DEVELOPING A VIABLE MANUFACTURING STRATEGY

or

"How to Convince the Program Manager that He's Really in the Manufacturing Business"

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The Manufacturing Engineer's Lament: I Don't Get No Respect!

Those of us in the Manufacturing career field (whether by a conscious choice or accident of fate) no doubt discovered not long after we entered this arena that members of other functional disciplines in our organization somehow just don't exhibit the sense of urgency we have regarding problems on the production floor. We could waste a great deal of energy blaming forces or agencies outside our control for this turn of events. We might be tempted to utter complaints such as, "Those contract weenies, or loggie pukes, or (fill in the blank) have such a well organized mafia that I can't make any headway with the Program Manager," or "If only I had the resources to cover all my areas of responsibility I could make a greater impact on the program," or even, "Those engineers and program managers have only *cost, schedule and performance* on their mind! How can I expect to get their attention when it comes to manufacturing issues?"

Aside from the fact that we should all be concerned about cost, schedule and performance, what is it that seems to cause most program managers and engineering personnel (as well as most everyone else not directly involved in manufacturing matters) to maintain a disinterested viewpoint when it comes to considering manufacturing issues? At a time when these issues are consuming greater attention in the commercial marketplace than ever before, why is it that in the government acquisition community, we see the manufacturing career field growing smaller and smaller and our manufacturing functional organizations on the slide to oblivion?

At this point the reader may assert, "That's not true. Under the 'Integrated Product Team (IPT) concept,' we are seeing a departure from the older functional way of doing things, and we are finally seeing Manufacturing come into its own, wielding great influence in the overall program management structure." In reality, the program emphasis given to manufacturing is usually done by the contractor, and the IPT contributions of government manufacturing personnel are frequently given low attention until it's too late to avoid a schedule slip, cost overrun, or quality catastrophe. At this juncture, the program management team casts about looking for someone to blame. Then guess who finally gets his "day in the sun"?

To Blame or to Change? That is the Question!

We can blame fate for these circumstances, or we can change them. Why are other functional specialties successful at achieving their objectives while manufacturing personnel in many cases meet obstacles? The reason is: these other specialists have convinced program management that they have the ability to influence the issues that most concern them: *cost, schedule and performance.* Until we speak in these terms, we will be unsuccessful in convincing upper management that we have other than our own narrow parochial interests at heart.

Part of the problem we've had in the past is that, although we intuitively understand manufacturing issues have a significant effect on overall program cost, schedule and performance, manufacturing engineers have generally failed to articulate the causal relationships between manufacturing issues and overall program concerns in other than a very general way. Although the civil industrial sector has been influenced by men like Deming, Juran, Goldratt, Genichi Taguchi and Taichi Ohno in Japan, the Department of Defense has a long way to go to implement the principles these men espouse. The manufacturing function is still not generally perceived as "value added" by the program manager. We have failed to "sell" manufacturing. We have failed to convince the PM that he is in the business of *manufacturing a product.*

