Evolving Manufacturing Practices: Lessons for the Quality Control Engineer

by Thomas W. Eagar

There is a great need for a nation to have high productivity if it is to maintain a high standard of living for its citizens. If productivity is low over the short run, a nation may lose jobs to more productive nations. This is damaging enough in the short period, but the greater problem occurs when productivity remains low for a long period. Over time, citizens will find new employment, but the jobs will require lower skills and provide lower compensation than jobs found in more productive nations. With a slower generation of wealth as compared with more productive countries, the low productivity, low wage nation will provide a lower standard of living for its citizens. National security and the nation’s position of influence worldwide will deteriorate. Experience suggests that crime will increase, health care will become inferior, and the population will become dissatisfied. Indeed, over the long run, a nation’s manufacturing productivity influences nearly every aspect of society. Without the wealth generated by manufacturing, we will lack the ability to pay for defense, education, health, or other social programs.

Can America Compete?

It is often argued that American manufacturing, once the pride of the world, is in decline. The loss of employment in the manufacturing sector is cited as evidence of our inability to compete. Politicians blame businessmen for not investing in future productivity, while businessmen blame the government for failing to educate the populace. There may be some truth to both of these arguments: our rate of investment is inferior to many other manufacturing nations and our educational system has deteriorated markedly in recent decades. Nonetheless, the problem is not lack of productivity.

Figure 1 shows the employment, consumption, and productivity of the U.S. steel industry during the 1980s. Although employment has decreased by half, this is not evidence of inability to compete. To the contrary, productivity in this “mature” and much-maligned industry has doubled during the past decade. The problem is that consumption has remained flat. You don’t need a graduate degree in economics to realize that doubling productivity while maintaining stagnant consumption will result in a halving of employment. The loss of employment in the manufacturing sector of the economy is due to the fact that productivity is increasing faster than consumption.

“To live well, a nation must produce well.”
—DeTouzos and Lester, 1989

During the decade of the 1970s many U.S. industries, such as steel and automobiles, were somewhat stagnant in productivity improvements as compared with other nations. They lost market share to imports, but during the 1980s many of these industries corrected their problems. Today, many of these American companies are regaining market share, in part, through major gains in manufacturing productivity.

“America is...one of the industrial world’s cheapest producers of many goods. Even in manufacturing, America’s output per man-hour (is) roughly the same as Japan’s; it is 50% higher than Germany’s.” (The Economist, 1992)

Yet, the politicians and the unions still blame the businessmen for the loss of jobs in the manufacturing sector. One is reminded of the quote by Huxley: “The great tragedy of science is the slaying of a beautiful hypothesis by an ugly fact.”

While some people hypothesize that American businessmen are incompetent, the facts show that a major revolution is occurring in U.S. manufacturing. There is no productivity crisis in U.S. manufacturing today. There is a major restructuring of employment in the world. Increasingly, the best companies employ people for their brains—not for their muscle. Muscle-intensive jobs are being automated, with a subsequent improvement in the working environment of the laborer. The tasks of manufacturing are changing. Current employees need retraining if they are to remain employable in this new environment. Current students in vocational schools, colleges, and universities need to be educated differently. One can no longer learn a skill which will be useful for a 30- to 40-year career. The lifetime of skill-based training has shrunk to ten years or less. As a result, the worker who stops learning after formal schooling becomes obsolete within a decade or two. While lifelong education and continuous learning were once a means to improve one’s employment over time, today they are required to maintain one’s employment over a career. Schools need to educate students on how to learn, not merely what to learn. No one can predict with certainty what skill will be required in the future, or as Niels Bohr once said, “Prediction is very difficult, especially if it concerns the future.”

