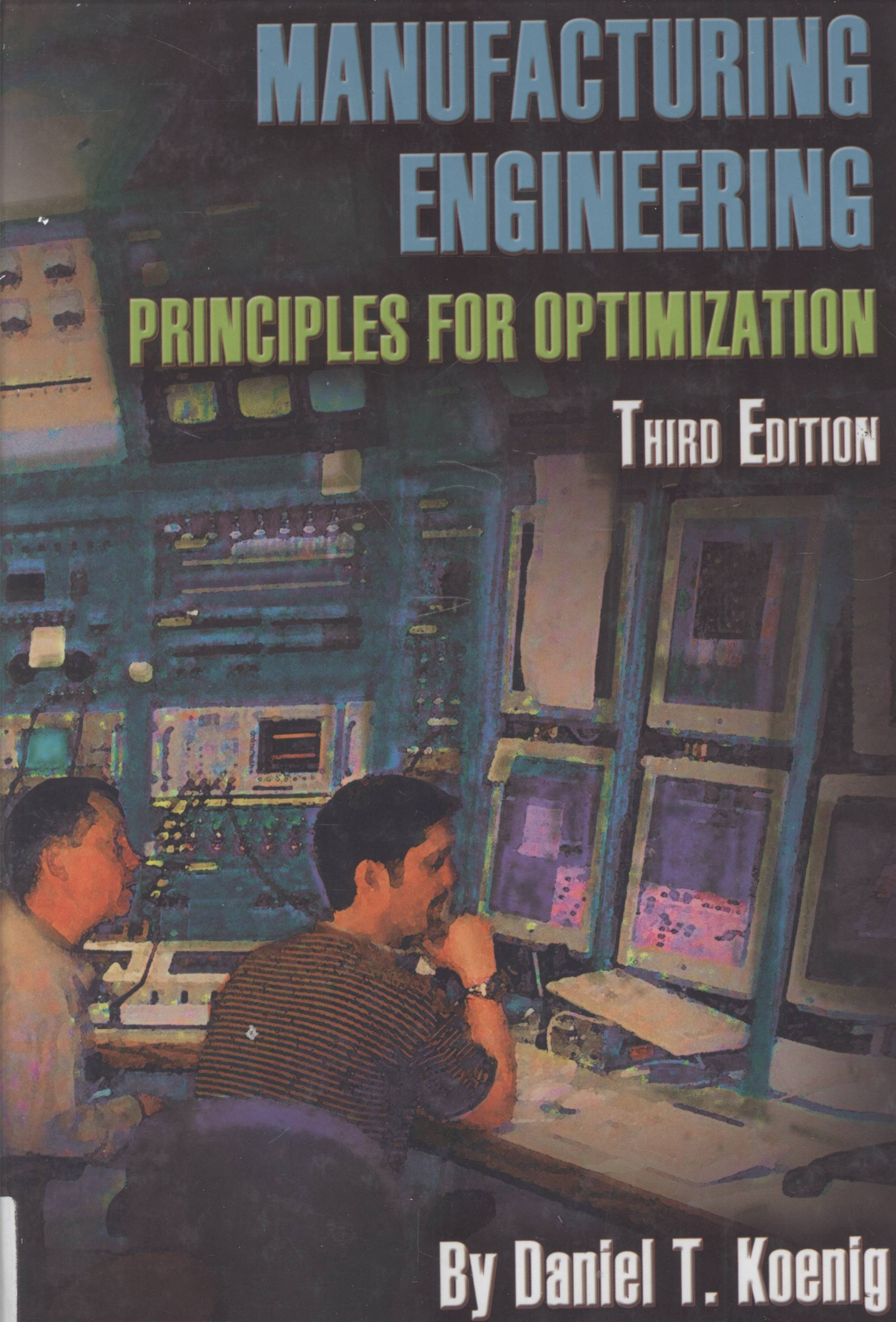
MANUFACTURING ENGINEERING

PRINCIPLES FOR OPTIMIZATION

THIRD EDITION



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Principles for Optimization

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DEDICATION

This book is dedicated to my granddaughters Alison and Jillian, may they grow up to be wonderfully accomplished women. To my sons Michael and Alan, my daughters-in-law Donna and Cindy. And to my wife Marilyn who encouraged me to continue with this project even though it meant many hours of isolation for her. I love you all very much.