TYPICAL SYSTEM LIFE CYCLE COST DISTRIBUTION

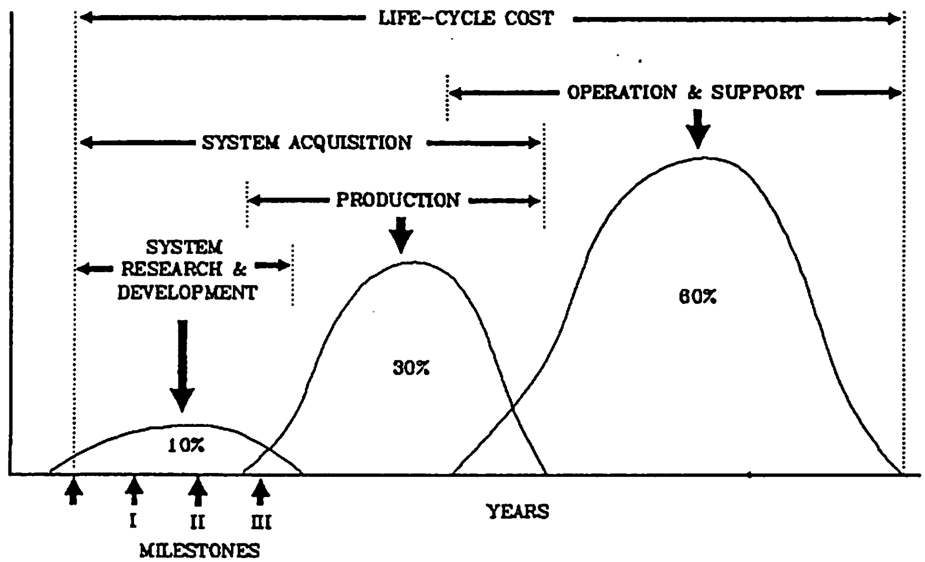


Figure 1

TYPICAL SYSTEM LIFE CYCLE COST
COMMITMENT VS EXPENDITURE

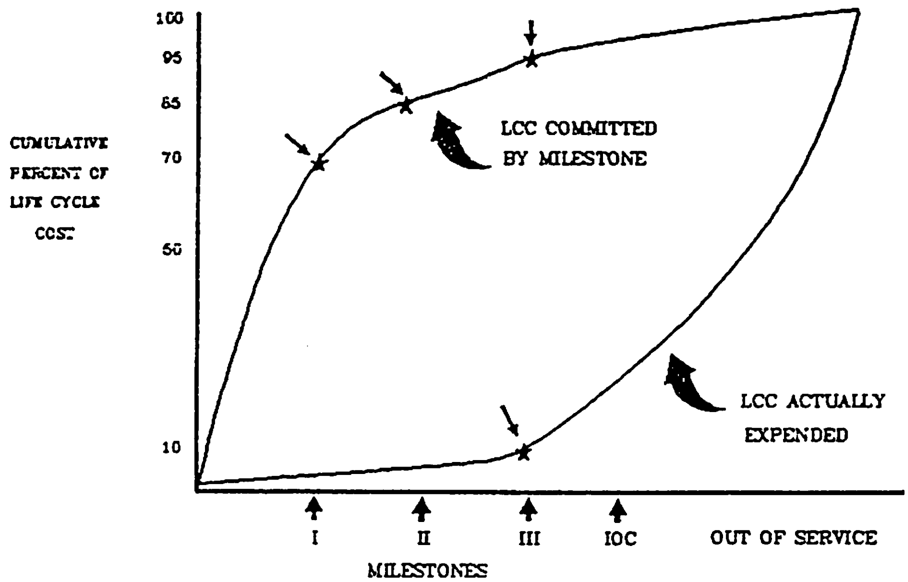


Figure 2

SYSTEM ACQUISITION RELATIONSHIPS
(Manufacturing Strategy)

