineering and manufacturing problems, e.g., equations solvers, matrix analysis tools, etc., are group dependent and are not well maintained.
- *Files and Data*: many kinds of files, such as geometric models, analysis results, NC tools and process plans, generated by their parent applications are scattered around on a number of computing platforms and are stored in a variety of formats: vector, raster, or text.

The technological race has created a dilemma for the users of such (computer-based) products. Due to the rapidly declining useful life of such products, technological obsolescence is becoming a major setback. Moving to the new technological solution is not always the right answer. Though this may improve the potential loss in productivity of the workforce, prior investments in technical memory and knowledge stored in old formats (legacy database) cannot be discarded completely.

2.4 Product and process reengineering pull

In the midst of all of this, management focus and organization structure are changing. Many organizations are aligning themselves along the lines of Strategic Business Units (SBUs). Many competitive multi-tiered initiatives have rippled through the organization: just-in-time, quality function deployment, supplier involvement, employee empowerment, ISO 9000, quality circles, six-sigma program, continuous process improvements, cross-functional teams, process management and control, etc. [5]. The walls between engineering and manufacturing groups are crumbling. The computational tools that have been developed to perfection over the years work well with each specialized unit. This is because they are designed for independent departments. Coercing these tools to fit into the changing organizational structure does not meet enterprise needs. It creates a backlash of many problems, such as production delays and communication bottlenecks. There appears to be a growing technological imbalance among the activities of a production cycle.

In conjunction with technological push, many companies are introducing reengineering. Reengineering means evaluating a company's current product, process methods and manufacturing practices, documenting what is successful and recognizing wasteful and inefficient practices. It also means weeding out the non-value added activities and pulling in what are the right things to do. Blindly following automation is not always the right way to enhance productivity. If we do not reengineer the process correctly, there is a danger that one might simply automate their wasteful processes and make the same old mistakes only more quickly this time. Reengineering team should be clearly represented in any PDTs just as sales, manufacturing, engineering and others are.

3 Areas of manufacturing competitiveness

A basic premise of manufacturing refers to the best transformation of customer expectations and requirements into useful products and services (Figure 2). Alternatively, the identification of the best manufacturing transformation process is that which produces satisfied customers recurrently. A large number of companies across Europe, the USA and Japan were recently studied [6], with the focus on manufacturing strategies and competitive priorities. It was observed that Western countries lead the world in product innovation but do a poor job when it comes down to implementation. Manufacturers who used to be able to differentiate between themselves because of a lock on raw materials, technical knowledge, capital, process superiority or innovation, have found that manufacturing is a vulnerable market. Technology by itself cannot create long-lasting competitive advantage. The relative affinities among push and pull elements are shown in Figure 3. If the push for emerging technology is high, the pull for product and process engineering is usually low. Similarly, high competitive pressure is created due to low performance or productivity improvement level or status. If the performance or productivity level of a company is high, there is less of an urge towards an emerging technology push. However, this should not stop a manufacturer from striving to push product and process reengineering even if competitive pressure is low. Manufacturers are constantly 'watching' their competitors. When products come to market, forward thinking manufacturers always compare and frequently 'benchmark' their products with other manufacturers to remain competitive. It is not very difficult to duplicate the 'visible features' or even improve some of their salient characteristics. The competitive edge, in such cases, is usually short lived. For example, when IBM first introduced its 80286 chip based PC, in good faith, it openly published the interface specifications and directory. Soon, its market share was reduced by a multitude of 'clone' manufacturers. Since IBM did not hold a patent on the integral specifications or the chip, it could not prevent its competitors from copying the functions of its PC ATs. IBM had to price its PCs higher than its competitors to cover its R&D costs. The 'clone' market operated on narrow profit margins with low overheads and undercut IBM's price. In the absence of an exclusive right on the 'integral system-wide specifications' of the PCs, functions were easily copied.