Daniel T. Koenig
Lake Worth, Florida

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Chapter 1

MANUFACTURING ENGINEERING ORGANIZATION CONCEPTS

A FABLE: THE COMPANY THAT COULD AND THE COMPANY THAT COULDN'T

Let me tell you a story about the Company That Could and the Company That Couldn't. Both of these companies were vying for a lucrative market for the same new product, which was different from anything that had been made before. The market for this product was enormous, and both companies were very eager to enter it.

The Company That Couldn't specialized in selling. They could literally sell "refrigerators to Eskimos." They did not understand manufacturing well. They were content to let equipment vendors equip their factory and were miserly about providing manufacturing management support. They were convinced that sales were of primary importance and all other functions were secondary. Their philosophy was to emphasize sales, and whatever resources were left over, which were not much, were parcelled out to finance, design, and manufacturing.

The Company That Could specialized in nothing. They believed in maintaining a balance of skills within all of their functions. Their salespeople could sell, but not "refrigerators to Eskimos." They sold to serve the needs of their customers. Their engineers designed products that their salespeople could sell and their factory could produce. Most important, they tried to determine how best to make their products and did not depend on vendors to equip their plants.

The competition to introduce the new product to the marketplace was fierce. At first, the Company That Couldn't had a substantial lead over the Company that Could. Their order books were full and their factory was swamped with production requirements. In order to produce the new product to meet customer demands, they relied on their traditional method. They asked their equipment vendors to supply them with equipment to do the job. The vendors, exceedingly happy to do so, provided the Company That Couldn't with all sorts of equipment which, they claimed, "was the ultimate in making the new product." Perhaps it was, but the Company That Couldn't failed in making the product. The price to make it was higher than the selling price, and the output did not meet demand. Why? They did not have an understanding of the equipment. It was probably too complex. They also did not have the knowledge to manage the factory. Their management staff did not know how to train their workers to make the product on the vendor-specified and vendor-designed equipment. They also did not match their product design to the equipment they bought. All of this happened because the Company That Couldn't did not pay attention to supporting a balanced organization.

The Company That Could had a much different approach. They found out what the market wanted in the new product. Then they designed the product and presented it to their marketing, finance, and manufacturing departments. Marketing reviewed it for what the customers really wanted in the product. Manufacturing reviewed it for ease of manufacturing and how much it would cost to make. They determined whether existing equipment could do the job, or whether they had to develop something new. They thoroughly explored how they would train their operators to make the product. They determined what the critical design elements were and how many units of the new product they could produce in a given time period. They also estimated the costs for development and implementation. Finance reviewed these costs and stated what the company could afford.

After several iterations of this process, the Company That Could was satisfied that it could successfully enter the market for the new product. And as a result, the Company That Could took the market away from the Company That Couldn't. They were able to produce products that were of better design and higher quality, to produce them at a lower cost, and to deliver them on time. This was possible because the Company That Could had a balanced approach. It worked as a team with all facets of its operations participating. Perhaps even more important, before it tried to sell the new product, it learned how to make it so that it could be sold at a profit.

The moral of this story is that manufacturing engineering is a vital part of a company's success. Learning how to produce at the lowest costs and still meet the constraints of the design and the marketplace is essential for any company. This fable is universal. As long as a company is engaged in providing a product or service it will require a balanced team approach to be successful, and manufacturing engineering will always be a vital team member. This book is about the techniques and philosophies of manufacturing engineering that make industrial organizations "companies that could."

THE INDUSTRIAL MATRIX

Let us first look at the makeup of a typical industrial organization to see how manufacturing engineering fits in this matrix. An industrial organization must, at a minimum, consist of sales, operations, and finance. Traditionally we think of this breakdown as: marketing, finance, design, and manufacturing; where the latter two make up the entirety of operations. These basic functions can be further refined to another level. For example, design can be broken down into research and development, applications engineering, and product service.

