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FACILITIES, PLANNING AND MANUFACTURING SYSTEMS DESIGN

A DISSERTATION

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FACILITIES PLANNING AND MANUFACTURING SYSTEMS DESIGN

A Dissertation Presented

By

ALBERT HENNING JACOBS, JR.

Submitted to the Graduate School of the
University of Massachusetts in
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ABSTRACT

A conceptual framework for the logical planning and integrated design of manufacturing facilities. A logical, systematic approach to the creative conversion of the corporate need for goal satisfying outputs into specifications for an economically and socially optimum plant is developed to fill the void between the well developed technologies of long range planning and structural design.

Research revealed a prevalent incognizance of the importance of effective planning for facilities and specification of plant systems before commissioning the design of a plant structure. This dissertation develops and describes the management technology needed to overcome this deficiency.

The concept of the plant as an open, living, adapting transformation system is developed and followed by managements's role in creating optimum manufacturing systems. The critical need for and impact of corporate goals, strategy, and long range planning, plus plant location and timing of planning and implementation are discussed.

Means are developed for determining the scope of transformation needs: including stochastic demand/capacity analysis, an original management science technique, and the incorporation of new technological developments. Methods are developed for analyzing the firm's ability to engage in plant expansion or replacement and for adapting to long term limits in physical and human resources, particularly management. Effective completion of the analyses of needs and ability, the facilities planning effort, enables the auspicious launching of manufacturing systems design.

Manufacturing systems design is divided into four principal activities: determining the characteristics of three major subsystems - managerial, technological, and environment - and integrating them into an optimum system. The effectiveness of designing management control systems prior to establishing physical configuration is developed. The validity of integrated product/process design and the need for creativity are expounded, and a comprehensive logic of production is developed. A systems approach is developed for alleviating if not negating the cost of environmental control. Finally, the means of integrating the subsystems into an overall plant configuration are developed. The result is a set of specifications to guide the detailed structural and mechanical design, construction and implementation.

INTRODUCTION

This is not a dissertation on architecture. Plant layout and location have been covered well by those before me. The field of management science has spawned a myriad of applicable planning, control, and analysis techniques.

But no one has presented the means of planning and designing a plant - the base system of a manufacturing concern. All of the expounded techniques are "tack-ons" to the historic, often chaotic, process of building, equipping, and manning plants. The customary approaches consistently lead to costs over budget and long "de-bugging" periods. They often lead to gross errors that commit a firm to a poor way of life for a generation.

Facilities planning is not a problem in engineering or architecture. It's a problem in management. Success or failure in the development of new manufacturing facilities is entirely within the purview of management. This discussion is intended to bring to management's attention the means of effectively and economically planning for new facilities and guiding their design.

To accomplish this purpose, the concept of the plant as a complete, integrated system is developed in Chapter I. The interrelationships among the management, the people, the environment, and the technology of the plant are emphasized. The basic contention is that effective planning for industrial expansion demands viewing the plant as a system.

Then this discussion outlines the essential long range management planning prerequisite to effective industrial expansion. Chapter II develops the vital relationship between the plant and corporate strategic goals, and develops the means of determining whether expansion is actually needed. Chapter III defines the resources essential to effective expansion - particularly, management - and deals with their development. When the firm truly needs expansion and has developed the wherewithal, then, and only then, can effective plant design begin.

The next three chapters describe and outline the means of determining the characteristics and interrelationships of three major subsystems of the plant -- management, physical technology, and environment. In each, management technology is advanced with new concepts and approaches to superior plant design. In Chapter IV, the effectiveness of designing control systems prior to establishing the configuration of physical facilities is developed; in contrast to the literature, needs for control are recognized as parameters of physical structure in many circumstances. In Chapter V, the validity of integrated product/process design and the need for creativity are expounded; further, a comprehensive logic of production is developed -- a break with the traditional, limited concepts of line, job shop, and fixed position manufacture. Chapter VI develops a systems approach to alleviating if not negating the cost of environmental control.

Finally, Chapter VII brings all the planning and systems design factors together in the form of "outline specifications", in architectural parlance. The means are developed for setting the parameters for the following stage, detailed product, process, control system, equipment, and building design. The organization of and communication among professional personnel are discussed.

The outgrowth of years of research and consulting in systems, long range planning, and new plant design, this dissertation develops an advanced management technology for determining the economic need and timing, the systems requirements and relationships, and the design of the plant, defined as an integrated socio-technical system. This is a new technology that establishes the parameters of optimum industrial facility design. The techniques are foreseen to be adaptable to other areas of long range planning and systems design, but the discussion is limited to industrial facility expansion.

As with any advancement in knowledge, this technology is related to other technologies and built on a foundation of preceding technologies. These are recognized throughout the text and in the references. The primary preceding technology is the growing application of systems concepts and techniques to:

- understanding general management
- long range planning and strategy development
- the development of management control systems
- the design of man/machine systems

Throughout this dissertation and, particularly in the discussion of product/process design, the influence of my interest and research in creativity and in the management of integrated design is revealed. Finally, my research, and teaching, in the subject, Technology in Society, led to the development of a systems approach to designing and controlling the plant environment at minimum cost and to the exposition of the essential recognition of human needs in plant design.

In developing and confirming my theories of optimum industrial facilities planning, 22 firms, considering or involved in plant expansion, were examined and interviewed. In addition, a number of others were investigated to varying degrees to a total of about 40 that are pertinent here. The theories were applied and corroborated with success in a $6,000,000 plant of unique design for Package Machinery Company of East Longmeadow, Massachusetts.

I wish to acknowledge my indebtedness for the indispensable aid given by:

1) Roger L. Putnam, Jr., President of Package Machinery
2) Dr. Stephen R. Michael in organization and long range planning
3) Dr. Van Court Hare, Jr. and Dr. Robert E. McGarrah in management information and control systems
4) Dr. Pao L. Cheng in my development of "Stochastic Demand/Capacity Analysis".

CHAPTER I

THE PLANT

Industrial engineers are often faced with the workman's contention that more production means more and harder work. "On the contrary," is my answer, "I'm here to show you how to work smart, not hard."

"Production is not the application of tools to material. It is the application of logic to work," according to Peter F. Drucker.

This philosophy can be applied on a grander scale to prevent unnecessary work by properly planning the plant before it is built. Unnecessary work means unnecessary cost whether in design, construction, or operation.

Basic to the logic of facilities planning is that a plant is not a building - it's a transformation system. It transforms inputs of limited resources (men, materials, money) into outputs (products) of higher value, we hope, than the inputs.

The plant system is made up of a number of major subsystems:

process, including machinery
material flow (or lack of it)
management schedules and controls
management structure, coordination, and politics
social systems, including workmen and unions

plant utility and effluent systems

and, incidentally, a building.

That these subsystems exist is evidenced by the prevalence of manufacturing engineers, industrial engineers, production control specialists, personnel directors, plant engineers, etc. Each of these does a fine job in his area - with insufficient regard for the others, as will be developed later.

Knowing that all these subsystems exist, why is it that we continue to design the building and then force all else to adapt to its shape? Why do we continue to build factories with 40' x 40' x 20' spacings for apparel, food processing, armaments, plastics, machinery, tires, etc.? Why do we continue to build monuments to architects and contractors instead of plants for the stockholders and community?

I submit that plant design has been mistakenly delegated to the specialists in factory building design. That they are not competent to design plants is manifest in every industrial park in the nation.

I was once asked to lay out a paper converting process in a proposed plant with column spacings in a multiple of ten feet - because the old plant had columns ten feet apart. I refused because the machinery required 12' spacings. (I later visited the plant to find the columns spaced 48' x 60'.) I was engaged to develop a plant for a major American corporation within a building set by the financial group in a sale-lease-back arrangement. The necessary building alterations added leasehold improvements amounting to 25% of the original investment. (Try converting a warehouse into a plant requiring elaborate security and ecological control systems.) These are but two examples of the recurrent errors that cause new plants to be excessively costly and initially inefficient.

If not to architects or builders, to whom is management to turn for effective plant planning and design? The plant layout specialist will optimize material flow. (I haven't seen a plant yet where optimum material flow meant overall optimum operation. Invariabley machine utilization, production control systems, etc. mitigate optimum flow.) The process engineer will tend to maximize machine utilization. Production supervision will endeavor to minimize direct labor. This list could go on with questions about the natural bias of specialists in financial requirements, management controls and supervision, market trends, new products, community relations and requirements, social responsibilities, etc.

Then to whom is management to turn? Only itself. It must take the responsibility for planning the total plant system and setting the design parameters for the specialists.

An impossible task? No! I have guided a number of managements in performing the needed functions. Only one key generalist needs to be obtained (preferably from within the organization) to manage the necessary project.

The chapters that follow hopefully point the way for management to accomplish the tasks necessary to the effective planning of new plants and their subsequent design.

Manufacturing Systems

It is appropriate here to outline the concepts from systems theory adapted to the needs of manufacturing systems design.

In order to establish a base of reference we should first define the term system. A system is a group of units so combined as to form a whole and operate in unison; an organized whole. Thus, a manufacturing system is a collection of diverse, interacting man and machine elements integrated to achieve some objective through manipulation and control of materials, people, energy, and information.

Systems engineering (or design, analysis, planning, approach, etc. as suits your taste) takes an overall view of large, complicated and costly projects and questions the details of subsystems or components only insofar as they affect total system performance, effectiveness, and cost. Thus, details of forecasting, process and plant layout, architecture, construction, etc., are to be dealt with only by reference and as required to show the interactions of the various plant subsystems. This is because the subsystem technology has been covered well by publications before this one, and the approach in this discussion is to organize the plant subsystems into an integrated whole, operating in unison.

The systems approach, adapted to our needs, consists of the following:

a) defining in quantitative terms the needs to be met by the manufacturing system
b) determining the criteria of effectiveness by which the system is to be measured - economic, technical, social, adaptive
c) determining the resources required to operate the manufacturing system
d) conceiving or selecting subsystems that are at least potentially capable of forming the desired system; innovation, creativity
e) determining and specifying the optimum characteristics of the subsystems and their interrelations through trade-off studies
f) determining the configuration of the total system
g) specifying the characteristics of the total system and subsystems for the benefit of specialists in design and implementation
h) buiding the design and implementation of the manufacturing system

i) evaluating the performance of the system by comparing it with a) and b) above.

These general definitions, as widely applicable as they are, serve only as a place of departure for a more explicit definition of a plant as an integrated manufacturing system.

The Plant

What is this thing called a plant?

If this question brings to your mind an image of building and machines, you are oriented to the technological subsystem. If you visualize "the boys in the shop," your orientation is to the social system. And so on.

The plant was earlier characterized as a transformation system made up of several subsystems recognizable in terms of staff functions. To enhance the effectiveness of overall design it is better to view the plant more comprehensively as a socio-technical system.

The traditional view of a plant is that of a building containing machinery. In reality, this is only the physical manifestation of a technological subsystem of the total plant system. More generally, the technological subsystem is the chemical or physical process and material flow necessary to transform material into products plus those myriad techniques of control and maintenance. This sybsystem cannot function alone.

Alongside it there must be a work organization to carry out the tasks necessary to the functioning of the technology. Technological demands certainly limit the work organization, but the ability to develop appropriate work organizations significantly limits the ability to apply technology effectively.

The work organization may be viewed as two interrelated subsystems. Within every plant there is a psycho-social subsystem consisting of the people - their social relationships, aspirations, and personal values. There is also a managerial subsystem consisting of supervision and econotechnical control systems - but more of this later.

Overlaying all the plant subsystems is a system of objectives or goals. Included here are more than market, product, or profit objectives. The company's basic policies concerning social responsibilities to employees and community warrant major concern in planning. The response to legal and ecological demands is becoming of increasing concern. And not to be forgotten are the basic ethical values of the owner/management.

A somewhat different view of the plant system which is of value to facilities planning may be drawn from Talcott Parsons. He suggests that there are three managerial levels in the hierarchical structure of complex organizations:

1) the technical or production level
2) the organization or managerial level
3) the institutional or community level

The technical system involves the actual task performance of the firm. This does not mean just the physical work in producing a product; it includes all forms of technological activity using knowledge - production control, accounting, maintenance, warehousing and distribution activities, market and product research, engineering, etc.

The second, managerial, level coordinates and integrates the task performance. A primary function of management is to determine and integrate the input of material, manpower, energy, and information into the transformation system and to evaluate its output for purposes of feedback and control.

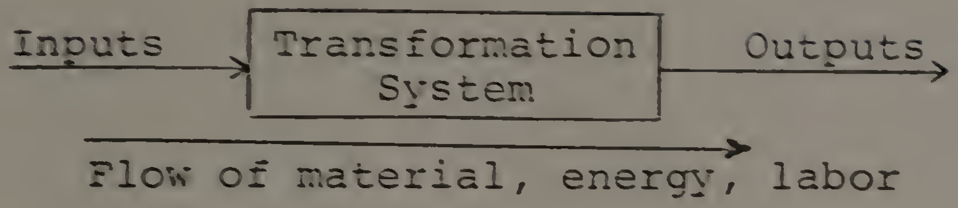
The institutional level involves relating the organization to its environment and, today, the ecological system. An organization, or more generally any system, must receive supporting inputs from society continually if it is to continue to live and perform its transformation activities. A major function of management is to continually evaluate the demands of and opportunities in the organization's environment and "feedback" the information to the transformation system. Thus, a plant may adapt and evolve to thrive in its environment.

The concept of feedback has been mentioned, so it should here be defined. Feedback, simply defined, is information. Since so much early control work with systems involved evaluation of output for purposes of controlling input, the information on output was thought of as feeding back to modify input. Actually feedback may be any information input into a system; it may be "negative" or corrective to modify off-quality output or "positive" in the sense of recognizing new opportunities and changing the output to fulfill these opportunities.

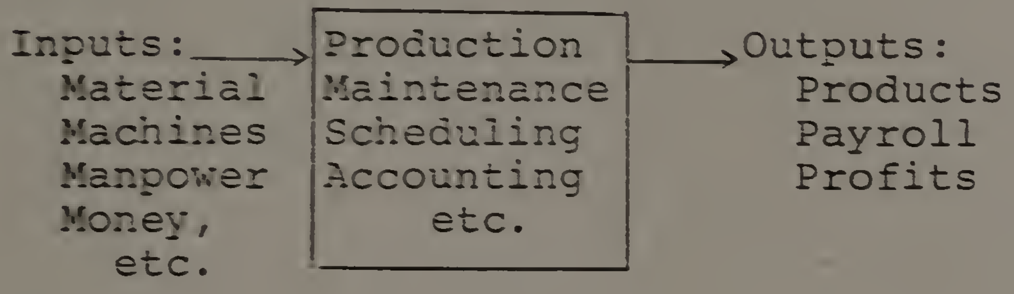
A concept implied but not yet isolated has been system boundaries. Any system has points of interaction with other systems and also as a subsystem of a still larger system. (The term interface is also used in this context.) Thus, the production process has boundaries with production control, maintenance, ecology, etc.; the plant has boundaries with the corporation, community, government, and the ecology.

Traditional approaches to plant expansion have been inadequate primarily because of insufficient recognition of the interactions and feedback among the plant subsystems and between the plant and its environment. Thus said, the burden of this discussion is to point the way to adequate recognition and response.

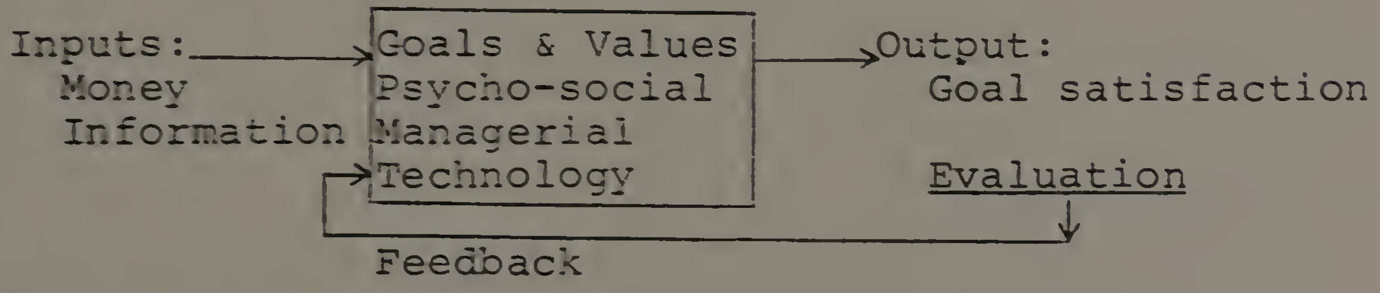
The concepts of the previous paragraphs might be better expressed graphically. First, the plant was simply defined as a transformation system.