Figure 2 Basic premise of manufacturing

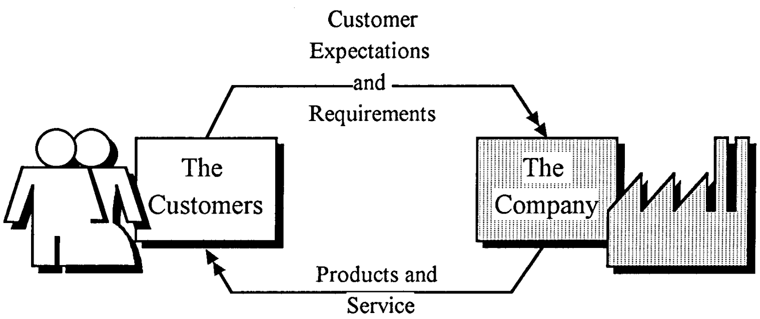
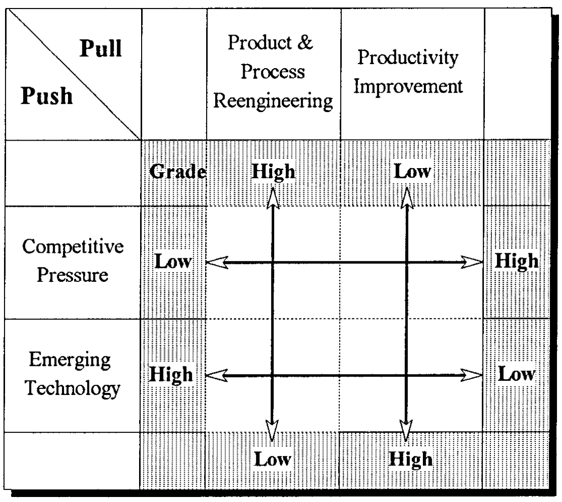


Figure 3 Relative affinities among push and pull elements



In principle, however, what is difficult to duplicate is how the technology is 'deployed into one's process.' This may include deployment of product in terms of management techniques, organizational culture and goals. Therefore manufacturers should continue to focus on the most efficient 'way of producing' the product (achieving efficient product realization). The improvements made through deployment of technology and subsequent product and 'process reengineering' can provide a real competitive advantage. The need for process reengineering is even more pronounced when different manufacturers produce similar products. Engineering schools and researchers tend to ignore the process reengineering factors and look exclusively at the visible technological solutions (e.g., CAD, CAM, CAE, computer-integrated manufacturing (CIM), computer-aided X-ing (CAX), etc.). Industrial researchers, on the other hand, think of computers and all off-the-shelf tools as 'commodities' that anyone can buy and use. Most truly successful companies (both in the USA and Japan) believe that process management techniques are the product of decades of 'corporate learning' that others cannot easily buy or copy. The Japanese seem to be far ahead in mastering the technology and structuring it to fit their unique environments. Two significant technological innovations are product innovation and process innovation. From 1955 to 1990, Japan's real gross domestic product increased almost nine times, output of manufacturing in monetary value increased 17 times and the added value of this industrial sector increased 21 times [7]. Labour productivity in manufacturing increased over the same years at an average of 6.8% annually. Coming to terms with the Japanese market was one of the challenges Americans and Europeans had to meet to narrow the competitive gap. The only thing competitors cannot buy is someone else's unique process or someone else's unique organizational culture. This can be a blessing in disguise or a curse depending upon how one looks at it. For most US automotive industries, the production process is deeply rooted in the way teams design and manufacture their products - thus inflexible, while the Japanese seem to have a better handle on it. With regard to culture, Americans seem to be more open minded than the Japanese - thus controversial, while Japanese strong cultural ties facilitate better collaboration and teamwork. Americans, thus, seem to fall short at both ends. Japanese industry has practised CE for a long time without naming it. This was the conclusion of a recent study done in Europe, when Hartley and Mortimer [8] compare the time to market of the Japanese with European automotive manufacturers. Based on the 11 projects they studied, they discovered that Japanese companies could develop and introduce a new car to market 20 months faster than European companies. The two studies have also shown some subtle differences in the way an enterprise looks at its processes. Europeans still focus on quality improvements and operational efficiency during the process of manufacturing. The Japanese seem to focus on flexibility while continuing improvements in quality, dependability, cost and productivity. To the Japanese, flexibility in manufacturing means the rapid and efficient process of introducing changes in production volumes and product mix [9]. In the field of manufacturing, the Japanese focus on a process of rapid development of new products is aimed at becoming innovators of new process technologies. Those local to the Toyota factory in Japan can receive their car built to their specification within a few days of placing the order. Achieving perfection in process flexibility did not come without pain even for the Japanese. Such process flexibility cannot just be attributed to an edge in technologies. It has been observed [10] that the success of the Japanese was largely due to practising socially appropriate production, supremacy in process management and continuous refinements. They seem to understand fully and internalise among workers the tasks of transitioning product and process innovations into commercial success. They train their employees amply in techniques of implementing innovations, spend enough time early on, work diligently on uncovering 'how-to' problems of commercialising their technical success. Examples are the well-known *Kanban* system of production control, *Kaizen* (continuous improvements), the *Taguchi* method of quality control, market-oriented manufacturing, etc.