Now let us look at the basic responsibilities of each of the major functions.

Marketing: Define what is sellable within the charter of the organization and then sell it.

Design: Based on what is sellable, design the product in accordance with good scientific and engineering principles and produce the specifications for the product.

Finance: Raise the necessary funds for the organization and dispense them in accordance with recognized fiscal practices. Keep track of all funds to optimize their uses.

Manufacturing: Produce the product at the lowest possible cost, in the shortest possible time, and in such a way that it meets all design specifications.

The four functions are interrelated, of course. Marketing cannot obtain orders for products that manufacturing cannot produce or design cannot engineer. Finance must recognize that it is supporting a manufacturing entity; its policies, for example, cannot be based on principles developed for the successful operation of banks and insurance companies. Design cannot specify products that are beyond the scope of manufacturing to produce. Nor can it ask for nuances that improve the elegance of the design but do little to improve the saleability of products. Manufacturing must live within the budgetary levels deemed prudent by finance and must make the product within the specifications required by design. Manufacturing must also deliver finished goods in accordance with the desires of the customers as defined by marketing. Marketing must take into account the effects on manufacturing of all delivery promises made to customers.

THE MANUFACTURING MATRIX

How does manufacturing engineering fit into this organizational matrix? Manufacturing consists of two major categories: shop operations and support. It is necessary to understand the duties of these categories to properly understand the role of manufacturing engineering.

Shop operations is the producing arm of manufacturing. Here management directs the activities of people, machines, and processes in producing the product in accordance with an overall schedule.

Shop Operations receives the equipment, instructions, raw materials, and master schedule from the service groups, then applies labor to produce the product.

The service groups consist of materials, quality control (sometimes known as quality assurance), and manufacturing engineering. Their function is to provide direct support to operations in the form of raw materials and equipment to work with and information on how to use both.

Materials

Materials has the responsibility for producing a master production schedule in accordance with orders received and anticipated by marketing. The materials sub-function, then, controls and monitors the production schedule of shop operations, the transmission of specification information from design to manufacturing, and the supply of manufacturing instructions from manufacturing engineering to shop operations. It has the other major function of purchasing raw materials and supplies and ensuring that they arrive on time to support the overall master production schedule while minimizing inventory costs. It also controls all raw materials and finished goods in storage locations before the former is released for production and the latter distributed to customers. It normally does all this via management of the Manufacturing Resources Planning (MRP II) program, also known as Enterprise Resources Planning (ERP).

Manufacturing Engineering

Manufacturing engineering has the responsibility for instructing shop operations on how to make the product, the sequence, and the facilities to use. It also has the overall responsibility for planning the nature of the factory and its present and future equipment.

In addition, manufacturing engineering evaluates capacities per time frame for marketing to use in sales strategies; evaluates manufacturing capabilities for design engineering to use as constraints on product specifications; and evaluates current manufacturing performance for overall monitoring and for modifiers to capacity and capability evaluations.

Manufacturing engineering is responsible for the maintenance of current equipment and the evaluation and purchasing of new equipment. It also provides this service for non-producing facilities such as buildings, offices, vehicles, and other miscellaneous items.

Another function frequently assigned to manufacturing engineering is that of process control. Measurements of quality are continuously made during a process, usually as part of the traditional system of evaluating productivity performance. This is a relatively recent amalgamation of duties and strives to combine the requirements for high quality with those for improved productivity necessary for corporate survival.

Quality Control

Quality control has traditionally been the liaison between manufacturing and design. This function interprets design's specifications for manufacturing and develops the quality plan to be integrated into manufacturing engineering's methods and planning instructions to operations. Quality control is also responsible for recommending to management what level of manufacturing losses (cost of mistakes in producing the product) can be tolerated. This is based on the complexity of the product design, specifically the degree of preciseness necessary in tolerances. Quality control traditionally monitors manufacturing losses by setting a negative budget that is not to be exceeded, and establishes routines for measurement and corrective action. Although, now with zero defects being a defined goal, the concept of losses budgets is becoming increasingly taboo. This is unfortunate, since from a pragmatic view, a six sigma realization is fictitious (but not necessarily an erroneous objective).