Viewing the plant traditionally, the "black box" might look like this:

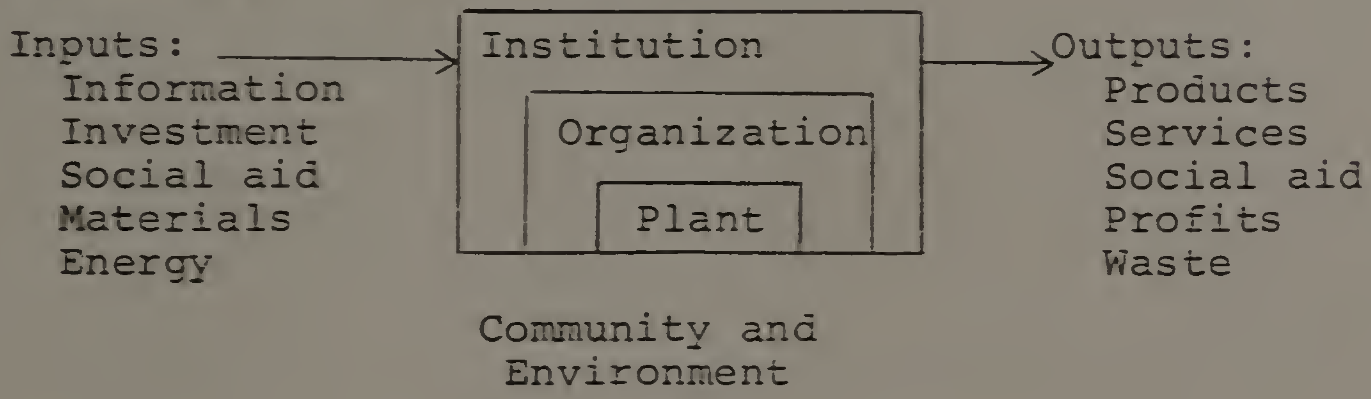


A more comprehensive view of the plant using the same graphical approach is:



Here the "black box" contains the basic plant subsystems: technology, a work organization made up of psycho-social and management subsystems, and an overlay of goals, values, ethics, and policy. Note that the choice of inputs and outputs is effected by the view of the plant as a part of a larger corporate system. The corporation (institution) puts in only money and information; the plant secures its men, materials, etc. Its only output is goal satisfaction. A product must be considered as a means to corporation satisfaction rather than as an absolute end. Negative goal satisfactions will be found in waste, ecological and community damage. Later sections will further develop the concept of goals.

Expressing this last view after Parsons, the manufacturing system would appear as:



Note that the outside line expresses a boundary with still larger systems of community, government, and the ecology. One side of the plant boundary depicts the impossibility of isolating the plant completely from the greater environment.

Drawing on the above concepts from systems theory, throughout this discussion the term plant shall refer to a productive transformation system made up of a group of socio-technical subsystems so combined as to form a whole operating and adapting in unison in an ever changing environment.

Management's Role

A widely recognized, prime responsibility of management is the integration and coordination of operations. Unfortunately, the same responsibility for design is not generally recognized. With such exceptions as aerospace hardware and chemical processing where the technology enforces a systems approach, little effort is made to coordinate design activities so that an integrated system may be achieved.

It is the thesis of this discussion that if a goal satisfying plant is to be achieved, management must act on its responsibility to coordinate and integrate the design. Further, the thesis is that only management is in the position to achieve integrated plant design. A plant, as defined, needs to be recognized as a means to a corporate goal and as a subsystem in its environment - market, investment, community, and the ecology. As noted earlier, policy making management - the institutional level - serves as the interface between the technological plant and the greater socio-ecological environment.

Since the output of a plant has been indicated simply as goal satisfaction, to whom is management to entrust its ability to satisfy its goals in the future? An architect? Plant layout, plant engineering, or plant manager? Marketing? Finance? By the nature of the pressures in our society and organization hierarchies, each of these will tend to optimize his own subsystem to the detriment of the total system. To illustrate, the architect unfettered would design an attractive, stable building in which material handling and machine location might be utter chaos. Optimum materials handling does not lead to optimum machine or manpower utilization. Plant management will tend to minimize labor at the expense of investment. Marketing will want quick response and infinite product variety. Finance will tend to optimize investment at the expense of environmental damage and flexibility - the ability to adapt and survive.

Systems engineers have long known of the principle of sub-optimization. Stated simply, it means that several optimum subsystems do not add to an optimum system. "Penny wise, pound foolish", goes the adage. If each subsystem is designed optimally and independently, they will not fit into an integral whole. The pieces won't fit the puzzle. The system lacks integrity.

A form of suboptimization particularly a problem in plant design is allowing one subsystem of management to dominate the other subsystems. Such a plant may have integrity and fulfill an objective - but a biased objective, say productive efficiency versus market flexibility. The plant would not be optimum.

Thus, management is derelict when it attempts to delegate its determination and achievement of goals in plant design. Management may think it is determining goals when delegating plant design to a specialist but it will find after the plant is built that the system is determining the goals instead of the goals determining the system.

Means of determining goals will be discussed in the next two chapters, but it is pertinent here to outline three universal management goals that are basic to all facilities planning and to this discussion.

First, it is assumed that the universal corporate motive in planning facilities expansion is long-term maximum return on investment (ROI). Rapidly increasing costs of construction, equipment, manpower, and money will force closer scrutiny of ROI in coming years. There is a danger that this need will cause the more effective but complex techniques of calculating ROI to be adopted with misunderstanding and therefore misuse. Despite this danger, the only "universal" measure of economic optimum is time adjusted return on investment. All subsystem design alternatives can be evaluated in this manner; though the social ones, quite subjectively. To fully utilize the measure, the economists' concepts of marginal analysis, time value of money, and value added must be brought in. (See references.)

Second, purely economic considerations must be modified by accepting in spirit the myriad social responsibilities. For instance, employee facilities must not only fulfill code requirements but also be attractive, easy to maintain, and conducive to employee acceptance. The ecology must not only be maintained but improved; management must prevent pollution in noise, water, air, erosion, etc. Facilities must be designed to encourage acceptance as a neighbor in the community and nation. We could be crass and rationalize this as not all altruistic. In the business environment today the firm that abuses society or the ecology may find its survival as well as its ROI in jeopardy. Recall that in the diagram of the plant system social aid appeared in both inputs and outputs. Business expects aid and services from governments and communities, and those social groups expect, nay demand, social contributions by business.

The third goal of universal applicability is the flexibility to economically adapt to changing technology and environment. This might better be thought of as a criterion of design resulting from the basic goal of survival. There is only one thing in planning of which we can be sure. Change will occur - in products and markets, processes and materials, communications and transportation, and in social needs. Firms and plants that can adapt will survive, thrive, and, just possibly, prosper. In addition, consciously including flexibility in the design generally enhances economic construction and later maintenance - thus, ROI. Adaptability also alleviates some of the problems in dealing with uncertainty in forecasts.

To the three basic goals each management must add its unique objectives - product strategy, quality level, aesthetic desires, ethical considerations, etc. Simply adding them in is not enough. Because of the "crisis in values" occurring in our society today, there is a growing need to be explicit in expressing management goals and in confirming their fulfillment. Thus, we are back to the coordinating and integrating function of management.

In order to achieve its goals and fulfill its coordinating function, management must build its own organizational structure and talented managerial manpower. Adequate management is so critical to industrial growth that much of Chapter III is devoted to the needs and their development. Without it, industrial growth is but of academic interest.

Finally, it is the thesis of this discussion that management must perform its own plant design. To do so, it must:

develop the necessary management talent
determine and explicate its goals
coordinate and integrate the necessary design
    activities.

Management may employ outside experts to aid its efforts, but only management is in the position to design its house and evaluate how well it lives.

Some Definitions

Throughout this discussion "design" is used in its broadest sense - particularly, including its planning connotation. With the physical and technological implications of the final product, a plant, it is felt more appropriate to use "design" instead of planning with its long-range forecasting and strategic planning connotations. These latter will be taken up in Chapter II.

The terms efficiency and effectiveness will have distinctive meanings that should not be confused. Efficiency follows the engineering context of output as a percentage of input equals efficiency. Effectiveness refers to the extent to which an action results in fulfilling a goal or objective.

It should be emphasized that "technology" is used in its broadest concept as application of technique or knowledge. It is not restricted to physical design, process, or structure. It includes organization, control, information processing, "social engineering", and others. In summary, technology is the rational ordering of means to achieve definite ends.

References

For the novice in the application of systems concepts to management, an excellent, brief, lucid discussion is given in Chapter 5 of: Kast, F. E. and Rosenzweig, J. E., Organization and Management: A Systems Approach, McGraw-Hill, Inc., New York, 1970.

A more engineering approach is given in the introductory chapter by R. E. Machol in System Engineering Handbook, Edited by Machol, McGraw-Hill, 1965. For the serious student of systems engineering the classis is: Hall, A. D., A Methodology for Systems Engineering, D. Van Nostrand Company, Princeton, N. J., 1962.

The publications that have influenced the thinking in redefining the term "plant" are:

Thompson, J. D., Organizations in Action, McGraw-Hill, 1967, particularly Chapters 2, 3, and 4.

Parsons, T., Structure and Process in Modern Societies, The Free Press, New York, 1960, Chapter 2.

Price, J. L., Organizational Effectiveness, Irwin, Homewood, Ill., 1968.

Hitch, C. J., and McKean, R. N., The Economics of Defense in the Nuclear Age, Harvard University Press, 1960, particularly Chapters 7 and 9.

Although strongly advocated as a prime tool of plant design analysis, the following references have done so well in dealing with return on investment (ROI) that this discussion will avoid detailed description.

Dean, Joel, Managerial Economics, Prentice-Hall, 1951.

Barish, N. N., Economic Analysis, McGraw-Hill, 1962.

Jelen, F. C., Cost and Optimization Engineering, McGraw-Hill, 1970.

Machlup, Fritz, "Theories of the Firm: Marginalist, Behavioral, and Managerial," American Economic Review, Vol. 57, No. 1, March 1967.

Hitch and McKean, op. cit., Chapters 10 & 11.

A number of other publications have influenced the thoughts expressed in this chapter, but are better referred to in later chapters in their respective contexts.

CHAPTER II

IS IT NEEDED?

Desmond Morris, author of "The Naked Ape" and "The Human Zoo," recognized the sad truth that the leader who does the wrong things in the right way will tend to attract greater allegiance than the one who does the right things in the wrong way. Man has long been attracted to find technique while seldom questioning the right or wrong of what is being done by the technique.

This discussion may concentrate on how to properly plan plant expansion, but is would be crucially remiss if it did not start from the question, "Is it needed?"

Myths Leading to Unneeded Expansion

Managements generally feel the need for expansion when the existing facilities become crowded and production management complains that it cannot meet the demands of marketing management. Seldom does a management build large new facilities for a new, untried product.

Let's look at some of the reasons for crowded plants before concluding that expansion is necessary.

When the plant was new, the building space was probably in excess of the needs then current. Since space was surplus, space conservation was not a concern of production management. Material was scattered about the floor because pallet racks were not justified by space savings. As new machinery was added the old was not removed, because the space was not needed and the availability of the old gave flexibility to the operations. Gradually these practices became a part of the plant system -- the accepted way of doing things.

Finally, growth of the market, product and process evolution, and the accepted practices have stuffed the space "to the gills". The hue and cry rises for building expansion. In none of the number of plants investigated at this stage has expansion been warranted by current sales or near term sales forecasts. The kind of space or its obsolescence may warrant change but not the amount per se.

A study of a machinery manufacturer revealed that a radically different kind of space was needed because of product change, but now there is surplus space in the older facility amounting to two-thirds that in the newer. An armament manufacturer's new plant is smaller than the space originally allocated to it in a complex of older buildings that the new replaced. A tool manufacturer found upon investigating new processes for an expansion that it had surplus space that could be leased. (In these plants and in others investigated the final layouts were more spacious than the original in spite of freeing space or using less.)

Often during good times a "crowded" plant, perhaps aggravated by poor scheduling or inventory practices, will experience exaggerated backlogs. A common practice under these conditions is to allocate shipments among customers. The customers, realizing this and expecting sales growth, over-order in order to get shipments adequate to their expected needs. Thus, there accumulates "a lot of water" in the backlog. This coupled with optimism in sales forecasts can result in building sizes that would roof a county. When the business cycle changes direction the backlog vanishes not by production but by cancellation.

A thorough study of this and related phenomena of fluctuation has been made by Jay W. Forrester. At least Chapter 2 of his book "Industrial Dynamics" (Wiley, New York, 1961) should be required reading for sales forecasters.

Fortunately, managements have traditionally balked at committing millions in what instinctively appears to be exorbitant size. Nevertheless many plant buildings have been built twice the size necessary.

A related problem in sales forecasting is unwarranted trend projection. The typical product growth pattern is a slow start followed by rapid growth and then a leveling as the market becomes saturated. Sales forecasters often overlook the social, demographic, and economic factors that force sales to plateau. They further tend to overlook the attractiveness of a rapidly expanding market to competition. Thus, excessive plant expansion can result from trend projection.

The habit of trend projection also permeates capacity analysis. The widely touted mathematical techniques of determining machinery and building needs are based on extending present process and production levels to meet projected sales. Unconsciously, present product mix is also extended by this method. Extension of present process is fundamentally wrong in that it:

1) ignores opportunities that have become available in process technology
2) ignores opportunities that become available with a significant change in scale of operations - e.g., batch to continuous
3) Ignores opportunities in changing building technology and often a change in the type of facility needed
4) extends present dysfunctional operating practices and ignores opportunities in the growing technology of control
5) extends present management structure, often beyond its capacity, and ignores the changing economics of scale in administrative personnel.

For a given amount of production, the technology of manufacture available today leads to fewer machines and, therefore, less space and personnel than traditional methods. Thus, extension of present process can result in severe over building, over investment, and over staffing.

Perhaps the most insidious cause of over-expansion is "empire building." While investigating numerous plant expansions, the practice was observed many times. There is the plant manager, whose small plant operates in chaos, who begs for more machinery, men, and building so he can start making a profit (with no increase in sales). There is the sales department that sells volume - at any price. There is the corporation whose managers' remuneration is based on number of personnel, size of facility, and rate of growth - not on profit or return on investment. And there are the firms that make investments based on who requests them - not their economic justification.

The listing of myths leading to over-expansion could go on into the minor causes (including the firm that built a warehouse alongside a factory because of a quirk in their accounting system). Suffice it to say that over-expansion is prevalent.

From the scores of plant expansions investigated, it is concluded that when a management "feels" the need for expansion the odds are about 50/50 that any building expansion is really needed. Additional capacity may be needed, but this does not necessarily mean additional buildings.

Corporate Strategy, Its Impact

It is far beyond the scope of this discussion to delve into the extent and imperativeness of corporate strategy.

The only intent here is to point to its importance in determining plant needs.

For the serious practitioner of corporate strategy development a group of comprehensive references is provided at the end of this chapter. These begin with Boulding's and Drucker's classics and extend through Steiner's tome on planning. The reader is also reminded of the earlier references for a better understanding of the relations of an organization to its environment in formulation of strategy.

A cynical observation drawn from the many investigations leading to this discussion is that a large minority if not majority of managements extant have no strategy or objectives save that of personal survival. When such prevails, these managements have as much need of plant expansion as the black plague. The outcome is likely to be the same - ultimate demise. When corporate strategy is lacking, the problem is management development, not plant expansion.

With the thought that the calibre of management sufficiently concerned with effective plant expansion to read this is also concerned with developing effective strategy, the discussion is better turned to positive consideration of applying plant design to fulfill strategic goals than to cynically deriding those lacking strategy or objectives.

Peter Drucker is probably the most popular writer to recognize that a business enterprise has only two basic functions - to market and to innovate. Fundamental to the development of a strategy is the determination of the proper marketing domain of the firm as related to its resources - particularly management strengths. If the firm is also innovative, it may develop a strategy of expanding or shifting its domain to take advantage of new opportunities created by resource, product, or market development. Whatever the strategy, its market development objectives will determine the need for plant. Plants built for other reasons are doomed to a tenuous future.