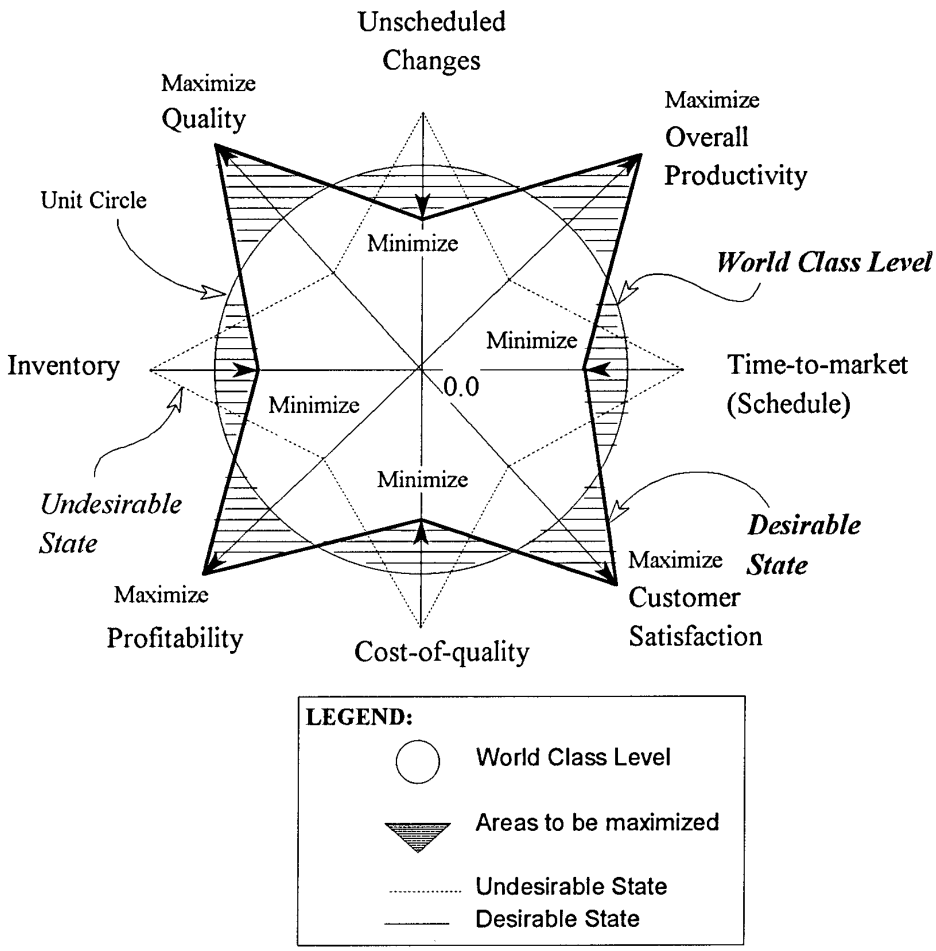
The recognized decline in the productivity of many US companies has been a strong stimulant to search for ways to improve their operational efficiency and become more competitive in the world market-place. Many have changed their attitudes towards customers, their production processes and their internal management approaches; whereas others still continue to search for the reasons for their demise. Successful companies have been the ones who have gained a better focus on eliminating waste, normally sneaked into their products, by understanding what drives product and process costs and how value can be added. They have focused on product and process delivery systems - how to transition process innovations into technical success and how to leverage the implementation know-how into big commercial success. They have chosen to emphasize high-quality production in product delivery rather than high-volume production. With increasingly pervasive global competition, engineering excellence is becoming as fundamental a competitive weapon as manufacturing excellence. Significantly, what we are seeing is the completion of a definition of what it takes to be a World-Class Manufacturing (WCM) company.

