A Materials Researcher on the Manufacturing Floor

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To enjoy working in manufacturing, one needs to be comfortable with chaos. In fact, it is best if one can thrive on chaos and constant motion. Two years after joining Hewlett Packard as a research and development engineer, I transferred to manufacturing into a production manager role. I went from responsibility for a small piece of a larger project to managing close to 100 people in a 24-hour-a-day, 7-days-a-week operation manufacturing light-emitting diodes (LEDs). I was responsible for the operators in three distinct areas—bulk crystal growth, epitaxial growth, and wafer fabrication. After production management for two years, I became a process engineering manager at the Colorado Springs Technology Center of Agilent Technologies (formerly Hewlett Packard). The Tech Center designs and manufactures multichip modules and hybrid assemblies for Agilent Technologies instruments.

Daily operations meeting at Colorado Springs Technology Center of Agilent Technologies.

Managing engineering or production in a manufacturing environment is a hectic job. First thing in the morning, I check the passdowns from the night before to see if any problems were encountered overnight with any of the processes, products, or equipment. Then it is off to the daily operations meeting to assess the current situation on the production line. Are parts moving through the line quickly and efficiently? Is any of the equipment down? Did one of our vendors miss a key shipment, therefore halting the line? Did our customer just double the shipment requirements? Are the yields unexpectedly low? On a good day, production will run fairly smoothly and only minor adjustments to priorities or schedules will need to be made. On a bad day, I could spend a couple more hours resolving the problem or working with a team of people to begin to address the issue.

One of the reasons I find manufacturing challenging and rewarding is because of the wide range of work responsibilities. It is impossible to get bored. I often think of the job as split into three components—people, business, and technical. The technical side is often the easiest to define. Process yields and throughput are metrics to measure performance. Technical projects usually are due to unacceptable yields, insufficient throughput, or the requirements of a new product. On the business side of the job, I must understand our customer needs such that I can set priorities for the technical teams. Finally, people management is important. Motivating, leading, and enabling the people who work for me is simultaneously the most frustrating and rewarding part of my job. My primary goal is to create an environment where people know their priorities, have the resources to do their work, and enjoy their jobs. Communication is critical to efficient manufacturing operations. The operators, technicians, supervisors, engineers, and managers need to share common goals and priorities. Miscommunication or lack of communication quickly leads to inefficiencies and frustrations.

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It often seems as if every hour and every minute is filled with reacting to crises with no time to look forward, work on projects, or make progress. The problems can range from dealing with unexpected absences of technicians resulting in minimal support for the production line to reliability issues when a process or part does not behave as expected. Resources must be focused on resolving issues that have the largest payback. Therefore some problems are left unresolved. Workarounds such as extra inspections can be put in place. In other cases, with lower volume parts, low yields may be considered acceptable.

Here is an example of a typical crisis. Our vendor shipped capacitors with the wrong termination metal. The combination of the wrong termination metal with the conductive epoxy used to attach the capacitors provides for a galvanic cell. The error was not caught in time and product was already shipped to our internal customer. In addition, a large amount of product was in WIP (work in process) with a very aggressive shipment schedule. Now the question becomes how to recover from this problem. If our final customers do not get product on time then we may lose the business, an immediate impact to revenue and profit for Agilent Technologies. First priority is to rework all WIP with the correct part and get the production line started again. The vendor must ship the correct capacitors as soon as possible. Meanwhile a process to rework the parts must be created and tested for capability and reliability. In addition, the reliability of the parts already built must be determined. Can the product be shipped and the problem parts replaced later? If so, when will the first field failures occur? The business risks of shipping potentially unreliable instruments versus the impact of missing shipments must be assessed and a decision made. To do this, it is important to estimate the lifetime of the parts. Clearly this is a corrosion problem but there is not time to set up a detailed experiment. The question needs

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to be answered within days. What are the normal operating conditions for the part? How do we accelerate the corrosion mechanism and predict the lifetime of the part in the field? This problem sounds interesting and challenging from a materials standpoint but there is no time to set up a reasonable experiment.

Suggested Resources

Robert H. Hays and Steve C. Wheelwright, *Restoring Our Competitive Edge, Competing through Manufacturing*, (John Wiley and Sons, New York, 1984).

Richard Schonberger, *World Class Manufacturing*, (Macmillan, New York, 1986).

Peter Senge, *The Fifth Discipline*, (Doubleday Books, Garden City, NY, 1994).