A strategy, well developed as the result of market research and analysis of corporate talent, will define objectives for market growth, new product families and extensions of present ones, vertical or horizontal integration, and the demise of products. Achievement of these objectives requires transformation of material inputs into product outputs. It is these strategic changes in needed transformations that determine the need for new plant or for major alteration of the old.

Since the required outputs have probably not been designed, manufacturing methods are hardly obvious. Further, the innovative firm is constantly adopting and developing new technology of transformation. Thus, as corporate strategy forecasts what is needed, there is also a need to forecast how it is to be obtained. A forecast of developments in process technology coupled with a forecast of product developments gives a picture of the probable contents of a plant. Adding a forecast of volume gives an indication of size.

Suffice it to summarize that the only proper base for determining the need for a new or expanded plant is a well developed corporate strategy. Using systems engineering idiom, it is imperative when solving a problem to determine the true problem and the goals to be attained by the solution.

Based on the objectives set by corporate strategy, a plant may be designed to meet the long range needs of the corporation rather than merely repeating the past including the errors. As might be garnered from the previous paragraphs, since strategy is a living, developing thing, so must a plant be a living, developing, adapting organism. This is the reason for isolating flexibility as a prime objective in plant design.

Plant Location, A Strategic Decision

When the corporate strategy indicates the need for new plant the next question becomes where. Surprisingly little is written in the plant location literature about the effect of strategy and long range planning on location. The implication is that management uses a map and dart when the location checklists provided by the literature are not used.

To illustrate, when the strategy calls for both expansion and opening a regional market for a product that requires rapid or costly delivery, the obvious place to put the plant is in the region. (The checklists can aid in being more specific.) When the plan shows the need to convert a mineral or agricultural raw material, the economics generally draw the plant to the material source - e.g., paper, copper, meat, grain. When transportation and distribution are major factors, the plant must obviously fit within the logistical strategy of the firm - e.g., oil and automobiles. The point here is not to deride the plant location experts but to point to the overriding nature of strategy in location.

Location of plants for social or labor relations reasons is also a strategic decision. Locating or relocating a plant to secure a desired labor climate can be a long range disappointment. This writer theorizes that a management gets just the union it deserves. If the same errors are to be repeated in the new location, time will provide the type of union that was left. To have any chance for success, locating for labor reasons requires thoroughly developed strategy and tactics for labor relations and a management thoroughly reindoctrinated in the new approach.

In their efforts to revitalize, urban areas have established industrial parks and have offered enticing inducements to locate in them. Answering the call can have social and economic advantages provided the plant is needed to fulfill corporate goals and:

1) labor skills are available or can be economically trained
2) management talent and professional staff can be obtained
3) appropriate transportation is consistently available.

These three necessities are frequently lacking or unecon-ic to obtain. The euphoria of early public relations dissipates when the plant proves unprofitable or must be closed. In short, location in an urban industrial park must be compatible with corporate long range strategy, goals, and plans in order to assure its vitality.

Urban development often involves replacement. With the spread of large urban renewal projects and expanding highway construction, older plants are often removed and must be replaced. Plant replacement, urban or otherwise, is subject to the error of repeating history. It should be obvious, but is frequently ignored, that replacement presents the opportunity for complete re-evaluation of needs. It provides the economic incentive to completely reshape the corporate strategy. The logical admonition here is that when the opportunity is presented a complete restudy of strategy and long range plans is needed before determining the if, what, and where of new plant.

with this we leave plant location per se. For the "how" of plant location there are scores of articles and consulting specialists in the field. Probably the best book, but out of print, is Leonard C. Yasseen's "Plant Location" (American Research Council, New York, 1960). For the remainder of this discussion it will be assumed that "where" has been determined.

Long Range Plans

Translating strategy into reality involves the long range plan which explicates the marketing and development objectives and their timing. For purposes of this discussion it is expected to include forecasts of present product sales in current markets, extensions into new market areas, probable new product developments and their relations with present and different products and markets, plus stated goals in productivity, profitability, management and professional development, worker development, and material and financial resource development.

The techniques of translating the product/volume details of the long range plan into physical plant requirements are deferred to the section following process projection. This is done to give a better understanding of the impact of developing manufacturing technology on physical requirements.

Analysis of the long range plan may well show no need for new manufacturing facilities. As old products die out and are replaced by new, there may be the need for altered rather than new facilities. Technological developments in process and management can increase production within the present buildings as fast as expansion is reuqired. Product redesign can reduce the amount of work required to achieve the same marketing objective. New products may often be absorbed into present plants through increased capacity utilization.

Suffice it to say here that the forecasts of products and volumes in future years are the input to demand/capacity analysis. The corresponding resource requirements, particularly management, are the grist of corporate capability analysis. The first is covered later in this chapter and the latter in the next chapter.

Timing, A Planning Problem

To this point the long term nature of plant decisions has been strongly implied and is probably obvious to the reader, but the critical decision of "when" deserves explicit recognition. Plant building design and construction requires at least two years from the decision of what and where to full operation. If we include adequate time for planning, it will take three to five years before full operation is achieved.

From the moment that a decision has been made to build a new plant the following are the basic steps and times for a near term project plan.

1) Analyzing and obtaining the necessary managerial and financial resources for the project - 3 to 6 months.
2) Product/Process analysis and design, preliminary layouts - 6 to 18 months.
3) Develop management resources, structure and control systems for operation - one to two years, but may overlap others.
4) Process/building/environment analysis or total system integration - 3 to 6 months.
5) Architecture, engineering, and construction - two to three years.
6) Start-up - 3 to 12 months.

Although some overlapping can be done, about the best that can be achieved with proper design is three years.

From the times necessary to obtain plants, it becomes apparent that anticipating plants being "on stream" at the proper future times to fulfill strategic objectives is a long range planning endeavor. Unfortunately management's track record has not been good in this respect. It takes courage during a recession to commit some of the firm's professional talent to the planning for a new plant needed three years hence at the business peak. It takes wisdom to avoid the crash programs so tempting during a business boom. Crash construction programs are costly, often shoddily designed and built, and often caught by a recession on completion date.

Every economist knows that our boom and bust economic cycles are partially caused by industrial plant investment cycles. This is referred to in the media as business "confidence". When times are good "everybody" is planning, engineering, or building new plant facilities. Engineering, construction, and equipment firms are pushed to capacity and put on overtime. When the economy shows any sign of wavering the whole process grinds to a halt. During my investigations, I observed these phenomena consistently. I was particularly struck to learn that the score of companies contacted in early 1971 were consistently planning to start planning new plant facilities only after the economy rises again. They were, in effect, planning new crash programs.

To summarize the argument, determining when a plant is needed is of necessity a part of five to ten year strategy development and long range planning. The timing of the completion date may be adjusted because of forecasts of future cycles, but the decision of whether should not be based on current business climate. If management waits to see if new plant is needed, the decision comes too late.

There is no time for the kind of planning necessary to secure optimum plant. Only crude guesses, substitutes, adaptations, and uneconomic force fits are available. Without the time for management planning, managements of hastily built plants find much of their future marketing and product strategy determined by draftsmen and construction tradesmen.

It was earlier mentioned that long range marketing and innovation objectives and forecasts are the inputs to demand/capacity analysis. The outputs are physical facilities requirements corresponding to the marketing needs in each future period. These outputs represent complete, operating facilities requiring three to five years to achieve. Therefore, when the future physical needs warrant significant additional capacity, the decision to add capacity must feed back into the long range plan. The start-up, construction, engineering, and planning times determine the starting times for the commitment of resources. The corporate resources needed at each stage can be critically examined, as described in the next chapter, and, if restrictive, early planning can begin for the removal of the restrictions.

Thus, corporate strategy and long range forecasts determine the whether, where, and when of plant planning, while plant needs feed back into the long range plan to set resource development objectives and plans.

Process Projection

The major area of process projection in plant planning is covered comprehensively in Chapter V, but the impact of its feedback on physical facilities requirements is so great that it becomes part of the decision as to whether new plant is needed. An outline of certain fundamental factors in rapidly changing process technology can point to the current and future impact that must be considered before demand/ capacity analysis.

First, automation has reached the fabricating plant - the job shop. Numerical control of machine tools is well established. Robots and numerically controlled machines have been successfully applied in assembly. Direct digital control of groups of machines has been launched in several plants. Automation and digital control have reached materials handling and storage technology. Further, automation has reached into production and inventory control technology.

Numerical control machinery is by far more productive (and flexible) than conventional machine tools. It generally performs a more comprehensive job than the several different machines it replaces; it spends more time working and less time setting up, checking, tool adjusting, material handling, and drinking coffee. It is not uncommon for one NC machine to replace two to several conventional machines. Thus, less machinery is required for a given production volume. In one case eight NC's, all performing the same operation, replaced some 300 machines performing 192 operations.

Second, as a principle of plant design it must be recognized that the real space consumers are people and product. As production expands through productivity there is no corresponding increase in lounge, toilet, locker, aisle, office, parking, and other personnel facilities. As product volume in process is reduced through modern handling, storage, inventory control, and scheduling techniques, the space requirements per unit of output plummet in comparison with conventional methods.

Third, systems engineers have come to the realization that effective information handling has far greater impact on productivity than efficient materials handling. As a principle of systems engineering it may be asserted that if the information flows are properly handled the material flow will almost take care of itself. Further, adequate information flow has a tremendous impact on the productivity of indirect personnel - handlers and set-up men, supervision, and production control personnel. Thus, information flow is critical to the utilization of people and work-in-process - therefore space.

Fourth, the principle of events of low probability states that the fundamental objectives of a system should not be significantly compromised in order to accommodate events of extremely low probability. A common example is those old machines kept around "just in case"; they consume resources while producing nothing. In designing a new plant it was found that providing crane capacity for 5 to 10 heavy moves per year would have added about $1,000,000 to the cost of cranes and building structure while compromising the other 99.99% of the operations; it was cheaper to hire an outside rigging contractor periodically.

Fifth, there is a developing technology of the logic of manufacture based on two fundamental concepts. First, mass production need not mean large volumes of uniform products. Through the use of uniform parts mass assembled in various combinations, it has the potential of delivering greater variety of output than any other method devised. A thousand parts assembled in combinations of 100 can result in millions of potential products. An example of this is the proliferation of automobile styles in recent years. The second concept is that variety in parts need not mean variety in process. By grouping parts according to the technology of their manufacture, a limited number of processes can deliver diverse components at costs comparable with unique product manufacture. Combining the two concepts, a few varied processing methods can provide a large number of standardized parts that can be mass assembled into potentially an infinite number of products. To illustrate, if only 1,000,000 product varieties are needed, a few thousand standardized parts can be made in, say, 5 basic processes. As a serendipitous byproduct, a plant organized around "group technology" is more responsive in meeting the daily changes in parts needs than the allegedly flexible job shop.

Sixth, industry is beginning to accept an integrated approach to product/process design. No longer is it universal practice for product engineering to "toss it over the fence" to process engineering with the dictum, "Just make it; don't bother us with your cost problems." Value engineering is the frequent manifestation of an effort to relate product design to process, but broader concepts are available and will be discussed in Chapter V.

If industry would assiduously apply these technological developments, perhaps it could "get at" the major portion of every product that is waste material, time, and energy, and stop complaining about poor labor attitude and productivity. Perhaps it could also take advantage of the growing science of man/machine systems to formulate more enriching work for its employees and thus motivate better quality work.

In any case, rapidly changing plant technology calls to question the mechanistic methods of determining plant facility needs. Process technology needs to be thoroughly evaluated before translating sales forecasts into numbers of machines and plant size.

Determining Plant Requirements

Provided the firm has done its homework, the process of determining the number of productive units - machines, men, space - is simply mathematical conversion of market demand into plant requirements. But, it is necessary that management recognize that output can be no better than input. (To use computer systems idiom, GIGO - gargage in, garbage out.) To iterate, the necessary input is:

1) a well developed long term strategy
2) an explicative long range plan
3) a creative forecast of product and process technology
4) explicit knowledge of resource limitations and development rates.

The basic process of converting sales forecasts into requirements for productive units consists of:

1) breaking the product down into its assemblies and components
2) multiplying the number of each component required by the time required per unit per operation
3) accumulating the production times required by operation type
4) repeating for all products and accumulating
5) converting the total operation time requirements into the equivalent number of productive units.

This basic process, familiar to production control people as demand/capacity analysis, is conceptually simple but exhaustingly iterative. It is most efficiently done on a computer.

To this point the uncertain, probabilistic nature of forecasts has not been confronted. The mathematical models heretofore available for demand/capacity analysis either enforce the use of definitive (deterministic or certain) forecasts or require completely repeating the process over several forecasted levels. Faced with the time consuming, tedious process of trying several probable levels to bracket the problem, most managements set planning levels, or "best guesses", for purposes of determining capacity requirements. As these move through the organization they are progressively accepted as edict rather than forecast. This can lead to "don't blame me" answers when shortages and excesses are later revealed.

Since marketing forecasts are by their nature probabilistic, they should be dealt with as such and transformed into probabilistic forecasts of capacity requirements. To do so with pristine rigor would require the use of multivariate statistical analysis - a complex form of statistics requiring expert knowledge. However, examination of a number of plant requirements studies leads to the contention that such rigor is neither justified by the needed results nor warranted by the quality of the available input. Yet there is a need to communicate probability in capacity forecasts as well as in market forecasts.

To answer the need for a method of handling probability in plant capacity studies, a simplified form of multivariate transformation has been developed and is presented in the Appendix to this chapter. It can be handled by a clerk, but for any sizable job it's more efficiently done on a computer using off-the-shelf matrix multiplication software.

Using probabilistic forecasts in demand/capacity analysis does require consistency, if not statistical rigor, of management. In addition to the "best guess" it requires that management forecast a range within which actual sales of each product might vary. This range must be forecasted to some chosen probability level consistently - say, 95% reliable. The capacity requirements forecasts will then be to the same chosen level. (The forecasts of ranges needed from management are not unlike the common practice of forecasting two levels of sales - optimistic and pessimistic. The difference between the two would be the range.)

As is covered in the Appendix, "Stochastic Demand/Capacity Analysis", the process can be simply extended to:

1) provide feedback of resource requirements to the long range plan
2) operations simulation

3) short-term demand/capacity analysis for production control purposes
4) provide input to cost studies and economic analyses.

Summary

The intent of this chapter has been to take to task common, but often fallacious, reasons for building plants. In their place, an approach based on the universal logic that the real problem must be ascertained before searching for a solution has been offered for the determination of plant needs. This approach has been confirmed by investigating scores of expansion projects and by several successfully built.

Outlined, a sufficient approach to determining needs for plant requires of management:

1) a well developed corporate strategy
2) a definitive long range plan
3) a thorough assessment of technological developments
4) a thorough assessment of corporate resources
5) a knowledge of systems engineering
6) an innovative attitude

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APPENDIX

CHAPTER II

STOCHASTIC DEMAND/CAPACITY ANALYSIS

Recognizing the impact of rapidly changing markets, management has made significant progress in long range forecasting and product planning, but has done little to translate the forecasts into reliable projections of specific requirements. Alongside the developing science of long range forecasting, the method of determining plant needs remains an art involving a number of adaptive games managers play because of the lack of a pragmatic quantitative method of dealing with the probable error in sales forecasts.

The purpose of this article is to present a practical, simplified means of applying the power of statistics to the error in sales forecasts in order to reliably determine the probable plant requirements.

CURRENT PRACTICE

It is necessary to understand where variation comes into sales forecasting in order to picture wherein simple statistical calculations would be of value. Further, the current accommodations to variation need to be understood in order to gain a feel for the communications needed.

Forecast Methods and Inherent Variation

Probably the most common method of forecasting future sales is by projection of recent trends. One needs only to recall the radical changes in trends among consumer products in recent years to recognize the danger of blindly projecting trends. Trend projection does have validity in the case of staple products, but even here nothing can be said absolutely about sales five years hence. The probable error in the sales levels forecasted must be recognized.

One approach to dealing with variation in future trends has been to try to find correlation between sales and various economic and demographic factors. Since we don't fully understand all the interrelationships of our economic system or the impact of public confidence on the economy, forecasts of sales based on economic factors will be subject to error in the forecast of the chosen economic factor and to variation in the relationship to that factor.