4 Measures of competitiveness

Figure 4 shows a list of eight indicators that determine the performance of enterprise competitiveness. Each indicator provides a measure of a company's efficiency in the world market-place. Each indicator is shown by a directed radial line pointing away from the centre of a unit circle. A point on the unit circle represents world class level for an indicator. Such points represent a normalized or scaled value of 1.0. A point at the centre of the circle usually represents a value 100% out of range from the world class. A point along a radial line inside the circle, thus, ranges from a value of 0 (at the centre) to 1 (on the circle). A point outside the circle ranges from 1 (on the circle) to any positive number, depending upon its distance away from the centre. The desirable state depends upon whether a performance indicator is to be maximized or minimized. The desirable state is outward of the circle (pointing away from the centre), if a performance indicator is to be maximized. The desirable state is inward of the circle (pointing towards the centre), if a performance indicator is to be minimized. For instance, a point 1 unit out from centre may represent a level 'twice' as good or bad from the 'world-class' level. Depending upon whether the performance is to be minimized or maximized the corresponding arrow is shown pointing inside or outside the circle. It may be noted that there are four indicators that need to be maximized and four that need to be minimized. They are placed alternately around this unit circle. The solid line shows the current state (Figure 4). The shaded petals are formed due to the lines drawn connecting these max- and min- points and the unit circle representing the 'world-class.' Clearly, the shaded petals represent the net contribution from each performance indicator. In order that the current state of the process must perform better than, or equal to, the world class, the following must be true:

Sum of the Petals Areas ≥ 0.0 (1)

Figure 4 Performance indicators for measuring an enterprise's competitiveness



The overall performance must show a net profit at the current conditions with or without the new product development or technology insertion. The objective is to move the four indicators away from the centre and four towards the centre as much as possible. In other words, the objective is to maximize the petal areas created due to the intersection of the straight lines and the circles. Performance in this context represents the system's performance. It is important to note that performance of an organizational unit is governed largely by the system in which it is contained. It would be a worthless exercise to improve the performance of a local unit without changing the entire system, if units were interdependent. New accounting measures (such as Activity-based-costing (ABC) and Goldbratt's theory) are helpful in obtaining the system's performance.

Overall Productivity (gain or loss): Overall Productivity means cumulative gain or loss. A higher level of productivity in one specific department or discipline is not a good measure. Productivity means creating concepts that positively impact on the whole system - both the upstream and the downstream operations. The overall productivity is defined as the ratio of the throughput (T), to the operating expenses (OE). The point to note here, contrary to what is generally understood, is that productivity is not a simple ratio of the outputs to the inputs. Throughput in this context is defined as useful outputs (that customers can use) - end product or services completed in a given period of time. In other words, scrap or waste is not a measure of productivity.

$$\text{Productivity (P)} = T/\,OE; \tag{2}$$

Thus, productivity entails the effective measure of how inputs (people, materials, means, etc.) are utilized in a certain period (measured in terms of operating expenses), in order to realize certain useful outputs in this period. All outputs are not throughput, some outputs (for example, scraps, defects, etc.) are waste. The throughput is defined as follows:

$$T = \sum_{i=1}^{N_o} [\, P_i * N_i * Pv_i \,] \tag{3}$$

Where, P_i is the proportion of acceptable outputs (which are non-defective) of variant i,

Ni is the total number of outputs produced of variant i and

Pv_i is the production (or throughput) value per acceptable output i.

N_o is the number of outputs (say number of assembly variants).