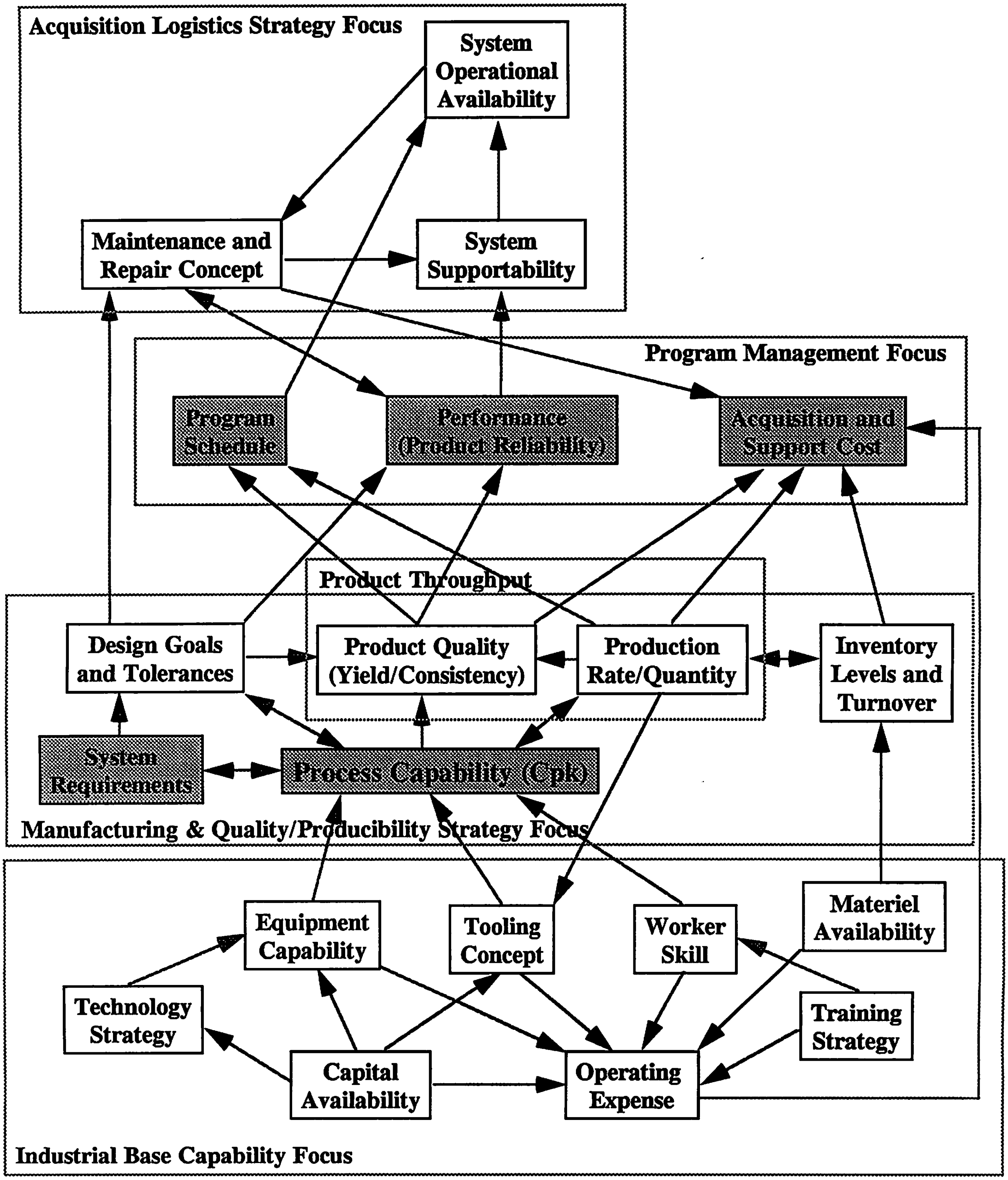


Figure 3

What is it that Really Jacks Up Product Life Cycle Cost?

Examining the cost distribution across the acquisition cycle of a typical system (Fig. 1), we can see that production costs consume an average 75 percent of acquisition costs and an average 30 percent of the entire system life cycle cost. Life cycle costs, particularly operation and support costs, are typically determined early in the program by systems requirements, and design and manufacturing process decisions (Fig. 2). These decisions have a heavy influence on operation and support concepts which impact O&S costs. The reason for this influence is because of cause-effect relationships that exist within system's acquisition and support chain (Fig. 3).

At the base of the cause-effect chain are two fundamental considerations that interrelate with each other and which ultimately drive product life cycle cost: *systems requirements* and *manufacturing process capability*. The contractor's equipment capability, tooling, and worker skill level are what determine manufacturing process capability. Equipment capability is determined, in turn, by corporate technology strategy and capital availability. Capital availability and planned production rates also determine corporate tooling strategy. Worker skill is impacted by experience and corporate training strategy. Finally, capital availability, equipment capability, tooling strategy, worker skill, training strategy and material availability impact corporate operating expense (Fig. 3).

In developing a strategy for manufacturing, quality and producibility, which are interrelated, you must look at how the systems requirements will affect system design and, in turn, manufacturing process requirements. The design goals and tolerance requirements must be related to available manufacturing process capabilities; otherwise, product yield will be lowered and performance will be adversely affected.

How Important is Process Capability?

In the past, the typical strategy has been to design a system so the upper specification limit (USL) and the lower specification limit (LSL) coincide with the plus-or-minus three sigma process limits in a process with a normal distribution (Fig. 4). This provides a process capability of one ($C_p = 1$), assuming the process is centered and does not shift around the target value. The formula for process capability is

$$C_p = \frac{\text{USL - LSL}}{\text{3 sigma}}.$$

A process with the capability of one provides a yield for any single process task of 99.73%, with 0.27% of the items falling outside the USL or LSL. For a simple process of few elements or with a low production quantity this may be acceptable, but with complex items or high production quantities, the amount of rework or scrap soon climbs to unacceptable levels. For example, with an item consisting of only 100 elements (either components, steps in the manufacturing process, or any combination of the two), the short-term yield of a process with a $C_p = 1$ would drop to 88% (Fig. 5) and the long-term yield would quickly drop to 0% (Fig. 6). With a "complex system" (i.e., with more than ten components or ten steps in the process) or with long production runs (i.e., more than ten items), the majority of items being produced in a process with a $C_p = 1$ would either need to be reworked or scrapped.