Faced with problems of variation - and therefore reliability - in forecasts made by quantitative methods, many managements turn to judgement by a panel of management. For a number of reasons (availability of information and personal attitude among them) different managers on a panel will forecast different levels of sales. Here again a range in forecast levels will become apparent.

Finally, a number of managements have adopted methods of establishing strategic goals for the future. Though the goals may be certain, the factors leading to goal achievement will have inherent variation. The goal involves new products that haven't been developed, new sales or advertising campaigns, intentional or unintentional shifts in products mix, acquisition, etc. Forecasts of each of these factors contain probable error.

In summary, all means of forecasting future levels of business activity are subject to probable error.

Accommodating to Variation in Forecasts

In its desire to deal concretely with forecasts containing error, management has been forced to accommodate to the realities in various ways. One common way is to summarize the variation by judgement into one "best guess" or "most likely" level. Thus an "expected value" is communicated to the various organization functions for purposes of determining requirements. Another common way is to set "pessimistic-optimistic" levels of forecast; thus communicating the range of possibilities.

As will be shown later, the expected value and range are useful in a simplified statistical means of communicating probable error in forecasts and determining probable plant requirements.

Occasionally, managements use methods that beg the question. One such is forecasting gross dollar sales by division or company without any product line breakdown or indication of objectives or strategy. Another is adding "something" for growth, or new products, to a definitive forecast of existing product lines. These render the forecast too nebulous for realistic translation into plant requirements.

Accommodations to the Impossible

When the now summarized forecasts are transmitted to production management, it faces an impossible task. The forecast now implies certainty and production people are asked to plan to fulfill it. Yet these people know intuitively that the planned needs are not certain to transpire and that they are typically blamed for over or undersized plant when the true needs are known in hindsight. Without knowledge of the probable error in forecasts, production people are forced to develop defensive accommodations.

Among the more innocent methods of survival in this environment are budget substitutions and spreading the risk. The first involves anticipating during capital budgeting time the probable need to substitute funds from planned needs that don't develop into unplanned ones that do. Often funds are requested for plausible projects with the full intent to divert them into one of the projects actually under consideration. Spreading the risk involves getting "everyone" committed in print to the rightness of a major resource allocation. That is, the plant manager often has carefully filed letters from sales, engineering, safety, quality control, customer serivce, and, if possible, the controller backing his decision to request funds for a major project. (An offshoot of this is the engagement of consultants to add validity to the decision or to avoid the pitfalls as the case may be.)

Another pair of games plant managers play, often simultaneously, are the project game and juggling the timing. The first of these involves starting and letting simmer engineering or training projects for all potential needs - plant expansion, new processes, additional manpower, etc. Depending on the pressures of the day varying amounts of heat can be applied to the respective projects. If and when the need becomes imminent, only finishing touches are needed to place the facility into production. When it is believed that the need for a facility will occur sometime, but not exactly when, the trick is to make complete preparations and then juggle the timing of the appropriation request and later the purchase orders. Both of these games are wasteful of engineering, management, and vendor time, because much of the work never bears fruit, priorities are distorted, and crash programs are a common result.

Summary of the Problem

The availability of effective long range forecasting techniques does not in itself resolve the problem of plant facilities projection. A further need is for an effective means of communicating the forecast and transforming it into the probable requirements for facilities.

A WAY OUT

Recognizing that the need is to reliably determine the discrete number of units of capacity that are becoming fewer and more expensive, it was found that rigorous solution is unjustified. With some simplifications that may disturb the sensitivities of the statistical purist, we can apply statistical tools simply to this amorphous problem.

First, some modifications in the forecast documents are necessary to assure consistency, good communications and usefulness in statistical calculations. Next, requirements standards should be developed to facilitate the transformation of the forecast into plant requirements. Finally simple calculations will perform the transformation.

Modify Forecast Documents to Express Variation

If the forecasts are of the "best guess" or "most likely" type, recognize that you are forecasting an average or midpoint. This is analogous to the statistician's mean of the distribution or expected value.

If the forecasts are "pessimistic-optimistic," you are forecasting a range in statistical terms.

If both are available you have established the parameters of a probability distribution of the error in the sales forecast. Further (in statistical terminology) we can properly assume the distribution is normal since we are dealing with the "error of the estimate".

Going back to the sales forecast for a moment, unless there are strong reasons to the contrary the midpoint of a "pessimistic-optimistic" forecast will serve nicely as an expected value. The "best guess" type will require the addition of estimating the probable range about the expected value.

In later sections of this paper, the "best guess" or midpoint is defined as the expected value (X) and the difference between optimistic and pessimistic as the range (R). These are the parameters of the probable error of the estimate in a sales forecast.

Before covering the conversion procedure in detail, some warnings on input must be discussed. The basic problem is GIGO - gargage in, garbage out. Gross forecasts of gross groups of products will give gross results. Product groups are best broken into their models.

The alternating plus and minus errors from model to model will be leveled by the procedure, but it will not level bias. Consistently overly optimistic or pessimistic or conservative forecasts will carry through to have a corresponding effect on requirements projections.

In making a forecast to 95% reliability, it must be approached in that manner. Are the odds really 95% that actual sales will be within the range forecasted? Further are the odds 2/3 that actual sales will fall within 1/4 of the range (R/4) from the expected value of sales?

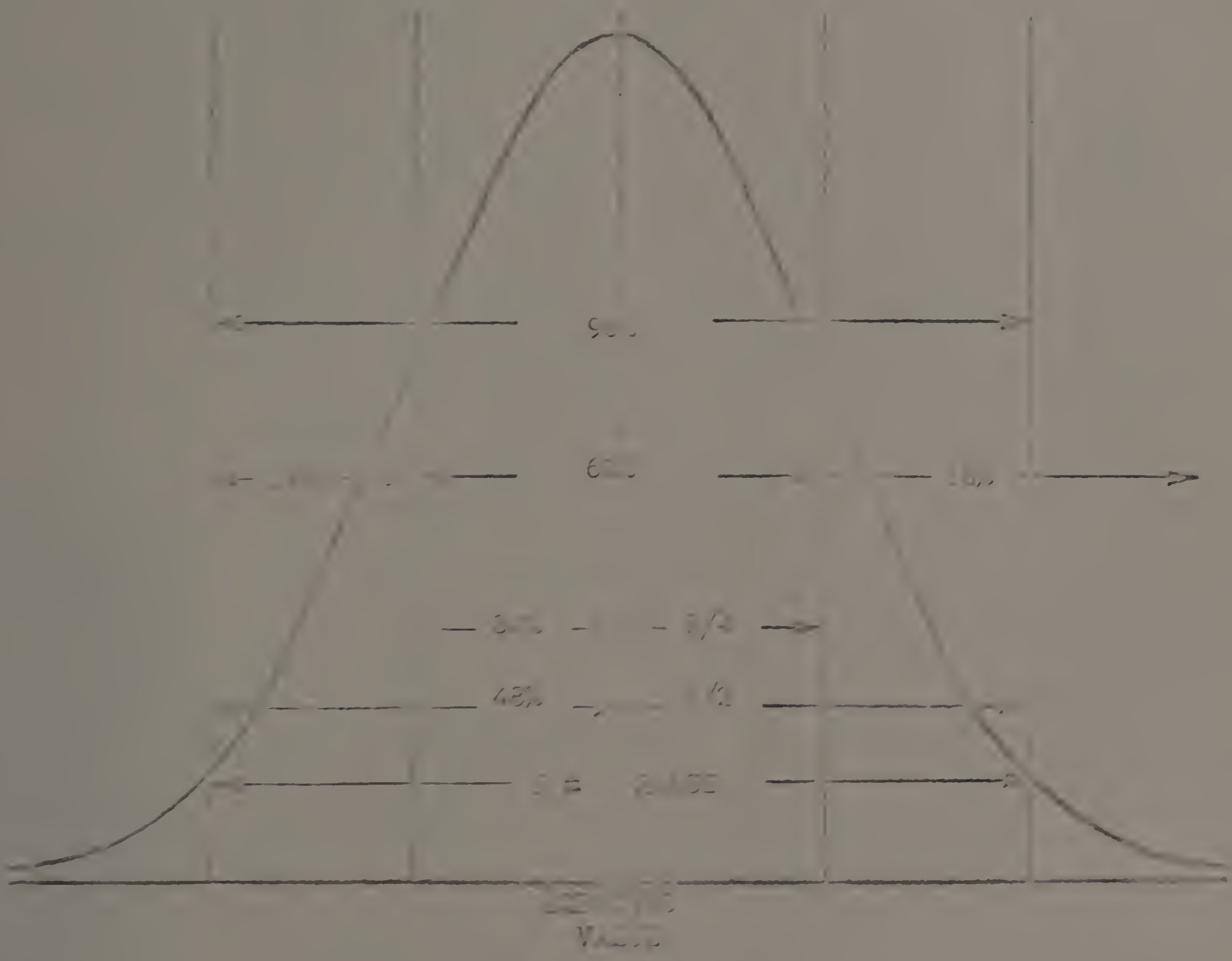
For the best of input, those forecasting sales should understand some of the implications of error probability and 95% reliability as applied to this procedure. Figure 1 is a sketch of a normal curve divided into quarters of the range (R/4) which is appropriate to the 95% reliability situation. If the range has been forecast for 95%, the chances are 95% that the actual sales will be within half the range above and below the expected value. Further, the chances are approximately 68% that the actual sales will be in the central two quarters of the range. Other probabilities are shown on Figure 1. (The probabilities within the range total to 96% because of rounding.)

Reiterating, for the sales forecast of the range to be 95% reliable, it must be forecast to such. Management must forecast the range it judges to be 95% reliable, and do so consistently.

In the forecasting process, don't look for 100%, for the range will quite literally become infinite. Looked at practically, to cover all possibilities you might have a Hoola Hoop or a flop. Heretofore, by using single point estimates of requirements you have been forced to accept a probability near zero of being correct.

The basic concepts of the transformation procedure can be used for reliabilities other than 95%, but for the sake of brevity this article is restricted to the use of 95% reliable forecasts.

Figure 1



Treat Production Standards as Transformation Constants

By treating production standards as constants, we may greatly simplify the calculations by avoiding the complexities of joint distribution development. That production rates are constant is not an unreasonable assumption in the case of established products. With unions and incentive standards, production rates are more fixed than we'd like to admit in most cases. Significant methods changes are necessary to affect production rates materially. The cases for which production rates are estimates and subject to error will be discussed in a later section of this article.

To explain the statistics involved, when there is a linear relationship between a statistical variable and a dependent variable, we may transform the statistical distribution into a dependent distribution by means of a transformation constant. Thus, if y is proportional to x, then the mean (X) may be transformed to a mean (Y) by $Y = cX$ with c being the constant.

To illustrate, when the sales forecast for a particular model (X) is multiplied by the standard time (c) for a particular class of labor per unit of that product, the total manhours of that labor grade (Y) required for the sales of the model is estimated. The result (Y) is unfortunately a single point estimate of manhours. It gives no clue as to the probable spread or error in the estimate.

To deal with spread, we must deal with variance. The variance in manhours V(y) may be determined by the formula: $V(y) = c^2V(x)$. Immediately we've complicated the problem if we attempt to calculate, sum, and interpret the thousands of individual variances. The point to this is that variance in sales forecasts can be transformed directly into variance in requirements by a statistically sound but highly repetitive process. Further variance is not widely understood, while its relative the range is and can be widely communicated and more simply processed.

To reduce the number of repetitive calculations for both the expected value and the range, the many production standards should be reduced into a smaller group of requirement standards by the procedures in the next section. That repetitive calculations are necessary may be seen in that sales forecasts generally cover a number of years and may be frequently revised.

Developing Requirements Standards from Production Standards

In describing the procedure, facilities (machinery) requirements will be used as a framework. This is done because facilities are the most difficult to change in magnitude and therefore the most subject to catastrophic error. Identical calculations,but over different groupings, will yield manpower, purchase, material, etc. requirements standards.

One, bills of material must be secured for each product model forecasted to be manufactured.

Two, the routings must be obtained for all manufactured parts against each bill of material.

Three, the operations within the group of routings corresponding to each bill of material are sorted and grouped by machine type. During the sorting, the quantities of each part for one unit product must be retained for later processing.

Four, for each of the machine type/product groups,

1) multiply each operating time by the "quantity for one" (product) of the corresponding part
2) sum these results over the machine type/product group.

To obtain the set-up requirements standard, the set-up time standards may be divided by the economic lot quantity - then multiplied and summed as in the previous paragraph.

If set-up time reduces the operating time available on a machine type, the operating and set-up requirement standards may be added to secure a single machine requirement standard for each product. If set-up is done aside while the machine is operating, the set-up requirement standard should be retained separately for determining set-up facility (and manpower) requirements.

The requirement standards (transformation constants) developed by this procedure may be used from year to year in the forecasting process PROVIDED they are adjusted for revisions in methods, product design, and economic lot quantities. If the information is available in the computer bank, it will actually be easier to calculate them annually than to periodically revise them.

During the annual forecasting process, the constants may be used repetitively for the projections of each of the future years and for as many revisions to the forecasts as desired. Fairly large volume changes can be tolerated without change until:

1) major methods changes are demanded by economics of scale
2) economic lot quantities are significantly affected.

For instance, volume must double to cause a 29% reduction in set-up requirements per unit because of increases in lot quantities.

Transform Forecast Distributions into Requirements Distributions

To transform any distribution by a constant into a related distribution, two things must be done - separately. The first, transforming the expected value, is mechanically simple. The second, transforming the range, is more complex and central to the technique described in this article.

One, to determine the expected value of a particular machine requirement corresponding to the sales volume forecasted for a particular model, multiply the expected value or "best guess" forecast for the model by the constant relating the machine type to the product model. This is the constant (requirement standard) developed in the preceding section. The mathematics of this may be expressed, as earlier, by $Y = cX$ where:

Y = expected machine requirement in, say, hours

c = requirement standard (constant) in hours/unit

X = expected value forecast of model sales in units

Two, to obtain the total expected value of a particular requirement, the procedure of the preceding paragraph is repeated over all the models. Then all the Y's are summed. This yields the expected value, midpoint, or "best guess" of that requirement in a particular period. Nothing yet has been said about the probable error in the projected requirement.

Three, to obtain the expected values of all the different requirements, the previous procedures are repeated over all the requirements.

If your organization has someone who is familiar with linear algebra, he will recognize that all the procedures of this section can be reduced to one simple matrix multiplication. A requirement standards (constants) matrix can be multiplied by a vector of product forecasts to yield a list of expected requirements. To handle the several years of a forecast, the vector becomes a matrix and the yield becomes a tableau of expected requirements versus years. A computer can handle this multiplication in seconds with readily available software.

Now that we have a list or table of expected requirements, we must deal with the range in order to estimate the probable error. Technically, the error must be determined by means of the variances, but there is a correspondence between R^2 and variance in this case. Therefore, R^2 may be used directly.

To determine the ranges (Rr) of the probable error in the requirements projections:

1) each range (R) between the optimistic and pessimistic forecasts must be squared.
2) all the requirements standards (transformation constants) that were used with the expected values must be squared.
3) using $(Rr)^2 = c^2R^2$, repeat the three step procedure used for determining all the expected values.
4) take the square root of each result in (3) to obtain Rr.

The result will be a list (or table if several years of forecasts are handled) of the ranges in projected requirements corresponding to the list or table of expected values of projected requirements.

If desired, the corresponding data from the two listings developed in this section may be transferred to a third listing which places the expected value and its range adjacent. Also, computer plotting programs may be used to create graphs similar to Figure 2.

Interpretation of the Results

Using the simplified procedure here advocated, it is practical to mathematically convert the expected levels of sales and their ranges into an expected level of requirements and their ranges. The procedure is not without foundation; it is based on thoroughly developed multivariate statistical analysis. Yet it's a pragmatic one - developed in response to the demands of my consulting work in planning new manufacturing plants.