For convenience sake, defective outputs (or scrap assemblies) are assumed to have no production (or salvage) value, since they cannot be sold to the market as they are. Successful manufacturers are those who measure the difference between outputs and throughput, identify the possible source of such discrepancies and take counter measures to prevent them at source.

- *Customer Satisfaction*: one of the purposes of developing the product is to achieve satisfied customers recurrently. Customer satisfaction means meeting the customers' needs, at the right time and with the quantity, price and performance they want. The cornerstone of these performance measures is the customer. Of course, if the customer does not want to buy a product, improvements in cost, weight and investment do not really matter. At the same time, if the customer becomes disappointed with the workmanship of the product or encounters problems over its life, he or she will not buy it again. The key to understanding customer satisfaction is the recognition that there are two basic types of activities: support and value-added. While support activities are necessary for internal planning and control, they consume the team's effort and time but they do not provide direct benefit to the ultimate customer. Value-added features or services are pleasant surprises to the customers.

- *Unscheduled Changes*: the success of rapid product realization depends upon the team's ability to handle unscheduled changes. Unscheduled changes occur in many ways: some are avoidable, some are not. Avoidable changes are typical of products thrown over the wall before they were ready for manufacturing. Once the parts are sent back to the originating team, unscheduled changes have to be squeezed in between work. Unavoidable changes occur when circumstances change, people move and the steps are no longer valid. Unwanted changes are caused by changes in product lines, product functionality, technology, etc. Though a number is an important measure, unscheduled changes can be very serious. For example, if errors are detected late in the process (say during a downstream operation), it might be very costly to fix them.

- *Inventory* (I): inventory includes all assets including property, plant and equipment, but excluding value-added parts. The new definition, broadly stated, includes any item that the company could sell, not just the finished products. By including capital assets in the inventory category, teams are forced to focus on the way they are utilizing all of the investments under their control. The finished inventory is the amount the retailer must keep in stock. This amount is equal to the average demand over the order ship time plus a safety factor based on the standard deviation of demand over the order ship time.

  If n is the average demand for one day,

  Sigma (σ) is the standard deviation for a day's demand and

  d is the order ship time in days, the required inventory is:

  $$\text{Inventory} = [n\, d + (3\sqrt{d})*\sigma] \qquad (4)$$

- *Cost of Quality*: knowing how much quality costs and the way the cost is made up can provide a strong impetus for management to set off on the quality improvement trail. There are two contributory elements that affect the cost of quality:

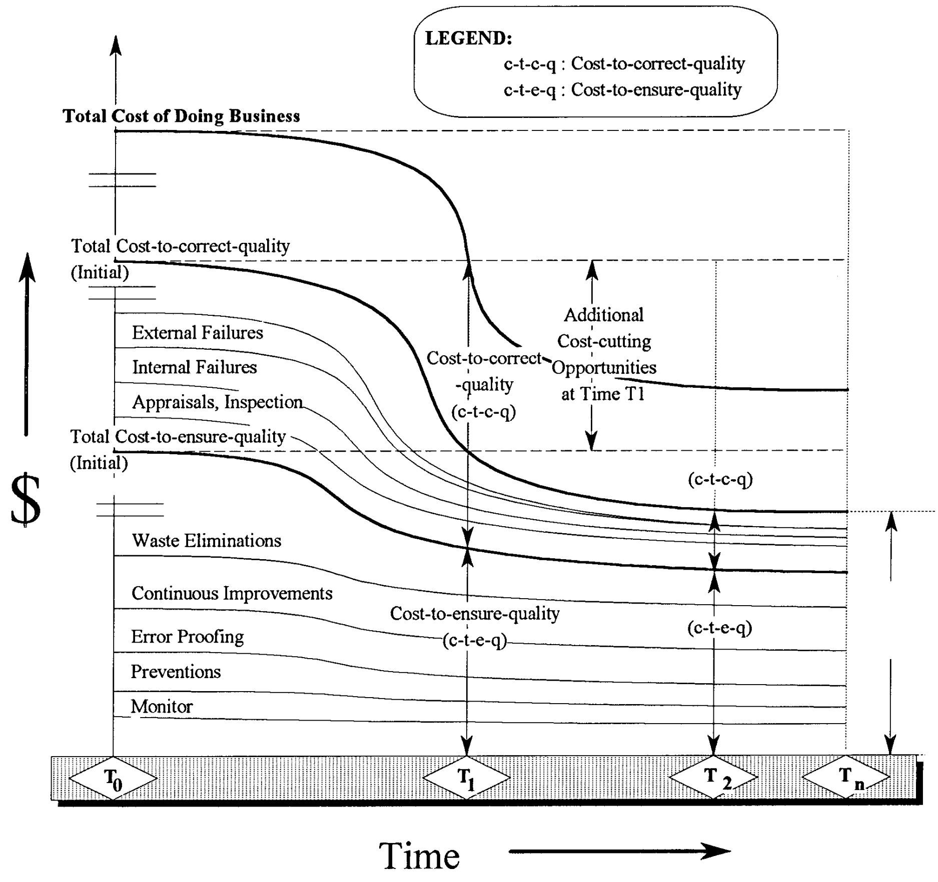
  1 cost to ensure quality (c-t-e-q) and