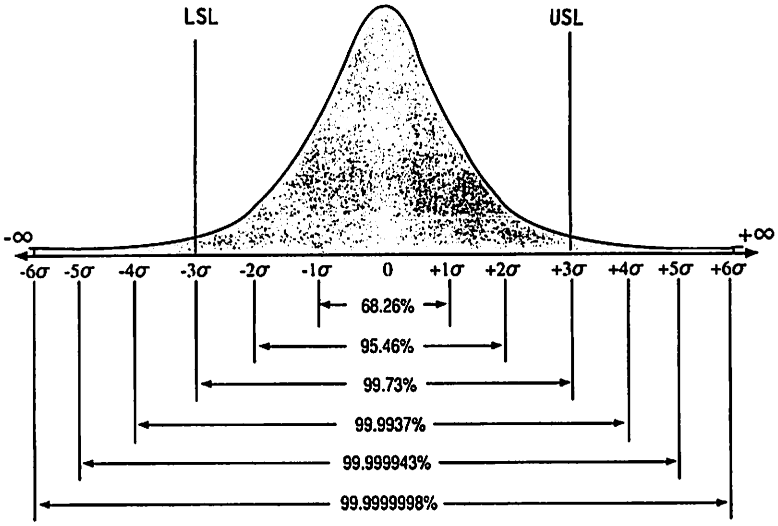


FIGURE 4 TYPICAL AREAS UNDER THE NORMAL CURVE

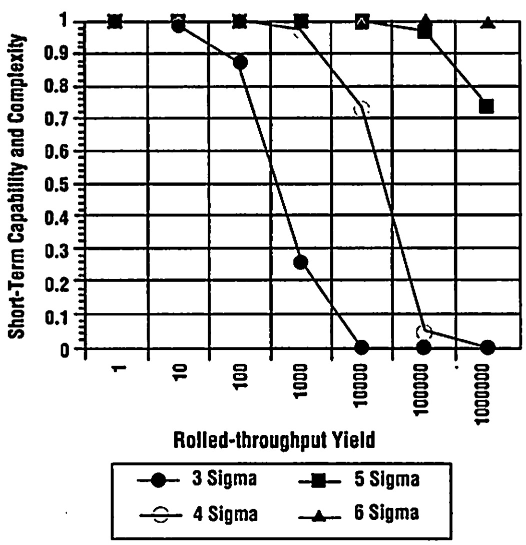


FIGURE 5 UNILATERAL EFFECT OF SHORT-TERM CAPABILITY AND COMPLEXITY ON ROLLED-THROUGHPUT YIELD

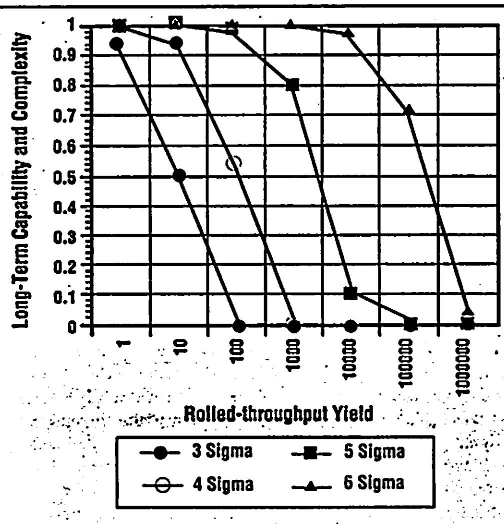


FIGURE 6 THE UNILATERAL EFFECT OF LONG-TERM CAPABILITY AND COMPLEXITY ON ROLLED-THROUGHPUT YIELD

This is obviously not acceptable in any normal production environment (although for some quirk of fate, it has been frequently tolerated in defense production). For this reason, a number of U.S. firms (e.g., Motorola and Texas Instruments) have made it their policy to drive to what they call a "six sigma process" i.e., where their process capability is equal to two. In this scenario, the process spread is decreased or the tolerance limits are increased, so that the USL and LSL are at the plus-or-minus six sigma points, providing a yield of 99.9999998% for any single task or process element (Fig. 4). The short term process yield for such a process with an item consisting of 100 elements would still be 99.99999% (Fig. 5) and the long term yield would be 99.9999% (Fig. 6), a significant improvement over a process with a C_p of one.