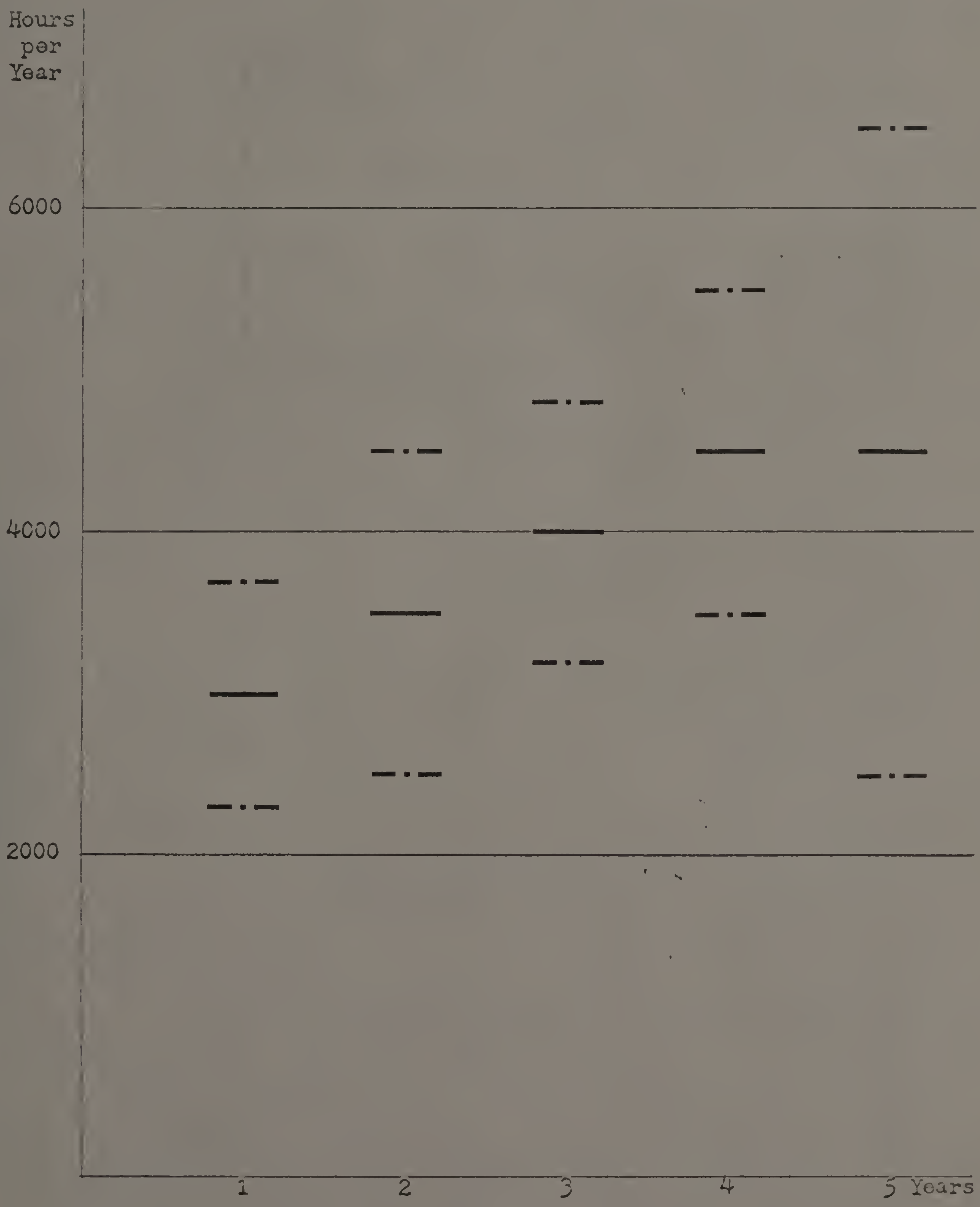
The outlined procedure is not a forecasting technique; it is a means of transforming sales forecasts into projections of the resources necessary to fulfill the sales expected. It will not tell you the probability that sales or requirements will be at some specified level but rather the probability that the expected value of projected needs is in error by some specified amount corresponding to the error in forecasts. To use the statistician's terms, it is a means of transforming the probable "error of the estimate" in sales forecasts.

Continuing this discussion on the premise that the forecasts have been made to 95% reliability and that the production standards may be reasonably treated as constants, some specific comments can be made about interpreting the results. The conversion of the expected value and range of sales forecasts by constants into the myriad requirements and the combination of those requirements over the product models has resulted in expected values and ranges of the requirements by types of machine. These are expressed by a pair of lists or tables - one for the expected values and the other for the probable range in those values.

For machine type A there will be a line of expected values (needs for coming years) in the table of expected values for machinery. There will be a corresponding line in the range table. Corresponding items in the lines express the probable needs for machine A in year 1. Say the expected value of hours on machine A is 3000 and the range is 1400. This means that from 2300 to 3700 hours will be needed in year 1. Since a shift is under 2000 hours per year, two machines on one shift or one machine on two shifts will be needed. This one is simple because the entire probability falls between two discrete units of capacity.

To get a picture of the needs for machine Type A, a plot of the expected values and ranges may be made. A hypothetical one for A is shown in Figure 2. To illustrate, 2000 hours is taken as the discrete unit of capacity. The

Figure 2



Machine Type A

amounts plotted for year 1 are those discussed in the preceding paragraph. For year 2 the mean is 3500 and the range 2000. The expected 3500 can certainly be handled by two machines, but what about the possibility of 4500? Referring back to Figure 1, it may be expected that 2/3 of the probability will be within the two central quarters of the range. In this case only 1/3 may be expected to be outside of 3500 ± 500; only 1/6 greater than 4000. Since the probability is only 1/6 that the capacity of two machines will be exceeded and the probably limited to 13% over capacity, perhaps overtime is more economical than a third machine.

For year 3 the expected value is 4000, and the range is 1600. This illustrates that the range is not necessarily proportional to the expected value. Here the probability is 50% that the capacity of two will be exceeded; 84% (5/6) that it will not be exceeded by more than 10% (400 hours). Since we forecast to 95% reliability, we can say that the probability is only 2-1/2% that 4800 hours will be exceeded.

For year 4, Y = 4500 and Rr = 2000. Here the probability is only 16% (1/6) that the capacity of two will not be exceeded. Unless you will tolerate excessive overtime or restricted sales, you probably (84%) better buy a third machine.

Year 5 (Y = 4500, Rr = 4000) is used to illustrate the situation in which the range is quite large. (Perhaps some product may or may not be continued in the line.) Here the probability is some 30% that two will suffice, 63% that three will be needed, and 7% that over three will be needed.

Impact on Facilities Planning

Some implications of the effect on facilities planning have already been made in the previous section. The probability of needing a certain number of machines can be read from the distribution parameters - the expected value and the range. Alternately the probability of overtime or excess capacity can be read. For instance, the probabilities can be used to compare the cost of overtime to the cost of extra capacity.

In general it may be said that when gambling on facilities investment, as with any other game of chance, knowing the odds of your being right or wrong enables you to make rational decisions during the play. "You can't win 'em all," but you can increase the frequency of your winning.

The great bulk of the necessary decisions will be easy. Enough capacity already exists; the projected change in capacity is easy to accomplish; or the expected value and its range indicate a specific number of machines.

Where the procedure will really pay for itself is in the borderline cases involving expensive machines that result in large single increments in capacity. Here the risk is great and there is a need to know the probability of error.

Another value of the procedure is to point out those needs not fully recognized by subjective judgment. So often the magnitude of service operations needed for small amounts over thousands of components is overlooked by intuitive methods. Examples are cleaning and heat treating facilities. Another often overlooked machine time consumer is set-up time. In short, the procedure offers the means of preventing surprise bottlenecks.

For the sake of brevity this article is restricted to machinery, but the basic procedure can be extended to obtain error probability distributions for all facilities, services, materials, manpower, etc. These may be further transformed into financial requirements - both investment and operating. Hence, the odds against which you are playing may be quantified throughout the planning process.

Impact on Timing

Implicit in what has been said to this point is that sales and requirements change in discrete steps from year to year. This is obviously not true. (Methods used in current practice make the same mistake.) Changes in sales levels do not occur arbitrarily at the turn of each year but rather continually over the year - even if a bit fitfully. This tendency of sales to follow a trend may be used advantageously.

If it is reasonable to ignore seasonal determinants, as will be done for a moment, the points in a plot such as Figure 2 can be connected. The points may be considered the middle of the year. Therefore, the requirements during the early part of the year (in the case of Figure 2) are less, and during the late year more, than the average. For any point during the year interpretations like those described for the complete year may be drawn. Thus planning the timing of capital investments may be improved.

To this point seasonal variation in sales has been assumed to be negligible. When seasonal variation is significant, the usual seasonal adjustment factors may be used as transformation constants. If the whole product line follows the same seasonal pattern the transformation may be applied directly to the annual requirement distributions to obtain monthly or quarterly distributions. The results may be interpreted in the same manner as those described for complete years.

If different products follow different seasonal patterns, the adjustment must start at the beginning of the procedure. The annual sales forecasts of each product must be converted into seasonal forecasts, say quarterly or monthly, before applying the procedure earlier described. Otherwise the procedure and interpretations are the same as for annual except that four or twelve times as many periods are handled. An interesting result of this kind of analysis is the vividness with which requirement fluctuation is shown to be smoothed or aggravated by differences in product seasonal patterns.

OVERCOMING LIMITATIONS OF THE PROCEDURE

The conversion procedure described above is based on the premise that production rates are essentially constant over wide ranges in volume. Admittedly, this is not always true; there are a number of circumstances in which estimates of production rates are subject to considerable error. In these circumstances, the procedure must be altered to overcome the limiting assumption.

In a number of cases the basic procedure can be applied by reversing the roles of sales forecasts and production rates, thereby treating sales forecasts as transformation constants. When confronted with error in BOTH sales forecasts AND production rates, the conversion procedure must be based on joint distribution analysis, a complex process. Yet even here, there are some simplifications that can often be used.

Before dealing with the methods of overcoming the limitations of the procedure, it is best to outline the marketing circumstances which cause the problem of variable production rates to arise. Further, the means of obtaining reliable production rate estimates are best covered before applying procedure.

Special Marketing Circumstances

A number of marketing circumstances involve new or non-proprietary products that are subject to design change and, therefore, process change. Whenever these situations exist, today's knowledge of production rates is subject to error.

The new product that has been conceived and approved for introduction to the market is the worst of them all to plan for. The sales forecast is subject to considerable error; the design is subject to change; and standards of production and methods have not been set. Yet it is critical that the facilities and manpower needs be planned. If the new product is indiscriminately thrown into an existing production system, it can cause bottlenecks that may bring the whole system down - to the detriment of existing products. The existing facility may lack the technology, quality, or capacity. "If you can't make 'em, you can't sell 'em," and the best laid marketing plans are for naught.

In today's business world of large purchase contracts from large corporations and government agencies, it is not uncommon for the "forecast" volume of the contractual product to be quite certain. By contrast the estimates of production rates may be subject to considerable error. This situation is the reverse of the circumstances handled by the procedures described earlier. Methods of dealing with such reversals are covered below.

Finally, there is the job shop that sells capability rather than products. This situation is beyond the scope of this article. However, the problem may be summarized as one of forecasting facilities directly. That is, the facilities are the product and need to be forecasted as such. Admittedly there is a relationship to the general class of output that can be manufactured and the market for that output.

Production Estimates for the New Product

For the established product, transformation constants (requirements standards) were developed from production standards. For the new product, estimates of production rates will have to suffice. These estimates are, of course, subject to error. The object here is to recognize and deal quantitatively with the probable error.

When the probable error in sales forecasts is multiplied by significant error in production rates, the probable error in requirements projections is very large. Consequently, the more precise (narrow range) the production rates, the more useful the expected value and range of requirements will be for guiding investment. To accomplish this, commit sufficient professional resources to:

1) make the product design firm, but not necessarily frozen.
2) make the process design in sufficient detail to serve as a reliable base for production estimates.
3) completely search the new process and existing processes for "like operations" from which production standards may be used.
4) use predetermined standard data on new operations.
5) use skilled estimates for those that are not set.

Production rate forecasts of this nature require the best in professional services. The persons charged with this task should be fully qualified in:

1) understanding the company's strategy, objectives, goals, strengths, and weaknesses
2) understanding the concepts of the future product
3) knowledge in production technology and trends in technology
4) ability to estimate rates reliably.

Costly perfection should not be sought by these methods, but there is some incentive to do better than the usual "blue sky" estimates. Where estimates of "production standard" quality can be developed, they can be used as constants in the simpler transformation procedure described earlier to yield greater precision in requirement projections. Where error is significant, the expected value plus the range in error should be thoughtfully estimated to, say, 95% reliability. Thus the parameters of a production rate distribution are developed for use in joint distribution techniques outlined below.

Reversing the Transformation Procedure

Although it may appear similar to the new product, dealing with the contractual product is conceptually the reverse of dealing with established proprietary products. The sales quantity is not subject to error in forecast, while the production rates often are. Therefore, in developing estimates of production rates, the admonitions listed for the new product apply, but joint distribution methods are not necessary.

To obtain requirements projections note that the contractual sales volume for any given period is mathematically a constant and may be treated as a transformation constant as were production standards earlier. By contrast the production estimates are subject to significant error and should be treated as distributions. Thus the procedure is the same but the factors have reversed roles.

For contracts with the federal government, an additional complication must be handled to gain reliability - learning curves. Learning curve factors may be used as transformation constants to convert distributions of base rates into rate distributions appropriate to the periods involved in a long-term contract. The resulting production rate distributions may then be transformed into requirements distributions by using the contractual output quantities as transformation constants.

Developing Requirements with Joint Distributions

When it is necessary to deal with error in BOTH sales forecasts and production rates, it is necessary to multiply one set of distributions by another to obtain joint distributions of requirements projections. Because dealing with joint distributions is complex and cumbersome, it should be avoided if practical.

Earlier the heart of the procedure was the transformation of a distribution by a constant. Here the heart is the multiplication of two distributions to obtain a joint distribution. For the sake of brevity, the details of the procedure will not be covered but are based on the mathematics outlined in the following paragraphs.

The expected value of the requirements may be obtained by:

$Y = CX$ where:

Y = the expected requirement

X = the expected value of the sales forecast

The letter "C" is used here to represent the expected machine hours (or manpower, etc.) per unit of product. Earlier the lower case "c" was used to represent a transformation constant. To maintain the conceptual relationships, the letter "c" is retained here to represent a variable - the error in the estimate of the production rate per unit of product. The variable has a range (Rc) and an expected value (C).

The complexity in using joint distributions comes in dealing with the variance. When two distributions are multiplied the variance in the joint distribution is determined by:

$$V(y) = V(x)\ V(c) + X^2\ V(c) + C^2\ V(x)$$

which here would be, for 95% reliability:

$$(Rr)^2 = (1/16)(Rx)^2\ (Rc)^2 + X^2(Rc)^2 + C^2(Rx)^2$$

where:

Rr = range of the error in the requirement projection

Rx = range of the error in the product sales forecast

Rc = range of the error in the production rate estimate

X = expected value of the sales forecast

C = expected value of the production rate

Interpretation of the joint distributions of projected requirements may be done in the manner described earlier when dealing with requirements distributions secured by transformation.

Simplifications of Complex Variation Calculations

Before dealing with solution methods, it is well to look again at the problem and the needed results. Only discrete units of capacity need be reliably projected to fulfill the requirements of facilities planning. Fastidious solution may yield 2.43, but the answer to the problem is 3.

To be rigorously correct, every situation discussed in this article should be handled by joint distribution techniques. In addition more must be done than estimate the range to determine the variance. But rigorous solution may take so long that the answer may occur after the need has transpired. And it is literally impossible to obtain the data needed for rigorous solution.

In addition to the problem of calculation, there is the problem of communication. The man who understands the definitions of mean and variance as the parameters of a probability function is a statistician. Yet everyone can understand expected value and range. They can even understand probability if expressed as odds.

From the beginning simplifications have been used throughout. First, the "best guess" of sales (the level you feel most likely to achieve) has been used as the mean or expected value. Your thoughtful estimate of the probable spread or error in the sales forecast has been used as the range. This range is analogous to the total allowance in tolerance measure of machined parts.

The principal procedure described in this article depends on one of the factors being constant. This enables the much simpler transformation technique to be used.

In the first instance production rates were treated as constant per unit of product. This will typically be valid for existing products with established production methods - probably the bulk of your calculations. Actually some variation in production rates can be ignored in order to treat them as constants. When the required discrete units of capacity are few, considerable variation about the standard production rate can be ignored. As the number of capacity units increases, less tolerance can be allowed if the investment per unit of capacity demands accuracy. Fortunately this seldom happens; it's the machines that are few but expensive that demand accuracy.

When it is crucial to the determination of a major investment, a correction may be made to the range of that particular requirement without the necessity of recalculating all requirement ranges by joint distribution methods. Note in the formula for determining the range of a joint tionships to socio-economic factors.