  2 cost to correct quality (c-t-c-q).

  They are shown in Figure 5. Cost to ensure quality is the cost of doing things correctly (for example, choosing the right process), the cost of doing the right things (for example, choosing the right actions) and the cost of preventing mistakes (such as anticipating problems). Prevention costs are the expenditures on activities whose objective is to prevent the occurrence of failures. They are designed to ensure or build quality during designing, implementing and manufacturing products and services. Typical examples include the cost of training, establishing procedures, insurance, preventive or contract maintenance, planning activities and analyses of performance data, surveillance, etc. The cost to correct quality is the cost incurred because of doing things wrongly (for example, choosing the wrong process), the cost of doing wrong things (e.g., choosing wrong actions) and the cost of inspections to discover mistakes committed earlier. Cost-to-correct-quality falls into two categories:

- *Appraisals* are the costs associated with activities like checking, evaluating, inspecting and measuring work, supplier monitoring, appraising performance and conducting audits on work done to assure ‘conformance to quality requirements.’ The conformance shows whether work has been performed according to the required specifications or standards. Other types of cost-to-correct-quality are internal and external failures.
- *Internal (or external) failures* are the costs incurred by failing to perform work correctly the first time. They are often associated with a product or service that does not meet the quality requirements (such as building codes) prior to transfer (or after transfer) to the customer. Costs of failures include: the disposal or correction of incorrect work, scrap or excess stock, time spent on rework, bad debts, waiting for work, and dealing with complaints from customers.

Figure 5 Cost cutting opportunities through prevention (measurement to cost-to-quality)



Most cited product quality indicators attempt to measure the parts per million (PPM) level of conformance. This does not, however, account for criticality - for example a one dollar part failure may result in a thousand dollar part failure if one part is encapsulated into another. Another measure of overall effectiveness is to track the cost of quality (c-t-q), both ‘cost-to-correct-quality’ and ‘cost-to-ensure-quality.’

C-t-q Effectiveness == [{cost-to-ensure-quality} / {cost-to-quality}] *100 (5)

Where, cost-to-quality is the sum of two parts.

Cost-of-quality = ‘cost-to-correct-quality’ + ‘cost-to-ensure-quality’ (6)

or c-t-q = c-t-c-q + c-t-e-q

If the c-t-q effectiveness number is close to 100, the company is doing things more right than wrong. The effectiveness number thus provides an analytical basis for decision making or to track quality improvement opportunities.

- *Profitability (ROI)*: the return on investment (ROI) is defined as the ratio of gain (G) minus the operating expenses (OE) to inventory costs (I), that is:

  ROI = [{G-OE}/ {I}] (7)

Where gain (G) is defined as

Gain (G) = Net Sales – Cost of Raw Materials (8)

where, Net Sales (or volumes) are defined as the irreversible transfer of the product to the consumer. Such a definition of sales does not allow the transfer of goods in a consignment from a manufacturer to a dealer to be counted as a sale. OE is computed using all normal operating expenses plus direct labour and factory overheads. By grouping direct labour and factory overheads in an OE category, there is little reason for teams to over-build their inventory. Direct labour is recognized as a fixed cost.