In reality, a "six sigma" goal ($C_p = 2$) may not be achievable, or even be desirable, for every process under a contractor's roof; nevertheless, it may be essential for critical processes. A compromise approach has been to require the contractor to identify those processes which impact on critical performance requirements and provide contractual incentives for him to achieve a minimum C_p of 1.33 on those critical processes, with the objective of improving all his process to a minimum C_p of 1.33 and having his critical processes achieve a C_p somewhere between 1.33 and 2.0.

How to Cut Costs at the Same Time You Improve Product Performance

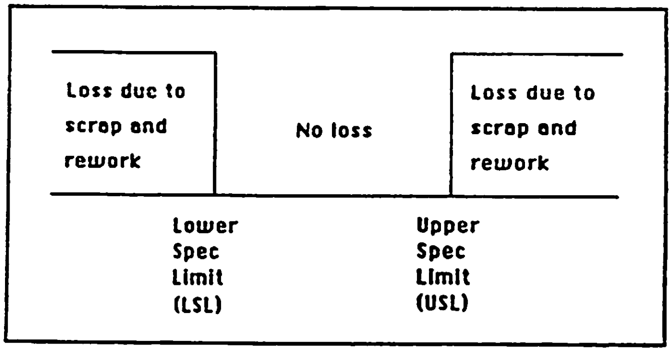
When you realize the importance of process capability and its relationship to yield and product quality, its connection to production rate and product reliability also becomes evident (Fig. 3). The more scrap and rework you have, the lower production rates are driven in an effort to correct problems. The higher the manufacturing process capability, the higher the yield, and the higher the rate that can be sustained in normal production. Also, the higher the yield, the higher the *consistency* of the product being produced. And *consistency is the key to reliability, or product performance.*

Reliability is determined by mean-time-between-failure (MTBF) of an item in the field. In an effort to reduce failures, systems (especially electronics systems) undergo stress analysis and are typically "derated" to prevent them from being operated beyond the operating limits of the individual components. In theory, an electronic system that is never operated beyond the limits of any individual component would never fail. This is the "goal" of reliability engineering in product design, although in practice it is never achieved. The reason it is never achieved is that in any system there are *hidden defects introduced by the manufacturing process*. These defects are introduced when the item being produced has upper and lower tolerance limits that are pushing, or are even beyond, the capability of the manufacturing process.

Genichi Taguchi has demonstrated that the old quality philosophy where the "acceptability" of a product is measured by whether it falls within the upper and lower spec limits is no longer an allowable way of doing business. *Quality losses are actually based on deviation from the target, not conformance to specifications.* In reality, an item that is slightly within the spec. limit isn't much better than one that is slightly outside the limit (Fig. 7). The closer the product is to the target (nominal) value of the process, the more desirable it is; however, *any deviation from target* is a "loss" to the customer. It can be shown especially with electronic parts that those items that deviate the most from the target value of the process will fail earlier in service than those that approach the target value of the process and the specification (assuming the designer has done his job right).

OLD PHILOSOPHY

- - QUALITY IS BASED ON CONFORMANCE TO SPECIFICATIONS



NEW PHILOSOPHY

- - QUALITY LOSSES ARE BASED ON DEVIATION FROM TARGET; NOT CONFORMANCE TO SPECIFICATIONS

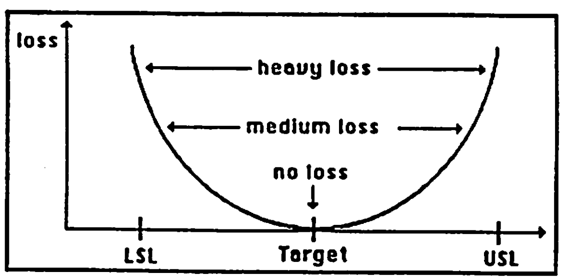


Figure 7

The closer to the target value, the more reliable a component is. In theory, if components could all be produced with no deviation from the target, and they were never operated outside their performance specification limits, they would never fail (again, assuming the design engineer has done his job right).