2) determination of the probable timing in project planning techniques, such as PERT and CPM.
3) determination of the probable timing in technological change or product/market evolution.
4) conversion of any of the preceding factors, or others, into projections of physical, financial, or manpower needs.

A major extension of the techniques discussed herein is their application in simulation. If the entire procedure is programmed and done on a computer, and applied to manpower, material, space, and services as well as machinery, it would be a simple matter to change any forecast to see what would happen to the entire manufacturing system - physical, financial, and human. For instance, incremental sales of the low profit product can be examined to determine whether the incremental resource commitment is justified. Solving backwards, resource restrictions may be examined for their restrictive impact on sales.

It should be noted here that this is an application of the continuous probability of error which is quite distinct from the broad use of the discrete, usually binomial, probability of yea or nay. Characteristic of the applications of discrete probability are:

1) product reliability
2) attribute quality control

3) queuing problems
4) probability of success in contract sales after the pattern of GE's PROFACS method
5) probability of success in technological development
6) decision theory in its various forms.

SUMMARY

Although gaining sophistication in sales forecasting, management to date has been forced to use rather rough means of translating the forecasts into corresponding facilities requirements.

By encouraging sufficient discipline during the cogitation leading to forecasts to ensure a consistent reliability in the range forecasted, the range may be used to communicate quantitatively the probable error in forecasts to those responsible for planning facilities. They, in turn, may convert the range and expected value into probable levels of plant requirements using the procedure described in this article.

While suffering some limitations that prevent its universal application, the basic transformation procedure will give, in the bulk of cases, output as reliable as the input from sales forecasts. Where error is present in both forecasts and production estimates, the more complex joint distribution procedure will fill the gap.

So here is a reliable and reasonably simple way out of today's maze of over-simplified rules of thumb, games, and guesses. The technique offers an understandable, communicable "handle" on the probable error in sales forecasts and the corresponding probable error in facilities projections. It quantifies the odds in the resource commitment game, but it's no substitute for the judgement required in deciding which way to play the odds.

CHAPTER III

CAN IT BE DONE?

The operating plant has been defined as a living, adapting system requiring continual inputs of resources to remain viable. For the plant to be a vital, integral part of the corporate system, its operating needs must be among the parameters of plant design and corporate long range planning for resource development. Further, for plant design and planning to be effective, creative, and efficient, it is necessary that management know, plan for, and obtain those resources required in the short run by the planning and design process.

Assuming the firm has determined that plant expansion is needed, the planning effort shifts to the simple question, "Can it be done?" As shown in Chapter II the long range needs for plant expansion feed back into the long range plan as requirements for resource commitment. Added to other resource requirements, the question shifts to, "Can the resources be made available in time?"

To the systems engineer the first question refers to the level variable and the second to the rate variable. So the question of ability to successfully expand industrial operations hinges not only on the given amount at a stated time, but also on the limits to the rate of resource growth and development. In planning resources, both level and rate must be questioned.

To determine corporate capability to successfully engage in plant expansion and subsequently in operation, a number of specific needs must be critically examined. They may be categorized as only three - financial, physical, and human. Contrary to general belief, financial resources are by far the easiest to obtain and human the most difficult. Each category may be further classed as short term for creation and long term for operation.

Financial Resource Requirements

To say that financing for plant construction is essential is banal. It is obviously essential. But, to say that it is difficult is false.

A well planned expansion program can be financed. One financial vice president referred to a well done expansion feasibility study as marketable paper. Investors, banks, insurance firms, and industrial development groups and agencies are searching for viable expansion plans.

Long term return on investment (ROI) has been established as a prime criterion for the evaluation of plant design. Also it is presumed that ROI is the justification for the marketing and innovation strategies and goals that in turn determine the need for plant. Should the strategy not be justified, there is no need for plant and the planning process stops. A viable strategy supported by a well designed plant will, by definition, produce sufficient revenue to far more than cover the cost of financing it.

To further define a plant as economically viable means that it must produce funds profitably in excess of those necessary to its own long term operation. Its operating funds include not only those for men, materials, and energy but also those for its own working capital, development of human resources, and amortization of investment.

In short, if a plant is truly needed and to be properly designed, it's not a matter of being able to afford it. You can't afford not to!

Financial commitment to planning. As outlined earlier, management's track record has been poor in timing the commitment to planning. Too little has been put in when needed and too much when it's too late.

Basic to effective long range industrial expansion is a continual commitment to strategy development and long range planning. This commitment is a prerequisite to the effectiveness of any commitment to designing a specific plant. Plant designers can be no better than the framework within which they function.

Relative to designing a specific plant, the problem has been management's reluctance to commit money and professional talent sufficiently early to enable effective design. It has also tended to misdirect much of its money into the wrong kind of professional services.

While management's relations with professional services will be covered comprehensively in Chapter VII, let's examine the typical procedure by which a plant is designed from a financial point of view. Management has waited until it is absolutely sure that it needs a new plant -- next week. It asks production supervision or staff to rough out how big while negotiating with architects from a position of ignorance. It lacks definitive ideas of what will be demanded of the architects so it is forced to judge based on the architect's general qualifications. The architect knows that under these conditions much preliminary work and frequent design changes will occur, so he wants 6% of the installed cost. (Note the lack of economic incentive for the architect to incorporate economy in building costs. In fact, the opposite prevails, for, lacking design parameters, he must structurally over-design to avoid failure caused by any conceivable contingency. He'll never be sued for excess cost, but he will for engineering failure.)

After some months of exhausting, frustrating work involving thousands of man hours in conferences, many false starts, and general chaos detrimental to ongoing company endeavors, a design is finally achieved. It's a design fraught with guesses and assumptions, personal desires, political compromises, oversights, and particularly extensions of the past. Not only is the design less than ideal, it was also obtained most inefficiently.

Contractors bidding on such plans may appear to be quite competitive, but management shouldn't be misled. So prevalent is the practice of poor planning that built into industrial building practices is the attitude, "First get the job; then make the profit on the extras."

Construction labor, knowing the rush caused by delayed planning, has been taking industry "to the cleaners" for years. Strikes resulting in large wage settlements and restrictive practices occur at the peak of activity. Overtime is demanded whether needed or not. (A number of studies have shown that work completed in 60 hours is comparable with that in 40 hours. So industry has been paying for 80 while getting 40. Many of the larger industrial firms are joined in the Task Force of Construction Users Anti-Inflation Roundtable to promote the policy of industry refusing to pay overtime to construction labor.)

For a comprehensive treatment of construction productivity, see H. W. Parker and C. H. Oglesby, Methods Improvement for Construction Managers, McGraw-Hill, 1972, particularly pages 138-142 on overtime.

A number of our largest, multi-plant industrial firms have learned "the hard way", but the thousands of smaller firms which build only once or twice in a lifetime haven't the opportunity to benefit from their experience. The few firms that plan well are frequently the subject of functionally oriented articles that advocate better planning by plant engineers or industrial engineers but that fail to point to the management foresight necessary to the commitment of internal planning resources sufficiently early to be effective and efficient.

As may be gathered from the outline of the wrong way, good planning requires <u>less</u> not more financial commitment. The financial commitment must be started two to three years earlier because good planning requires more calendar time, but the total commitment will involve less total manhours and expense. Thus, good planning and design are not only more effective, but more efficient.

Where are these efficiencies to be gained? The first and easiest to see is reduced fees for architects and other outside consulting services. When these people know the parameters of design they can be much more efficient. Architects are interested in 4% or flat fees. Consultants concentrate on solutions rather than finding the problem. Secondly, it <u>is</u> possible to eliminate the chaos caused in corporate organizations by accelerated design projects. Finally, the cost of design changes and "extras" can be minimized during construction, and the building need not be over-sized or structurally over-designed to avoid criticism or suits for inadequate design.

In addition to the financial efficiencies enhanced by early commitment to planning, early commitment of dollars to creative professional talent is a necessary condition to effectiveness in design. Early commitment allows time to find the optimum solution instead of merely a satisfactory one. It allows the design of a system rather than a conglomerate.

In summary, financing the initial investment and later operating needs of the strategically needed and well designed plant is easy. First, because less financing is required and, second, the plan is easier to "sell".

Early financial commitment to professional, creative planning and design talent is a necessary condition to effective, creative, and efficient design. It is not, however, the sufficient condition. There must be a commitment of specific human resources as will be discussed in the third section of this chapter.

Physical Resource Requirements

Since physical resource requirements vary so greatly among industries, it is difficult to generalize without being banal. Nevertheless the problems in securing adequate material resources should not be bypassed. In the interest of brevity the areas in which management has shown consistent success will be summarized while the areas in which wide difficulty is experienced will be comprehensively developed.

Included in this discussion of physical resources are a number that may be thought of as technological resources. This is done because it is the _thing_ that is needed. The technological skills and knowledge required are secondary to the need for the object. In fact, the technological means may have to be invented in order to reach the physical ends.

The physical resources included in this study are material, equipment, and energy. They will be approached from both the long term operations and short term construction view.

Plant location and logistics. The importance of raw material supplies to plant location is universally recognized by the process industries. With the growth of multi-plant, multi-national fabricating concerns and the growth of the technology of logistics, a growing number of plants are being located to fit within a total logistic system. These comments also apply to process industries that require unusually large quantities of energy - e.g. aluminum and steel. Seldom is information flow a determining factor in plant location.

It is the one or two plant fabricating firm that experiences unexpected difficulty with supply. Since it receives myriad inputs from thousands of competitive suppliers, it implicitly assumes that all its material and energy needs are right off the end of its receiving dock. As will be developed there are a number of circumstances wherein this assumption is not valid.

The development of stringent environmental controls is driving thousands of the fabricating industry's basic suppliers out of business. These controls have particularly hit the casting, forging, heat treating, plating and finishing industries.

Of the foundries in existence in 1965, only half survived in 1972. The small local foundry worth $250,000 to $500,000 cannot afford $300,000 in air cleaning equipment. This coupled with freight and energy problems is causing a rapid concentration of the industry in plant size and location. In 1971, a New England firm needing unusually large castings was limited to three suppliers in western Pennsylvania and Ohio. It was being forced into uneconomical product redesign. Castings of all sizes are becoming less readily available and more expensive. Many localities are finding themselves without convenient supplies.

The 1969 amendment to the Walsh-Healy Act has started the process of weeding and concentration in the noisy forging and metal forming industries. Fabricating industry will find the same problems with forgings as with castings.

Since casting and forging are generally at the beginning of the fabricating process, local supplies are not critical. The same cannot be said for heat treating, plating, and metal finishing. These processes are ubiquitous and intermediate to fabricating sequences. Long shipping distances cause severe delays and costs. Long term availability of these services may be judged by evaluating:

1) the availability of energy for heat treating - gas and electricity
2) water pollution control facilities existing in the plating supplier
3) air cleaning facilities existing in the metal finishing supplier.

Providing one's own facilities for casting, plating, etc. will seldom be a viable solution. The plant will face the same environment control investments with less volume to support them. A solution might be for a number of local firms to encourage the merger of all local, say, foundries into one or two large enough to support environment control. The consuming firms may be forced into stock interest or joint ownership in the combined supplier. The oil industry has done this a number of times in the national refineries of the smaller European and African nations.

Before leaving the subject of location's impact on logistics certain assumptions prevailing in this discussion should be listed to avoid their being overlooked. It is assumed that the better plant location references have been used and management has, in locating, made provision for land, water, climate, transportation, local services, and communications. Energy and raw material supply trends are given special consideration below.

Energy supply, a long range problem. Until the fall of 1970 industry generally assumed energy supply to be boundless. Gas, oil, coal, and electricity suppliers vied for the plant's dollar. Suddenly the use of high sulphur content coal and oil was restricted and every other energy became short in supply. This was just the prelude to a series of energy shortages that will extend for generations into the future.

Projecting present trends, all of the fossil fuels of the earth would be consumed by 2050. Presently applied technology of nuclear power generation would extend the availability of power to about 2100. These dates presume that fossil fuels will not be husbanded for long term use as organic chemistry feedstocks. Thus, we can foresee that within one generation most plants will be entirely dependent on electric power. Further, within the technology foreseen the electric generating utilities will be dependent on breeder reactors and/or possibly fusion reactors. Neither of these is now economically feasible.

In the interim industry will face many trying years of supply interruptions, increasing costs, and fuel conversions. The first of these has already occurred in the restriction of high sulphur heating fuels.

The shortages of electricity already showing up will spread and become more severe until the utilities can master the technology and economics of air and heat pollution. This is and will be aggravated by restrictions to hydro-electric expansion; the public is fighting additional dams and pumped storage. Location will not alleviate industry's problems; power is transported to level limited supplies over giant grids. The only defenses are voltage controls on sensitive machinery and emergency power sets for processes and machinery that cannot tolerate sudden shutdown. Where equipment (such as kilns, annealing furnaces, and electrolytic processes) requires large quanities of uninterrupted power, industry can profitably invest in the process research necessary to reduce or eliminate its sensitivity to interruption.

Natural gas will probably never again be plentiful. It is very much in demand as a clean fuel. Gas reserves are expected to peak in the mid-seventies unless we can practically include northern Alaskan reserves. Under present federal controls of pricing, gas discoveries are a by-product of the search for oil rather than a directed effort.

The FPC will probably succumb to price pressures in order to encourage exploration and development. Under all these forces wellhead prices are expected to quintuple before 1980.

Even at the higher prices uninterrupted supplies of process gas cannot be assured. Gas utilities are refusing such contracts. Plants are suffering interruptions during the winter - with warning and without. Utilities in many areas are refusing to supply any gas for expanded or new facilities. Home and building heating is taking precedence over process uses for gas as is politically and economically expedient.

Nor can industry turn to "plentiful" coal for its energy needs. Cheap, low quality, high sulphur, strip-mined coal will cease to exist about 1975. Environmental restrictions on strip mining, including rebuilding the land stripped, will remove "cheap" from its description and may remove strip-mined coal from the market. The use of high ash, high sulphur coals will be restricted unless costly air pollution control devices are used. High quality coal will be increasingly in demand for metallurgical and clean heating uses.

Oil is presently furnishing the majority of our energy needs and the United States is an importer. Expanded use of oil can be done only at the expense of tribute to Middle Eastern rulers reminiscent of the North African pirates of 150 years ago. Further, the cost of removing sulphur from heavy oils must be paid for by the customer.

In summary, there is no fuel which is economical or which can be depended upon. The only energy on which we can depend in the long term is not now commercially available and federal government dalliance portends further delays in its application.

Thus, plant designers must anticipate shortages, interruptions, higher costs, and future fuel conversions in process and plant utility design. This is one area in which flexibility in operation becomes a prime criterion in design.

The subject of energy should not be left without admonishing management to determine the basic availability of energy in a locality before designing a plant for it. Recently a number of firms have been denied the energy necessary to facilitate the installation of planned facilities. Expansions have been particularly stymied by the lack of gas.

Materials, in flux. Because of their significant impact on process methods and therefore plant design, some relative trends in material supply should be noted. The economics of these trends will be referred to relatively among themselves rather than in terms of today's dollar.

Although organic materials (plastics, elastomers, etc.) are becoming more varied and in greater supply, this writer is concerned about their long term economics in view of the coming competition for fossil fuel feed stocks. They can, of course, be synthesized from their common basic elements, but the economics of this awaits cheap second and third generation nuclear power.

Basic steel supplies are expected to remain fairly stable; world competition and advancing steel technology will assure this even if the U.S. steel industry becomes defunct. It can be expected that metallurgical technology will continue to proliferate better specialty steels. Further, advancing steel forming technology will offer product and process engineers new opportunities with extrusions, spinnings, forgings, laminates, and drawn forms.

Among the non-ferrous metals, copper will exhibit the most chronic shortages and high cost. It suffers from depleting high grade ores, pollution problems, and being an international pawn. Fabricators who depend on copper and its alloys are well advised to seek new product designs that alleviate dependence on copper. (An example is the effort to make aluminum auto radiators.) The shift to another material would involve a new process and therefore new plant design concepts.

Aluminum has been becoming more plentiful and economical. This coupled with the growing technology of fabricating aluminum is aiding its invasion of markets traditionally held by other metals. Its fabrication is quite different and requires different plant design concepts.

Except for silver, the other non-ferrous metals are expected to be in plentiful supply. Of course, the introduction of a technology or product requiring large amounts of one of the metals could change the picture. For instance, tin is not plentiful in the absolute sense; the lessening dependence on tin cans has made the present supply more widely available.