Eliyahu Goldratt and Jeff Cox, *The Goal*, (North River Pr., New York, 1992).

Gordon MacKenzie, *Orbiting the Giant Hairball, A Corporate Fool's Guide to Surviving with Grace*, (Penguin Putnam, New York, 1998).

Constant pressure exists on the manufacturing floor. Schedules for shipments must be made. New products must be released before the details of manufacturing can be worked out. A key learning point for me in moving from research and development (R&D) to manufacturing is the concept of manufacturability. As an R&D engineer, creating one or two or even a dozen working prototypes is sufficient. Yet the ability to make a consistent product over and over may have very different requirements. The key to manufacturability is process stability. It is critical to limit the variation in a process. Yet variation is a fact of life on the manufacturing floor. Different operators, different shifts, different technicians, even different engineers lead to variation. Also, variation occurs from incoming materials or from the upstream processes. These variations can result in low yield, inefficient operation of equipment, line stops, or poor reliability. It is enough to keep one awake at night—every night.

In many ways, the skills needed to be successful in manufacturing are the opposite of what we learn in graduate school. Decisions must be made quickly and often with an incomplete set of data. The language and concepts in manufacturing are not taught in a typical materials science program: just-in-time manufacturing, cycle time, statistical process control, self-directed work teams, assurance of supply, contingency plans, WIP, kanban*, ergonomic design, design for manufacturability, design for reliability, design for test, cost, absorption variance, and yield variance.

In other ways, skills I developed in acquiring a PhD degree have been useful in my other positions. Such skills as project management, literature searches, technical writing, and oral presentations are essential. The ability to approach a problem logically and lay out an action plan to resolve issues is critical. I have also found that the contacts I have made in the research community have provided valuable input when I have faced many different manufacturing problems. □

*Kanban is a Japanese term for a way to manage the production floor. It basically results in *a pull* of material through the process instead of *a push*. Usually kanbans are implemented with a card system or by limiting the space where work can be staged. Its real positive impact is that it is a simple system which stops material from piling up at a bottleneck process because it limits the amount of product that can be staged in front of any operation.

HISTORICAL NOTE

John Harrison's "Sea Clocks"

Despite centuries of experience navigating on the open seas, prospects for a safe journey were still grim in 1714. Whereas latitude, the distance (measured in degrees) north or south of the equator, was easily determined from astronomical observations, longitude (the distance in degrees east or west of some arbitrary meridian), yielded to no such easy solutions. Sailors relied on a method called "dead reckoning" whereby estimates of the ship's speed and the elapsed time at sea were combined with the captain's intuition to estimate longitudinal positions. Given that one degree of longitude equals 68 miles at the equator, even small errors in judgment proved to be disastrous: Sailors traveling through fog who thought they had 50 miles to go to reach the shore frequently found it sooner than they had hoped. Ships were running aground, lives and cargo were being lost, and something had to be done.

In 1714 merchants and sailors petitioned the British Parliament for a solution. The 1714 Act of Queen Anne established a top prize of £20,000 (the equivalent of millions of today's U.S. dollars) to anyone who could determine the longitude to the accuracy of half a degree on a routine 60-day voyage from England to the West Indies.

For several centuries the best scientific minds had wrestled with the dilemma of longitude determination. In its essence, it was a problem of timekeeping. Since the Earth rotates 15 degrees in an hour, two locations an hour apart by the Earth's rotation are separated by 15 degrees of longitude. Calculating a ship's longitudinal position at sea requires a knowledge of the time in two locations: that at the ship's current position, and at some arbitrary reference position of known longitude. Comparison of the time difference between the two locations yields the distance separating them.

Two possible solutions emerged: the astronomical and the mechanical. Astronomers such as Edmond Halley of the Royal Observatory at Greenwich strove to understand the clockwork of the heavens to the necessary precision, while artisans worked to solve the mechanical difficulties of keeping time on a rolling sea. No less an authority than Sir Isaac Newton expressed his skepticism that a mechanical solution would ever be found.

But John Harrison (1693–1776), a carpenter and clockmaker from the town of Barrow Upon Humber with little formal education, used a combination of mechanical skills and basic materials research to rise to the challenge. Realizing that he first had to understand and perfect timekeeping on land, which at that point was capable of an accuracy of only about a minute a day in the best clocks available, he set about analyzing and improving upon the current technology.

The main problems with the existing clocks of the time were the need for lubricants to minimize friction and the thermal expansion of the metal pendulum rod altering the length, and hence the period, of the pendulum's swing. The primitive