Recent Manufacturing Paradigms

The revolution occurring in the best American manufacturing companies has spawned a number of new phrases and acronyms—such as TQM, JIT, SPC, six-sigma, quality, continuous improvement, concurrent engineering, and the like (the acronyms stand for, respectively, total quality management, just-in-time delivery, and statistical process control). Together, these make a confusing array of “best practices” which often seem contradictory or are considered fads sponsored by zealots. Experience shows that no one of these is a “magic bullet” that will correct all manufacturing woes, but each has some usefulness when considered with respect to the whole system. The fact and fiction of several of these are examined below.

Quality Doesn’t Cost—It Pays

This is a popular phrase for which there are numerous anecdotal examples showing significant cost savings when the manu-

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Manufacturers pay more attention to quality. Belief that improved quality will improve profitability has caused companies like Motorola to embark on “six-sigma” quality programs.

Motorola, Inc., one of the first winners of the Malcolm Baldrige National Quality Award, is generally credited with championing six-sigma quality. The term six-sigma represents the fraction of parts which lie beyond six standard deviations from the mean of a Gaussian distribution of a quality metric. Six-sigma is equivalent to no more than 3.4 parts per million defective parts.

It is clear that if one has a product yield of 80 percent (see Table 1), improvements in quality to 99 percent or better will be equivalent to a 25 percent improvement in productive capacity without spending any money for new space or for manufacturing equipment. In addition, there are multiplier cost-saving effects, as scrap and waste are reduced, or as one eliminates the need for inspection when the six-sigma quality level (99.9997 percent good parts) is achieved (Pfahl, 1992). Nonetheless, if one is already at six-sigma, then the costs of further improving the quality will not necessarily be returned by improved capacity. The question of whether quality costs or pays is relative to what level of quality is being achieved. It almost always pays to improve a low-yield process, while a very high yield process may cost more to improve than can be regained.

In addition, as one approaches five-sigma or six-sigma quality, our improvement methodologies (TQM, SPC, design of experiments and the like) tend to fail us. When there are fewer than ten bad parts per million, it is often too difficult to get data on the few bad parts in order to discover the cause of the problem. Even more often, the few bad parts often have multiple causes and hence are difficult to define and correct. As a result, many quality improvement programs tend to stall at the five or six-sigma level.

It is also useful to consider the absolute value of the product and the consequences of failure when determining what level of quality is required. For example, although six-sigma is often considered a good quality target for general manufacturing, one may only require three-sigma quality when manufacturing concrete blocks, while nine-sigma may be required if one is fabricating Hubble telescopes.

**Table 1** Typical Ranges of Product Yield in Various Industries

<table>
<thead>
<tr>
<th>Industry</th>
<th>Typical Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semiconductors</td>
<td>5–95%</td>
</tr>
<tr>
<td>Composites</td>
<td>10–80%</td>
</tr>
<tr>
<td>Fine ceramics</td>
<td>0–75%</td>
</tr>
<tr>
<td>Steel</td>
<td>70–85%</td>
</tr>
<tr>
<td>Concrete</td>
<td>95+%</td>
</tr>
</tbody>
</table>

Build Quality In—Don’t Inspect It In

This is a correct principle of modern manufacturing. Building the quality into the manufacturing process reduces both the amount of scrap as well as the time for feeding back information that the process is producing bad parts. Building the quality into the process requires a new focus for the quality control engineer on the process rather than the product. This will be discussed in more detail subsequently.

Zero Defects

Several manufacturing consultants have made a career of calling for zero defects while some technical people have a philosophical aversion to the concept. These opponents liken zero defects to zero pollution, and argue that it is unattainable. (Although there may not be a fundamental reason why zero defects is unattainable, the Second Law of Thermodynamics does indicate that zero pollution is impossible.)

Even if it is unattainable, zero defects is a worthy goal since any other goal implies a level of complacency inconsistent with...
the concept of continuous improvement. For example, in the 1970s there was a rule of thumb in the printed circuit board industry that four percent of the boards would require repair. History has proven that this was a self-fulfilling prophecy. The industrial engineers designed the rework area of printed circuit board shops to accommodate four percent repair, while the process engineers improved the process until the rework area was capable of handling the number of boards that needed repair, and then the process engineers went on to another part of the factory (Pfahl, 1992). There was no incentive to reduce the repair rate below four percent until one enterprising manager declared that rework would not be allowed. This required that the engineers improve the process toward zero defects. Once the goal was raised, the quality improved steadily.