How does this relate to producibility strategy? We can argue that the more producible an item is, the closer it approaches the target value of the process, because the product will be designed to be inherently producible by the manufacturing process that is available. That is, the three sigma limits of the process used to manufacture the product will fall *well within* the USL and LSL of the product itself. The C_p will be well above one (which is the goal of "six sigma" quality). If it is not possible or desirable to "derate" a component (i.e., to open up its spec limits), *then resources **must** be devoted to narrowing the "spread" of the process*, i.e., to improve the process capability. It is no good to retain the original specification limits and "hope" somehow that some acceptable items will fall out of the process. As Taguchi has demonstrated, those items judged "acceptable" simply because they fall within the spec limits may well have hidden defects introduced in the process. When this happens, performance goals are not met, schedules stretch out, costs go up, and the U.S. taxpayer gets very unhappy.

In summary, the more producible a product, the greater its yield and consistency (quality), the greater its consistency, the greater its reliability, and the greater its reliability, the greater its supportability and availability. Ultimately, that's what counts for the Program Manager: to be able to field a system that performs *as required* and is available *when required* for the user.

Cause and Effect Revisited, or: How You Can Impact the Bottom Line

We have shown the cause/effect relationship between process capability and cost, schedule and performance, but there are additional cost implications to these traditional "production" concerns. As Goldratt has shown in his books *The Goal,* and *The Race*, there are three things that determine cost in a normal (civil) production environment: *product throughput, inventory, and operating expense.* In a defense production environment there are things that influence operating expense that fall outside the manufacturing arena; however, we have shown that within our area of purview, technology strategy, equipment capability, tooling, worker skill and materiel availability all have a direct influence on operating expense (Fig. 3).

It should be our concern as part of the program integrated product team to drive down operating expense wherever we can, unless by driving down that expense we have an adverse effect on producibility and product throughput. It may mean that we incur additional operating expenses up front to improve process capability or design producibility, if by so doing we can achieve greater yields and throughput in the end.

We can show that after operating expense, the greatest influence on cost is the throughput achieved by a production system, and throughput is determined by both yield and production rate. Even for low rate or low quantity production systems, costs can be driven down by improving product yields. For high rate/high quantity systems, the benefits of high yields are amplified. But there is another beneficial effect on cost, for *the higher the yield, the more consistent are both the product and the production rate.* The more consistent the production rate, the lower the inventory levels that need to be maintained and the more rapid the inventory turnover (Fig. 3)

To illustrate: Prime contractor, Defense Electro Aero Dynamics (DEAD), Inc. is receiving an item from Subcontractor Nadir, Inc. Let us suppose that the items received from Nadir are 25% defective and arrive late 30% of the time. DEAD will need to institute an extensive incoming inspection and screening (including test for electronic parts) to assure that defective Nadir components do not find their way into their production. They will also need to order 30% more parts than they require simply to get enough defect-free parts for production, and they will need to order these items to be delivered enough in advance to allow time for incoming screening and late deliveries. Also, they will have to maintain a parts warehouse and an inventory backlog "just in case" they have more defects than they originally planned for, or if they can't get replacement parts fast enough. They will incur additional costs to ship the defective items back to Nadir, or they may decide it is cheaper to absorb the cost. Either way, *the defective parts cost the government Program Manager money* (You didn't really expect the contractor to pay for defective parts, did you?).

Let's try a different scenario: Another defense prime contractor, Laser Integrated Vector Electronics (LIVE), Inc., orders parts from Subcontractor Acme, Inc. Items from Acme have a record of 99.9999998% acceptability (6-sigma quality) and are always delivered on time, because Acme has worked out its process problems. LIVE decides that incoming inspection is not required for Acme parts because the cost of uncovering defects that may be introduced into production by Acme parts is insignificant compared to the cost of incoming screening. Furthermore, LIVE does not maintain a backlog of Acme parts because they are virtually 100% usable and always available when needed. LIVE has gone so far as to arrange for "just-in-time" delivery of Acme parts to their production floor (compared to "just-in-case" delivery of Nadir parts) completely eliminating the expense of inventory storage, back ordering, and testing prior to assembly. The result: LIVE makes more profit and the government customer pays less.

Product yield not only drives cost via throughput and inventory levels, it also drives cost through its effects on reliability and consequent supportability and availability (Fig. 3). The reliable system will not only need less maintenance and repair, reducing support costs, it will require fewer systems to achieve required mission sortie rates, reducing cost even further.

The implications are inescapable. Increased emphasis on manufacturing processes and design producibility--things traditionally regarded as "only production concerns" can result in a big payoff for the government Program Manager. The manufacturing engineer or specialist that emphasizes this approach may soon find that instead of his having to fight for recognition, the Program Manager will become his strongest advocate.