For the fabricator and assembler, there are a growing number of semi-finished materials that will have impact on future plant designs. Among these are the growing availability and capability of steel die casting, investment casting, cold forming, powder metallurgy, extrusion, and welding. Many fabricators are finding it cheaper to buy components made by these new technologies than to make them by traditional machining processes.

Also of note is the growing list of non-metallics - ceramics, cermets, composites, and silicones, as well as plastics. These offer new product and process opportunities and therefore the need for different plant designs.

The conclusion to be drawn from the tumult in the materials markets is that a plant designed to optimally handle today's material input may not be economically viable five years from now. There are two basic ways out of this dilemma. The first is to design and build for tomorrow's material and process - at some risk. The second is to incorporate flexibility in the design to allow for economic adaptation to changing materials and process. This will be treated further in Chapter VII.

Equipment, a critical choice. A truism applicable to manufacturing processes is, "If it works, it's obsolete."

Manufacturing engineering has come of age. No longer is it adequate to examine a part and decide its routing through conventional machining processes. Consider any simple metal part. It may be cold formed, abrasive machined, investment or die cast, made by powder metallurgy, and, just possibly, machined. Further, it may be wise to throw it back to the designer with the recommendation that it be of plastic, ceramic, composites, etc.

This new "power" of the manufacturing engineer results from the current rate at which new, more economical process technologies are reaching the market. Some of the more significant trends are outlined below.

Probably the most significant trend in fabricating technology is the growing application of numerical control - the automation of conventional machining. It is permeating all forms of machining and is currently being extended to combine a number of machines into integrated manufacturing processes.

Two old processes undergoing rapid improvement of interest to fabricators are abrasive machining and cold forming. They have the common property of often being able to convert a blank into a finished part in one operation instead of the several required by conventional processing.

The trend away from metals has been encouraged by "one step" processes. This is particularly true in plastics molding. Dependence on metal fasteners and welding has also been lessened by the growing technology of adhesives.

A number of "exotic" processes are available to industry today. They enable commercial application of designs and metals not previously practical. However, their application is not wide yet.

The development of process oriented material handling technology has recently made great strides. Industrial robots and grasping devices have enabled near automation of Vega assembly. Complex transfer machines that enable complete machining of complex parts are becoming more commonly applied.

The problem with equipment availability is not usually the lack of technology. It is the lack of the machine being "on the shelf". In their efforts to standardize, the machine tool makers encourage the use of standard machines. These are often less than optimum for the particular need. When this is true, the machine manufacturer needs to be "encouraged" to combine the necessary technologies to achieve the "special" machine. For instance, a product needed large, heavy shafts with critical outside dimensions and surface finish. The conventional process required several steps with attendant handling and damage. The manufacturer forced the design and manufacture of a combination lathe, grinder, and polisher that completes the shaft in one operation and handling.

A related problem is the frequent need to extend a technology. In one case the overall systems concept for a plant called for an unusually wide bay with overhead cranes. The cost of American cranes to span 150' was prohibitive; the makers really did not want to do it. Periodical research revealed a British manufacturer employing a different approach that can readily span 150' in heavy capacities. When faced with competition, an American crane builder decided they could employ some ingenuity to rise to the challenge - economically. Without this extension of technology, the plant would have been a less-than-optimum compromise in design forced by the reluctance of a group of suppliers to try the new.

Another problem in obtaining equipment is the apathy with which the machine tool makers have approached human engineering. Although the science of ergonomics (or human factors) in machinery design is well developed, little equipment is designed for effective and efficient control and use by human beings. If the employee is to be able to work productively and safely instead of fighting the clumsiness of much machinery design, the application of human engineering concepts must be demanded by the equipment buyer. (Human factors in design will be treated further in Chapter V.)

Equipment manufacturers have not yet universally responded to society's demands for clean and quiet processes. Since pollution levels at a plant are the responsibility of plant and corporate management, they will find it necessary to specify pollution, including noise, standards on equipment purchases. It cannot be assumed that "reputable" makers' equipment will meet the requirements.

In summary, it would appear from industrial publications and shows that any conceivable equipment need can be filled, but when seeking optimum manufacturing systems design it will be found that much is not offered. As a generality, it can be obtained if the buyer is willing to demand instead of accepting and sometimes guide the machinery designer's efforts. The alternative is a series of compromises instead of optimum plant design.

<u>Physical needs, in summary</u>. From the dawn of time until the 1930's man faced a shortage of material resources - primarily because of his lack of the technology of exploitation. During the thirties, technology combined with Keynes' theories of consume and waste to wealth. In thirty-five

years we have consumed and wasted to the point that our "unlimited" resources have been found to have very definite physical limitations over which no technology will prevail. The only salvation for our grandchildren is to find ways of surviving not dependent on presently used resources.

For the plant built in the latter part of the twentieth century, the impact of shortages is already evident. Energy will be progressively short and costly. Materials will be more costly even if not short; someone must pay for the cost of cleaning the waste of our basic materials refinement processes.

Our economy may survive without the choice sources of materials (recycling may well become the prime source), but it would stop within minutes without energy - particularly electric power. Reducing this to the scale of one plant, the plant dependent on one source of energy faces the high probability of being defunct one day. The viable plant will, by definition, be designed to adapt to the shifting availability and costs of energy sources.

Provided this nation solves its basic energy problems the absolute availability of materials should continue. The problem for the plant will be to continually adapt to shifting relative economics among alternate materials and to changing material quality as the use of low grade ores and recycled materials is progressively expanded.

Equipment is and will be available if one demands it. The problem to plant planners will be anticipating the time of delivery for special equipment. This emphasizes the need for time, in years, to plan and build plants.

Since few corporations can significantly influence international supplies of materials and energy, the best approach is to design plants, including equipment, to economically use the materials and energy that will be available. Otherwise, the question, "Can it be done?" might be too vividly illustrated.

Manpower Requirements

It has been noted that of the three basic resources needed by any organization only the human resource is subject to growth. Material and energy are subject to the laws of mechanics. They may be used more efficiently or allocated more effectively, but they cannot be increased. Except for the additions by our Federal Reserve Board, which are mostly offset by inflation, the same laws apply to financial resources. Only human resources can grow, and only in capability.

It is assumed that growth in numbers may be ignored for planning purposes. Birth control has caught on among those reasonably affluent families concerned with the education and skills acquisition of their children - the prime source of industrial manpower. In addition, society no longer offers the incentives to self-improvement that it once did; no longer is work necessary to subsistence. In fact, if manpower is measured in manhours, the total supply can be expected to diminish with the continuing decrease in hours worked per year.

If we may project, as seems reasonable, that service industries and government will employ a progressively larger portion of the work force, industry can expect a decreasing source of supply. Unless it can reverse the trends, industry will further suffer from a disproportionate number of the well-educated being attracted to education, social institutions, and government.

A bit of deduction from these trends leads to the conclusion that industrial growth will be dependent on increased productivity rather than on growing manpower supply. When one reads the economic results of increasing competition for allocation of human resources, it becomes apparent that the high cost of manpower will mean that productivity will be crucial to the survival of many industries.

Investment alone will not fulfill industry's need for rapid growth in productivity. There must be quantum increases in the skills possessed by industrial manpower to meet the requirements of tomorrow's sophisticated equipment and systems. To obtain such skilled personnel industry must "pick the right seed and grow its own", for the "fruit" is not expected to be on the market.

If a firm does not have and cannot obtain the necessary talent, the planning of plant expansion is an academic exercise. Expansion should not be undertaken; it is doomed to failure and may take the rest of the firm down with it. This truism is corroborated by the experience of a number of firms, particularly conglomerates between 1969 and 1971.

The types, qualifications, and attitudes of human resources -- management, professional, and craft -- that a firm must secure or develop in order to embark on successful expansion are classified and discussed in the following paragraphs. After covering the general need for information (knowledge), the discussion starts at the top, works down, and spares no one.

Information, a chronic need. With all that has been written on information, treating it as bits processed by a computer with mathematical precision, it may seem presumptuous to classify it as a human resource. When it is realized that information is valueless until it becomes knowledge, and that knowledge is a necessary condition to considered judgement, it becomes apparent that information is a necessary input to growth in human resources.

It may be pointed out that knowledge is today's prime measure of human resources. Health, stamina, long life, and good sensory perception are necessary to support the reasoning processes, but it is knowledge and judgement that are demanded of a person. The whole concept of "unemployables" is based on their lack of skill, and skill may be summarized as ability to apply knowledge. Our technological society requires the application of knowledge not strong backs.

For our purposes it is insufficient to say that a firm should have comprehensive information gathering and dissemination systems, for drowning a problem in information is not the same as solving it. There is a need to be more specific as to the information needed to plan plant expansion. Thus, the informational needs implied throughout this discussion are outlined here.

First, among a management considering plant expansion, there should be a concerted effort to comprehend the general concepts of systems theory. While it is not necessary to gain expertise in mathematical systems analysis and design, a management should be competent to determine its organizational system, evaluate the work of systems design people, and understand the inputs necessary to effective output of the corporate system and its major subsystems.

Second, vast amounts of information about the firm's environment are necessary to the development of strategy. Among the classes are:

1) demographic factors - numbers, composition, interests, needs, economics, education, etc.

2) technological factors - new products, processes, materials, social response to technical developments, industry and government specifications, etc.
3) social factors - political trends, economic policy, technology assessment (coming soon?)
4) ecological factors - energy and material supplies, water and air inputs and outputs, land development policy, etc.
5) human factors - particularly human resource growth rates.

Given that a plant is needed and can be done, there develops the need for a number of specific bodies of information. Among these are:

1) Advanced process technology and its relation to resource availability
2) Advanced construction technology
3) Government restrictions and regulations on design; insurance regulations
4) Corporate policies and plans affecting design - economic, human, aesthetic
5) Management information systems effects on design (Chapter IV)
6) Plant organization plans and management development
7) Ecological regulations and policies.

Having the right information for effective planning is necessary condition, but it is <u>not</u> sufficient. It remains for management to apply it with skill to the problem.

<u>Top management, the key</u>. The research (sampling of firms and literature search) leading to this discussion indicates that only some 5% of American industrial concerns are in the position to consider expansion. With proper professional counseling this figure might be doubled.

A significant minority of industrial firms do not want to expand, primarily because owner-managers feel they are large enough or do not want to dilute control. This is a value judgement not to be condemned; it merely implies that our national industrial growth syndrome is largely confined to the few enormous, influential industrial corporations and to the politicians who hope to profit by their growth and plant locations.

The significance of these conclusions is that most industrial managements are unprepared to engage in plant expansion or even plant replacement. One need not look far to find firms that have built and moved, built and moved only to find themselves no better off than 20 or 50 years ago. The new suit does not fit better - it's just new - and may have been desired because the body corporate grew portly. These managements lack one or more of the critical characteristics outlined below in order of importance.

Once we get beyond the few hundred largest concerns, we find that too few managements realize management is by definition planning - all the rest is daily administration. Further, planning includes strategy development and policy formulation, and "objectives" means something more than survival of the persons involved. Myopic vision is inadequate to plant design which is by nature a visionary process. For the management that wants to improve its vision, the references at the end of Chapter II should be of aid. Suffice it to say here that managements without explicated long range plans and objectives are not in the position to design plants.

Too many managements give only lip service to innovation. Not only are they unable to innovate or even to accept the innovation of their employees; they are unable to adapt as is exemplified by the Japanese. While the Japanese have been increasing productivity by 8-10% per year, the U.S. experienced a traditional 3-1/2% until 1967 when it started degenerating to 0.2% in 1970. So prevalent is the "propose-dispose" syndrome that consultants make a practice of "digging the ideas out of bottom drawers" in a company in order to make reports that appear outstandingly creative. For a comprehensive treatment of the problem see Donald A. Schon's book Technology and Change (Delacorte Press, New York, 1967). Plant design, to be optimum, will require creative adaptation, innovation, and combination of new technology. A management predisposed to reject innovation will find itself with a costly new suit just like grandfather's.

Another common failing of top management is management development. Even if a new plant were built properly, the management organization and system necessary to run it optimally would be lacking. But more of this in the next section.

A related inadequacy is the too common lack of foresight in management's labor dealings. Too often has management disregarded labor reaction to process design proposals with disastrous results. (General Motors' problem with Vega assembly at Lordstown is a dramatic example. See "The Spreading Lordstown syndrome," Business Week, March 4, 1972, p. 69.) Too often has management failed to anticipate that precedence in labor relations consists of one action; that first crude, unplanned method used to start may have to be used for ten years. Labor needs are discussed in a later section.

One final lack that prevails is the inability to see the forest for the trees. This can be partially excused to the educational system of the thirties and forties and to the difficulty of keeping up with the accelerating complexity of our society. Nevertheless management cannot depend entirely on systems engineers for optimum design; it must become competent to evaluate the internal and external relations of the design to the overall needs of the corporation. It has been frequently noted that a prime function of management is to act as a means of linkage among the various internal sybsystems and between the organization and its environment. Not only must this be done, by management, during design and project stages, but also in the later operation of an expanded, more complex organization. The talent for understanding, planning, and coordinating complex socio-technical systems is not prevalent but can be developed. A major purpose of this writing is to aid management in their acquiring an understanding of systems and their impact on planning and design.

To summarize, management capable of effective industrial expansion is visionary, open-minded and innovative, economically and socially aware, and characterized by a holistic approach. A management lacking the expertise to launch a major expansion program is better advised to avoid it. Better successfully small than disastrously large. Such a management is to be commended for undergoing the critical self-evaluation necessary to recognize its inadequacies. Recognizing does not mean accepting. When the problem is recognized the management will be in the position to seek self-development. Then at a later date this management, from a stronger position, can shift to a strategy of expansion.

Plant management, a necessity. During observations of scores of plant expansions it was noted that rarely does top management purposefully plan and provide for plant management. Commonly the plant manager is not appointed until construction is nearing completion. Many foremen do not get involved until after startup is underway.

Earlier it was pointed out that designing and building a plant takes three to five years. Developing a plant management team in less time is fallaciously optimistic. The plant has been defined as a socio-technical system; designing it involves management structure and system design as well as hardware design. As the developing design makes specific management needs known, procurement should start immediately, for developing an effective, efficient, coordinated plant management team takes two or more years. For any plant design, the first and obvious need is for a plant manager.

A competent plant manager is critical to the success of any plant - no matter how well designed. He is necessary to bring the best of designs into full, fruitful operation, and a must to correct poor design or adapt operations to it. In order to fulfill his mission, the plant manager needs to be a man of many talents rather than a specialist. He needs the technical background to understand the physical process and should be involved in its specification during design. He should have the business background to understand markets, economics, accounting and budgets, scheduling, logistics, etc. and be involved in the specification of the plant's management control systems. He should be competent to build an effective organization structure and supervisory group. His education should include extensive study of labor relations and his talents the knack of applying the knowledge effectively; he should be instrumental in the early negotiations regarding the plant. To summarize in terms of standard disciplines, this paragon of virtue needs to be a master in engineering, administration, management and leadership, social and behavioral science, labor negotiations and law - and should be president of the company.

Truly qualified and effective plant managers are rare. Probably one is not available in the firm and cannot be obtained outside. So when the decision to expand is made the search for the most nearly qualified should begin immediately, both internally and externally. The qualifications to seek are, in order

1) managerial and social competence, leadership
2) appropriate technical competence
3) competence in labor relations and negotiations
4) administrative competence

It is to be expected that no one is fully qualified. The objective is to find those individuals qualified in areas requiring talent and/or long training. Administrative techniques are readily learned, and training programs are readily available. Labor relations expertise is a matter of education not often undertaken. Thus many inadequacies can be overcome in a short time but some, as management and technical competence, cannot be achieved quickly.

As soon as the individual is chosen he should be assigned at least part-time to the expansion project. He can both contribute to and learn from the design process. Concurrently he should be "filling the gaps" in his education, securing and developing his management team, and planning start-up and operational needs. Another advantage accrues from his being assigned to the project; he is a party to all major decisions in plant design, may influence them before the fact, and understands them after the fact.