The goals of zero defects and six-sigma quality are essentially the same. Six-sigma may be more palatable to the theorist who believes that perfection is unattainable; nonetheless, the principle is clear. A lack of tolerance for defects will drive the number of defective parts to ever lower values.

Just-In-Time Delivery
Some people claim that just-in-time delivery (JIT), with the subsequent savings in inventory costs, is the key to Toyota’s success as a low cost producer of automobiles, while others argue that JIT merely shifts the cost of inventory to the suppliers. Both views are too simplistic. While true reductions in inventory will reduce costs, the real meaning of JIT lies in the fact that manufacturing problems can no longer be hidden by excess inventory. If there is no extra inventory and a manufacturing process goes awry, then production engineers cannot ignore the problem. It must be solved. It cannot be postponed by using up an inventory of good parts. As a result, JIT places more pressure on the production staff to solve problems immediately. This reduces waste and improves quality. In comparison, the reduced cost of inventory is a secondary benefit of JIT.

The Changing Role of The Quality Control Engineer

Figure 2 represents the old paradigm of manufacturing. A process contained inputs and outputs. The inputs were inspected prior to use to ensure conformance to a standard. After the process was complete, inspectors checked the function of the product and scrapped or repaired any defective parts.

In the new, evolving, paradigm, the input materials are received from a prequalified supplier, hence, no incoming inspection is necessary (see Figure 3). The process is no longer a simple black box. It is the heart of the quality engineer’s job. Rather than inspect the finished product, the quality engineer must sense the process, feed sensed data into a process model, and develop a control methodology that can modify the process to produce acceptable parts. If this sequence of sensing, modeling, and controlling is working properly, there is no need for outgoing inspection, and scrap and repair are minimized. A process running at this level not only can be modified to meet the explicit requirements of the customer, but can be adapted to meet the latent requirements for which the customer does not yet know there is a desire. In addition, the reduction of waste makes the process environmentally sound.

The modern quality engineer measures the process, not the product.

The New Challenges
Although quality engineers have always been in the business of measurement, the types of measurements which are needed are changing and it is necessary to make a science of this new work.

As Lord Kelvin said: “Often say that when you can measure what you are speaking about and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science, whatever the matter may be.”

The quality engineer must put numbers on both the process and the product. Unfortunately, most people tend to measure what they can measure most easily—not what needs to be measured. Traditionally, materials were sold based upon size, thickness, weight, density, or the like. These required measurement of length, width, weight, and volume. Today, materials are sold based upon structure and properties as well as form and size. These new features require measurement of internal geometry, processing conditions, or specific properties. Sensors are not necessarily available for these purposes. It is up to the quality engineer to develop new sensing technologies. In addition, much of our materials manufacturing in the past was batch-processed. Today’s higher productivity requires that continuous flow processing dominate many industries. This requires “measurements on the move,” as materials will no longer sit
still in order to be inspected. With increasing value added per part, the rate of sensing must increase both spatially and temporally, while maintaining ever tighter environmental restrictions. A potential solution to these challenges lies in microsensor technology, which may make it possible to have many low-cost sensors distributed over a wide area.

All of this will require quality engineers to work closely with people in other disciplines, such as materials engineers, design-

Summary

The United States remains the most productive manufacturing nation on earth, but in order to maintain this distinction and to maintain our standard of living we must:

- Have a better educated workforce.
- Focus on process improvement as well as product quality.
- Require that persons performing inspection will make measurements during the processing operation—with greater spatial and temporal resolution—as well as perform more direct measurements of the structure and properties of the material.

It is a great challenge, and one which must involve the quality engineer as a key player in the manufacturing system.