- *Time-to-market*: this is a measure of the time period required to design and develop a marketable product (from concept through to rate production).

Some of these indicators might be contradictory. For example, a quality-based focus drives costs down and time up, whereas a time-based focus drives costs down and quality up. Additional performance indicators being used are in the areas of delivery, risk management and teamwork communication. Figure 6 shows the productivity and quality rankings comparison for 1988 and 1989 Years for a number of US and Japanese automobile manufacturers. The comparison for the next five years (up to 1994) for only the Big Three manufacturers are contained in Table 2. They are based on a recent competitive report by McElroy [11].

Quality: the quality rating is based on number of quality problems or defects per 100 vehicles. So the lower the number, the better the performance. There has been a significant gain in quality for American Automobile in the last few years. Ford’s quality performance is very impressive. Not only did the company show an improvement in the last year, it was a significant improvement. In fact, the company outperformed the industry average and broke through the 100 defects per 100 vehicles barrier. That is a first for any of the USA’s Big Three [11]. GM’s quality rating deteriorated by 3.7% and Chrysler’s quality rating deteriorated by 7.5%.

Figure 6 Productivity and quality ranking for automobile manufacturers

Company	Vehicles/ Employee Per Year*	Quality Problems Per 100 Cars**
Suzuki	70.4	--
Toyota	61.0	117
Daihatsu	57.0	--
Honda	56.2	112
Mitsubishi	50.4	--
Mazda	42.0	133
Isuzu	41.7	--
Nissan	39.5	111
Fuji (Suburu)	38.7	--
Ford	20.0	149
Chrysler	18.0	176
Peugeot	13.3	--
General Motors	12.5	169
Volkswagen	11.2	--

Source *Automotive Industries, Vol. 169, No. 4 (April) 1989.
**J.D. Power and Associates, 1989 New Car Initial Quality Survey

Profit-per-unit: the profit-per-unit shown in Table 2 is based on dividing automotive operating income by total factory sales [11]. Chrysler topped its best 1993 per-unit profit record again in 1994. Chrysler's per-unit profit margin was the highest that had ever been achieved in the automotive industry in the world. However, the increase from its last year's performance level was not so good. It was the lowest per unit increase of the Big Three ($401/unit). Ford achieved a strong $637 improvement in its profit-per-unit in 1994 compared to the previous year, just ahead of GM ($526/unit). GM improved its profitability on two fronts. First of all, it converted its net loss of $872 million in 1993 (corresponding to a profit rate of $208/unit) into $690 million net profit by raising the rate to $734/unit in 1994.

Table 2 US automobile competitive performance rating

Category	*Manufacturer*	*1990*	*1991*	*1992*	*1993*	*1994*	*Remarks*
Quality	Chrysler Corp.	172.5	168	150	132	142	
	Ford Motor	147.6	132	125	101	91.3	Best quality performer
	General Motors	149	150.5	133	109	113.1	
Profit/Unit	Chrysler Corp.	$209	($427)	$445	$1,709	$2,110	Best low cost producer in the world
	Ford Motor	$53	($700)	($307)	$240	$877	
	General Motors	($462)	($883)	($541)	$208	$734	
Productivity	Chrysler Corp.	15.7	16.4	18.7	21.2	24.6	High capacity utilization
	Ford Motor	16.5	17.9	19.3	19.0	19.6	
	General Motors	12.0	11.8	12.5	14.1	16.1	
Market Share	Chrysler	13.2%	12.2%	12.2%	14.7%	14.6%	Minimum % decline
	Ford	23.8%	22.8%	24.6%	25.6%	25.3%	
	General Motors	35.5%	35.1%	33.9%	33.4%	33.1%	

Productivity: the productivity ranking is based on the number of vehicle produced per employee per year. Chrysler's productivity increased by 16.3% in 1994, compared to 14.2% for GM and 3.3% for Ford. In 1994, not only did Chrysler improve the most, it was already the best of the Big Three and was pulling away [11]. It is hard to pinpoint the exact cause of this gain in productivity; one difference to note is that Chrysler is the least vertically integrated amongst the Big Three. GM's improvement was quite impressive (compared to Ford's), considering the number of problems GM had with the launches of its new vehicles in the USA. Strangely, Ford's productivity improvements have stagnated. Maybe the major reorganization efforts that Ford completed during Spring 1995 called 'Ford 2000' will give Ford the right boost.