Within the past decade or two, quality control has become increasingly involved with marketing and customers in establishing documentation systems to ensure guaranteed levels of product quality; e.g., managing the ISO 9000 program. This new role has led to the new title quality assurance, to differentiate it from traditional in-house quality control.

Quality assurance strives through documentation of performance and characteristics at each stage of manufacture to ensure that the product will perform at the intended level. Whereas quality control is involved directly with manufacturing operations, quality assurance is involved with the customer support responsibilities generally found within the marketing function. Many industrial organizations have chosen to establish an independent quality assurance sub-function within the manufacturing function and have placed the technical responsibilities of quality control, namely process control, within the manufacturing engineering organization.

MANUFACTURING ENGINEERING RELATIONSHIPS WITH OTHER FUNCTIONS

Manufacturing engineering interacts with the major functions of the industrial organization as well as the subfunctions within manufacturing. Manufacturing engineers are essential in future business planning activities led by marketing, where factory capabilities and know-how on optimizing costs are paramount in any strategy. Their inputs are vital to finance for planning future allocation of funds, and their definition of what is manufacturable and what is not, and the various degrees in between, greatly influences the design function and the type of design specifications produced.

MANUFACTURING ENGINEERING WITHIN THE MANUFACTURING FUNCTION

Figure 1-1 depicts the organization of the manufacturing function with a specific breakout for manufacturing engineering.

There are several alternative ways to depict the manufacturing engineering organization. For example, there could be a producibility engineering unit under advanced manufacturing engineering (AME) if there is a sufficiently strong need in a particular company's operation. Likewise, some managers choose to have separate methods engineering units if their products demand continuous redesign of workstations and fixturing. Another breakout could be that of a computer

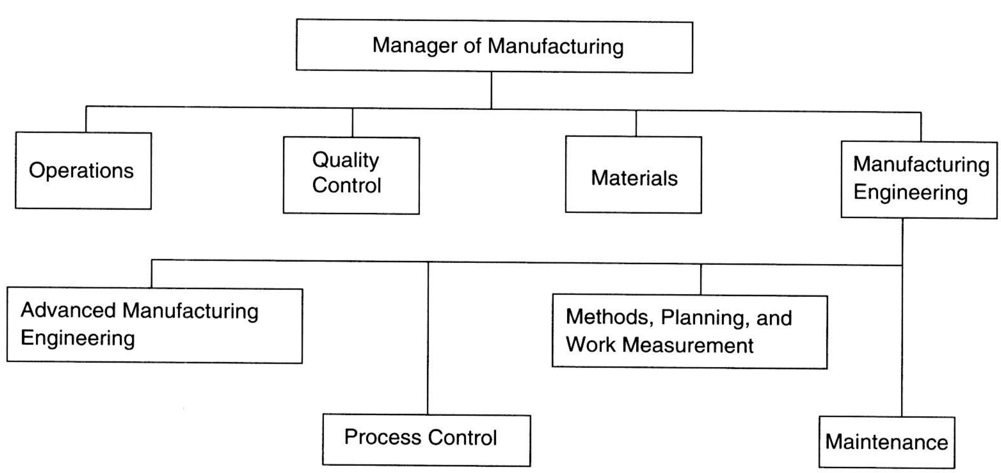

Figure 1-1. Organization of the Manufacturing Function with a Breakout for Manufacturing Engineering

integrated manufacturing (CIM) systems unit with resources derived from AME and from the methods, planning, and work measurement unit. This would be especially useful if the company was just beginning integrated computerization. Process control could very easily be a quality control unit, and in many organizations it is. It is included here as a separate unit because of its inherently technical nature compared to the trend in quality control toward nontechnical activities supporting marketing.