Market Share: 1994 will long be remembered as the most profitable year in the history of the US auto industry and 1991 the worst year. Altogether the Big Three posted $13.9 billions in profit - an all-time record [11]. Though there were many reasons, application of CE principles and practices were considered to be one of the major contributors in increasing productivity and quality and putting a stop to rapidly rising imports and market share. Import brands altogether increased their share during 1994 only by a mere (1/10) of a percent increase to 27% in total, while the Big Three ended up with a total of 73% of the US market.

Ford seems to do well in streamlining activities at manufacturing fronts and increasing efficiency [11] when it comes down to applying structure techniques built around CE. Chrysler appears to gain the major benefits by applying it to the up-front processes: product development, capital investment and marketing fronts. GM seems to be doing both.

Table 3 shows the average labour cost of six major US and transplant automotive manufacturers. The Big Three have too many workers on the assembly line, creating a competitive advantage for the Japanese automakers. GM is top of the list with 43,000 people heavy given GM's 227,000 member US hourly workforce. As far as labour hours per vehicle, GM improved most among the Big Three. In 1995 it took 3.64 people to build a vehicle. That fell to 3.47 in 1996. Ford is however, the best of the Big Three. It needs 3.09 people to build a vehicle. Chrysler takes 3.29 people; Toyota, 2.67 and Honda, 2.51. The benchmark is Nissan with 2.23, but that is up from 2.09 in 1995. GM numbers were better compared to 1995, because each vehicle had fewer parts and it used full body side stamping rather than individual parts [12]. However labour costs were still $700 more than Nissan's (see Table 3). In terms of quality, of the US Big Three, Ford made the greatest improvement - 81 defects per 100 vehicles. GM was the second best with 97 defects per 100 vehicles [13]. Chrysler was the highest profit producer recording a $1,868 per vehicle profit before tax [14].

Table 3 1996 average labour cost, quality and profit per vehicle

Labour Cost/vehicle	*Chrysler*	*Ford*	*GM*	*Honda*	*Nissan*	*Toyota*
People per vehicle in 1995			3.64		2.09	
People/vehicle or labour hours per vehicle (assembly, stamping & powertrain) in 1996	3.29/ 40.53	3.09/ 37.59	3.47/ 44.59	2.51/ 30.88	2.23/ 28.32	2.67/ 29.54
Labour cost per vehicle ($43 per labour hour)	$1,743	$1,616	$1,917	$1,328	$1,218	$1,270
Labour cost penalty per vehicle vs. benchmark (Nissan)	$525	$398	$700	$110	--	$52
Annual production volume (million)	2.767	4.271	5.039	0.664	0.414	0.483
Annual cost penalty vs. benchmark (Nissan)	$1,453	$1,702	$3,525	$73	--	$25
Excess worker vs. benchmark (Nissan)	17,968	21,062	43,610	905	--	313
Quality (number of defects per 100 vehicles)	103	81	97	62	76	64
Average profit or (loss)/unit (before tax)	$1,868	$794	$234	$182	($287)	$957

Source: based on the Harbour Report, [12]

5 Concluding remarks

Manufacturing competitiveness is a balancing act. There is no single solution - technical or non-technical - that can easily be copied or bought from other successful companies. A well-orchestrated process, not just a program, is required to achieve corporate goals and objectives [2]. The shorter life of products today simply does not leave room to fix problems, correct design errors, iterate, or redesign products many times to lower costs or improve quality [15]. A company is considered to have reached world-class manufacturing status if the goodness of products and services far outweighs the process and methodologies expended to produce it [2]. Such a company gets the product right the first time. They measure productivity not based on inputs and outputs but ‘throughput’ and ‘operating expenses.’

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