The point here is that manufacturing engineering organizations are not cast in concrete, but can and should be modified to fit the specific needs of individual companies. The organization shown in Fig. 1-1 is the classical manufacturing engineering organization. These units cover all phases of manufacturing engineering's responsibilities. We will now define the charters of the four manufacturing engineering units.

ADVANCED MANUFACTURING ENGINEERING

The major responsibilities of the advanced manufacturing unit are:

- Area planning
- Capacity analysis
- Capability evaluations
- New technology evaluations and needs
- Producibility engineering
- Computer-integrated manufacturing development
- Investment project management
- Long-range planning and forecasts

A separate engineer could have each or several of these responsibilities, or several engineers could share one area of responsibility. It matters little what the specific organizational structure looks like as long as all responsibilities are properly attended to. For simplicity, we will discuss each area of responsibility separately.

Area Planning

This activity determines the present and near-future shape of the factory to meet all needs for facilities. Area planners use the master production schedule of the materials subfunction to determine what the factory must produce. They match the requirements for production with the present capabilities of the factory and then develop plans for additions and modifications to the factory's equipment so that production plans can be met. Area planners are the experts on factory floor layout, well versed in the capabilities of the many types of equipment and processes. They must also have intimate knowledge of the services available and needed in conjunction with these types of equipment and processes. For example, they must be aware of the electric power, voltage, amperage, phase, AC or DC power, transformer, and filtering requirements for control circuits; availability of potable and sanitary water; purity and pressure of compressed air; pressure and condensate control of heating and process steam; hook height above the floor and lifting capacity of cranes; number of cranes on a rail; and sundry other items involved in making machines work and getting materials to and from those machines; and other technical specifications as needs arise.

Area planners work with materials schedulers, marketing analysts, design engineers, manufacturing engineers, and others to determine the needs of the factory for the near-term to medium-term future. They compare the requirements to current capacities and decide whether the factory has the necessary equipment to meet the future needs. If it does, the area planner simply verifies that fact for management. If there are shortfalls in capacity, the area planner will notify management recommend a course of action to remedy the situation.

The area planner has another function, that of optimizing present capabilities so that the factory can produce products at the lowest possible cost. This responsibility is a corollary to that of determining the shape of the factory to meet future production goals.

The work tools of area planners are the various layouts (factory floor blue-prints) and capacity evaluations for the equipment and processes. Area planners are systems engineers. Their task is to gather information from experts and determine whether a manufacturing flow exists. If it does, is the flow sufficient to meet production volume needs? If it does not, what must be done to rectify the situation? They obtain information on capacity from the capacity analysis and capability evaluation sections of advanced manufacturing engineering. Information on machine rates of speed comes from the methods, planning, and work measurements unit. The physical characteristics of the machine tool processes are obtained from the maintenance unit or the engineers responsible for new technology evaluation and needs or investment project management.

After assembling the necessary information, the area planner begins to place facilities on the layout to achieve the desired product flow. The layout covers either the entire factory floor or specific portions of it, depending on the scope of the task at hand. If the master production schedule calls for producing the same product, but more or less of it, the layout will probably cover only a portion of the factory and concentrate on optimization of current equipment, or perhaps an addition to the equipment inventory. If the plan calls for introducing a new product, a total layout will be required showing how to integrate the old and new products and how facilities are to be shared or dedicated. The flows will also have to be considered for interferences. Typically, the area planner will use templates derived from a computer software layout program to locate facilities on the monitor screen and will list the capacities and required services next to the templates. This procedure will reveal bottlenecks where there is too large a difference between facilities and capacities. After identifying bottlenecks, the area planner will determine the alternatives for solution, such as adding additional similar equipment or substituting improved or larger capacity equipment. Once a layout is produced, reviews with shop operations and other manufacturing engineering personnel are scheduled in order to obtain operational viewpoints and other technical inputs. Usually, valid points are made during these reviews which result in a need for further refinements and iterations of the layout.

As implied above, area planning is an art as well as a science. It involves many engineering disciplines, which must be artfully melded together to achieve an optimal factory plan. This melding is the task of the area planner, who is most often a senior manufacturing engineer.

Capacity Analysis

Capacity analysis is the detailed study of the amount of current product and product mixes that can be produced within a specified period of time. This information is vital for the makeup of the master production schedule and for marketing sales strategies.

Engineers in this discipline are very concerned with the product mix being imposed on the factory. They traditionally convert specific products to the basic elements of fabrication time, machine time, process time, and assembly time necessary to manufacture them. They create prototype workstation loads per product. Knowing the amount of product to be produced in a given time period and the work time per manufacturing element, it is possible to calculate capacity, which is normally expressed as capacity per workstation. The engineer can then specify which manufacturing areas have the capacity to produce the load and which areas do not. If a factory is required to make more than one product at a time, which is often the case, the job of determining the capacity becomes more complex, and as a practical matter capacity analysis is not usually done. Instead, the engineer will show limits; that is, 100% product A—0% product B, and 0% product A—100% product B, etc.. The engineer will also list the number of hours per workstation required for each product. With this information the factory limits are established. This is sufficient because the master scheduler, using the MRP II system, is mortgaging time against workstations in order to load the factory. Hence, the scheduler is interested in work elements as devised by the capacity analysis engineer.

The work of the capacity analyst is normally transmitted to the area planner for inclusion in the master plan for the specific area. In many manufacturing concerns, capacity analysis is considered part of area planning.

Capability Evaluations

Capability evaluation is the analysis of what tolerance can be created at what incremental cost, what critical processes can and cannot be performed, and what maximum size and weight can be handled in the factory. This information is critical for the design function's ability to continuously evolve the product or product lines. Design engineers must understand the limitations of the factory in order to design the products for the factory. Engineers involved in capability evaluations have the responsibility for determining the limitations and codifying the results for use by others.

These engineers require very detailed evaluations of equipment performance and an understanding of the present capabilities of equipment. They must understand the effects of deterioration of equipment on its ability to produce to close tolerances. Their primary function is to be aware of the performance level of the equipment and to periodically update the database.

Capability evaluation engineers perform another vital function, that of technically evaluating proposed products to determine whether they can be made. If it is feasible to make a proposed product, then capability evaluations engineers will develop the preliminary optimized sequence and workstation selection to be used in making the product. This is done in close consultation with the area planner for integration with the factory's master plan. Like capacity analysis, capability evaluation is often considered to be part of area planning.

New Technology Evaluation and Needs

The competitive marketplace requires that manufacturers continuously evaluate costs of production. Failure to do this invites competitors to erode away hard-earned market share and makes it more difficult to sell one's product. Just as the design function must continuously evolve a better design, so the manufacturing function must continuously evolve better ways of producing the product. The goal is always to reduce the cost of production. The process of reducing cost is done by knowing how the product is made and searching for new types of equipment to produce the product at lower cost.

Considerable effort is expended in keeping current on new ways to produce the firm's products. This is usually done by maintaining close liaison with vendors who sell equipment traditionally used by the company, attending trade shows, participating in technical societies' programming, and, of course, regularly reading pertinent trade and technical publications.

Engineers involved in new technology evaluation produce a series of reports on new technologies of interest to the firm. These reports become the research basis for long-range planning and product introductions.

Producibility Engineering

Producibility engineers ensure that designs produced by the design function are workable, that is, optimally producible in the company's manufacturing facilities. Producibility engineers deal in tolerance evaluations and changes in design to facilitate manufacture on optimal machines and facilities. Another task is to document detailed factory limitations and procedures for the understanding of design engineers. Their main goal is to lower the costs of making the product by obtaining design optimization relative to manufacturing needs. The producibility engineer is often said to be the manufacturing ambassador to the design function. They interpret manufacturing capabilities for the designers and convey the designers' real needs for product functionality to manufacturing.

The producibility engineering discipline has become more important as the need for productivity improvement in industry has increased. This discipline, once one of many in the spectrum of manufacturing engineering, has been singled out as decisive in helping industries compete in the