Within the plant management group, several professional positions will be very difficult to fill because top talent is scarce and probably already committed within the company. Among those that must be sought early, both internally and externally, are:

1) production and inventory control or materials manager - particularly one qualified in modern computer operated systems

2) process engineering - creative talent fully cognizant of recently available techniques is scarce
3) methods engineering - again the shortage of professional, creative talent, particularly with systems training
4) plant engineering - not quite so bad, but professional talent is short and needed early in design
5) personnel specialist - much mediocrity in the field

Without these, the effectiveness and efficiency of a plant will be severely impaired. The design project can be done without them, but it is strongly recommended that these professionals with a commitment to the output be enmeshed early in the project to greatly enhance the quality of design.

Obtaining the necessary managerial, professional, and other personnel will in probability mean developing the firm's own. This requires choosing the best talent available and seeing that it is educated to "fill the gap".

This development takes time - time that must be planned. Thus, securing the necessary management team is an integral part of plant planning and design, for the plant cannot operate without it.

Project management. Recognizing the millions involved in plant expansion and the degree to which the completed plant will influence future direction of the firm, it is apparent that the plant design project personnel must be of the highest calibre.

Of extreme importance to the success of a project is the choice of a project manager to guide the planning, design, construction, and installation of a plant. This manager needs to be a professionally respected leader of diverse individuals; capable of effective planning, scheduling and coordinating; technically competent in architecture, engineering, and construction; knowledgeable in manufacturing processes, methods, management controls, and labor relations; cost conscious; capable of diplomatically demanding a job done well and on time; and, finally, an entrepreneur who can make decisions under uncertainty. Obviously, it will be difficult for management to obtain or develop this paragon of managers, but it must if it is to manage its own destiny. Otherwise it must place its destiny in the hands of architects or builder/engineers.

Without an effective project manager, a firm can expect a standardized structure instead of a plant tailored to fit unique needs. That three million dollar plant will cost four. Without his guidance architects must over-design to cover situations that might happen in someone's plant someday.

The project manager's function is to put the whole thing together in an optimum way - to integrate the system. In this capacity he must farm out hundreds of sub-projects to existing corporate personnel and coordinate their efforts and plans. To be effective he must have the authority to draw on all the expertise within the firm. He must be able to speak with authority when dealing with outside professional help and contractors. In short he is the locus and nexus of plant planning, design, construction, and installation. It is recommended he report to the management level responsible for the long range effectiveness of the plant.

The project team may be filled out in parts or wholes, preferably from within the firm, by the following professionals.

1) plant layout and materials handling
2) process/product engineering
3) management control systems specialists
4) economic evaluation and systems analysis
5) management and personnel representatives
6) quality, plant engineering, marketing, and financial representatives.

Most if not all of this personnel should come from within the firm. Ideally the professionals to be assigned to operate the plant should be assigned to the design project.

A plant design project is an excellent medium for management development.

This writer has guided a number of firms in setting up and utilizing a project team made up entirely of existing company personnel. Some training was usually lacking, particularly in plant layout and in systems, but that can be overcome. Internal personnel also have the advantage of knowing the sources of information and the company "personality".

Observations of a number of firms who did not set up project management have revealed consistent results - poor to disastrous. Everyone had authority, and no one had responsibility. A cacophony of effort leading to plants far from optimum.

Craftsmanship. A chronic, nationwide problem in labor supply is skill. To have skilled employees, a plant must train and develop its own. This takes time and effort that must be planned. This training may be viewed as a portion of start-up cost.

Years of labor negotiations have removed the incentive to develop skill. Across-the-board increases have lowered the relative difference between common labor and craft, and seniority provisions have lessened the need to acquire skill. Don't blame unions; management allowed it. Now management is "stuck" with the shortage.

The bulk of the shortage exists in the support functions - particularly maintenance, tool and die, and set-up personnel. With the extension of automation, the need for these people will increase while the need for unskilled direct labor will diminish.

For management to alleviate the shortages, it must do two things. First, it must renegotiate labor contracts to re-establish the differential between skilled and unskilled. It won't be easy, for labor leaders think in terms of votes and the unskilled are a majority. In addition seniority provisions need to be modified to qualifications first, seniority second.

Second, the firm must demand quality. This means setting up the personnel controls necessary to ensure it and the training programs necessary to secure it. Quality workmanship needs to be a necessary condition to employment. On the other hand, management is obligated to provide the means for the employee to acquire the necessary skill. A number of self-help training programs are on the market - such as, those offered by the publishers of Plant Engineering for maintenance.

Finally, management can aid the growth in craftsmanship with efforts to enhance the social status of craftsmen.

Other manpower. Although there are some qualifications not universally available, outside professional aid is generally available. Only at the peak of boom times will consultants, architects, engineers, and builders be difficult to engage. Their qualifications will be treated in Chapter VII.

Much has been written on the availability of administrative, clerical, and labor personnel. Its availability is largely a function of location and is presumed to have been accounted for in the plant location decision.

Manpower, in summary. The key to industrial expansion is top management - a management that develops strategy and long range plans for its own growth and thereby creates the need for plant expansion through corporate growth; a management that attracts the kind of middle management and professional personnel that enables and enhances growth; an innovative, visionary, holistic leadership.

When a company lacks the management to facilitate expansion, the problem is not plant design but management development. This development may be at the top level or the plant management or design functions. In any case it must be well underway before detailed designing for expansion can be effective.

For the company that intends to grow, the natural processes of human development will not be sufficient. The top management must take an active part in accelerating the development of human resources - particularly management. Until the growth rate in human resources matches the physical growth desired, a firm will find all its growth plans limited.

Should It Be Done?

To this point in this chapter, we have concentrated on whether a firm is capable of expansion. In Chapter II we concentrated on whether a new plant is needed. When all the analysis and planning outlined and implied by these two chapters is done, Stage I is complete. The top management is at the point of decision, "Should a new plant be designed?" It is timely to review the steps in Stage I and look ahead to Stage II.

First, it is necessary that top management critically evaluate corporate capabilities and the environmental trends to establish realistic corporate objectives. This is a soul-searching process of studying corporate strengths, weaknesses, and values that leads to a long-range corporate strategy.

Second, a long range plant must be developed from the corporate strategy. This is a detailed plan that times the desired levels of development. It states the markets, products, and levels of volume - the outputs - and thereby calls for the transformation system - the plant - and for the inputs - human, physical, and financial resources.

At this point a technological assessment should be undertaken to outline the kind and magnitude of plant needed.

Substituting improved technology for the traditional may well result in the need for no new plant additions. Alternately it will indicate the need for replacement or addition or, with the marketing plan, new locations. In any case, the resource inputs are further specified.

Next, top management is in the position to undertake corporate "capability analysis" - the specific comparison of needs with resource availability and growth rates. As was indicated, the most critical resource is human - particularly, management and creative engineering talent. Without it all physical growth is stymied. Physical resource limitations can be overcome technologically by creative engineering. Financial resources are readily available to competent, innovative management. Resource limitations determine whether plant design and installation can be done and feedback into the continual process of strategy development.

So far, only the critically necessary factors needed <u>prior</u> to plant design have been discussed. In short, if a company hasn't a thoroughly developed strategy and long range plan plus the management to implement them, its problem is not factory construction but management development. If it has the wherewithal and the plans indicate the need, a management may complete Stage I with the decision to proceed with plant design - Stage II.

In Chapter I "design" was defined to include planning, but "plant planning" was frequently used in Chapters II and III because the prerequisites to plant design primarily involve corporate planning activities. Stage II emphasizes design but includes much planning. It is the process of determining the broad outline of the three major subsystems and the overall system configuration. The three subsystems are covered in Chapters IV, V and VI and their integration in Chapter VII.

Beginning with the "outline specifications" developed in Stage II, Stage III is the process of detailed system design done in conjunction with outside architects and engineers. Stage IV is the construction and installation, and Stage V, the start-up.

CHAPTER IV

MANAGEMENT CONTROL SYSTEMS: THEIR IMPACT ON PLANT DESIGN

It was pointed out in the last chapter that the one resource indispensable to success is management. Without it, plant expansion is not the problem.

Assuming that adequate management is available, the question now becomes how that management will operate. This leads to an examination of the interrelationships of the management control system and the total plant system.

When the plant is viewed as a socio-technical system consisting of a technical core surrounded by a managerial system as suggested in Chapter I, it becomes self-evident that the management system has an impact on the efficiency resulting from a particular factory arrangement. On the other hand, one only needs to examine any existing factory building and process to observe the severe limitations the physical facility places on the choice of management control methods.

Traditionally, buildings are built and equipment is installed with little explicit consideration of the requirements for management control. Subsequently, the methods of planning, scheduling, and control are forced to adapt. These adaptive methods typically result in excessive materials handling, in-process inventories, control personnel, delivery times, and costs.

Must we continue to force adaptation in a new plant? Would it not be better to plan for the needs of management control systems and design them into the total plant system? While the impact of physical design on management controls is recognized, it is here the thesis that the impact of needed management controls ("software") on the hardware should be incorporated into the planning and design criteria for the hardware.

To enhance management's ability to specify the "software" parameters on the hardware design, the following sections outline and illustrate the areas where hardware design can be improved by adaptation to the "software". Central to this treatment is the concept that a plant is a total system consisting of a technical core system operated by a management system composed of supervision aided by an econo-technical system of plans, schedules, controls, and information flows.

The Control of Technology

Traditionally, management has relied largely on financial measures and controls. These have the advantage of dealing with all in a common unit-dollars - and are related to the profit motive. Yet they lack full effectiveness because they are by nature historic (or projections of history) and, when operated by the psycho-social system, tend to be misused and abused because of often conflicting personal drives of the people involved.

With the advent of the computer it is now practical for management to gain control of quantity, time, and place, plus quality, the technical factors in effective plant management. Concurrently, product variety and technological complexity have increased to the point that their control is essential. Thus demand for control has grown as fast as the ability to supply.

It might be said that now management not only *can* but *must* gain control over more than just one of the economist's measures of value or utility - price, time and place, quantity and quality. (The technology of control has now even reached into the control of aesthetic and sentimental values -- color, cleanliness, noise, ecology.)

Technological controls have advantages that tend to offset the disadvantages of financial controls. They are far more oriented to the future and less subject to the emotional overtones that impair the effectiveness of dollar controls.

Without effective control of the technology of the plant, financial controls will largely serve to show only the need for technical controls, for control of the plant's technology is essential to favorable financial results.

Inventory controls. As with man in general, management is a product of its times. It is necessary to look at current inventory control philosophy to understand where improvement must of needs be made.

Currently inventory controls are almost exclusively financial in their orientation. On the one hand, elaborate procedures are established to account for the asset value of raw and finished goods, while work-in-process is often the "remainder" used to cover errors in other parts of the procedure. The asset value is of no use to plant management or plant planning, for the asset has no value unless it is the right thing, in the right place, at the right time.

The economic order quantity techniques are a financial approach to overcoming the human tendency to overstock until the cash runs out and then to understock until the plant runs out. They only partially solve the problems of right things and time while ignoring place. Further, their method is based on projecting historical trends, so they are effective only for staple products that are subject to mere random demand. Thus controls that work well on routine operating supplies tend to fail when applied to the prime products - particularly if subject to market or technological change.

For purposes of physical, technological control, EOQ techniques exhibit some severe limitations. Unless very closely controlled by engineering change notices, EOQ methods reorder obsolete components and fail to order the new.

More seriously, component inventories so controlled are not quickly responsive to product/market shifts. Finally they fail to deliver components in the proportions needed for assembly. EOQ mathematics will cause 10 of one component of an assembly to be delivered while 20 of another are; the result is ten assemblies and ten components awaiting the next order. This tends to make the component with the smallest current stock the controlling factor in assembly lot size and to swell aggregate parts inventory with left-overs.

Related to the above problem is the problem of having on hand before assembly all the components necessary to complete the product. When traditional inventory control techniques are used, safety stocks of parts must be very high to give any reasonable probability that the product can be completed. This leads to sizable work-in-process stockrooms, staffs, and financial commitment. Further, it hides large quantities of equivalent finished goods that are subject to product obsolescence.

Traditional inventory re-ordering procedures imply that the machine shops are just another vendor. Often little control is administered to the flow and amount of goods within the shops. This, coupled with misdirected emphasis on labor productivity, results in material stacked profusely near every machine, high WIP inventories, long lead-times, and, frequently, utter chaos.

These problems with inventory control culminate in excess demand for investment and space. As was pointed out in Chapter II, improvements in inventory and production control practices coupled with improved storage and handling equipment may well eliminate the need for new plant. If not, improvements will certainly delay or reduce the need for new plant.

Should expansion be undertaken AND the existing control system be extended, another horrendous problem can be expected. As the quantity and variety of items to be controlled increases within any given control system, the "tyranny of variety" takes over. In order to maintain reasonable probabilities of having the right item in time and place, inventories must increase in a geometric function of sales increase. To illustrate, in a recent plant expansion investigated, the increase in dollar value of work-in-process inventories would have been 50% more than the total dollar cost of the new building and its enclosed equipment. Instead, a completely new, and appropriate, control system is being installed as of this writing.

From all this it may be concluded that inventory magnitude, storage methods and controls must be investigated and determined before the parameters of plant design are set. Inventory will have a major influence on the size and arrangement of the plant.

An illustrative case. The impact of inventories on plant design is illustrated by the expansion of a machinery manufacturer. First, the expansion was not warranted in 1970 by sales expansion. (Inventory improvements would have delayed expansion by three to five years.) Rather, the product mix had shifted to much larger, heavier machines that require higher than typical clearance and heavy overhead cranes. For the near term, the equivalent of half the new building's floor space will be surplus in the old building which has the typical 40' x 40' x 20' spacings.

Early it was recognized that the equivalent of many finished machines were being stocked as parts. Further, inventories were expected to skyrocket with extension of the existing inventory controls. Investigation resulted in a fundamental change in the view of inventory. The production and inventory control system (PICS) being installed at this writing is to recognize all inventory in terms of finished machines. Inventory is to be ordered, made, stocked, and reported to management in terms of equivalent finished machines. So speculation in parts shows up as speculation in machines. That "wouldn't it be nice to offer" variation ordered by the sales department shows up as machines to be sold. For sake of brevity, the subsystems (within the PICS) necessary to make this philosophy workable and flexible will not be covered here. The focus will be placed on the affect of this on plant design.

Previously, machines were to be assembled to customer order from stock parts, so no provision was made to store finished machines. In practice machines were often stored - in the middle of assembly operations - finished or awaiting back-ordered parts. The new building provides space for storing finished machines that get all the way through the system without being sold. By contrast less parts inventory space and facilities are provided.

More significantly, the philosophy caused the arrangement of production facilities by major assembly groups. Thus the major, high value, components are to move rather continuously through machining and directly into assembly - with a large reduction in WIP. Extension of the point of view into the small parts shops results in significant reductions in minor parts stocks. Further it leads to the application of "group technology" (to be discussed in the next chapter).

If this sounds like "old hat", the economies of mass, line production, the reader is reminded that this is a giant job-shop. Many of the "lines" pass over the same machinery and through the same intra-process storage/check points.

At this writing it is too early to assess the results, but a feedback into management organization portends great results. Historically, the job shop foreman has been responsible for keeping a number of similar machines efficiently producing something - needed or not. He has not been attuned to the needs of the market nor the total plant system. With the plant organized under the described control philosophy, arrangement, and "group technology", the foreman becomes responsible for the manufacture of major component/assemblies complete. He now becomes product and system oriented rather than operation or process oriented. He now realizes where his group fits into the scheme of things, not just that he was 107% efficient yesterday. He is now a manager, not a "speed boss".

Capable management has been recognized as a resource indispensible to expansion. Now, an example has shown that a portion of the econo-technical control subsystem can feed back into the arrangement of the technical core subsystem, and through that into the management structure and methods - a portion of the psycho-social subsystem. This feedback and change in view can enhance the growth of management resources.

Control, WIP, handling, and facilities. The previous illustration dwelt relatively more on the impact of inventory control methods on arrangement, operations, and management. An investigation of storage and handling methods for the same plant can be used as a framework for outlining the impact of inventory controls on the handling configuration, and the feedback of configuration on controls.

As mentioned earlier the faster moving WIP reduced the need for space between operations. By contrast the need to store heavy castings and plate indoors added to space requirements. Because of the weight of heavy raw material and finished machines many areas of the floor required additional reinforcing. Such simple interchanges between needs and design occur repeatedly.

More significantly, the broader concepts of interrelated process, arrangement, organization, and control points basically set the overall building configuration. Concurrent with the studies described in the previous section, "broad-brush" layouts of material flow and facilities layout were being made. The developing results of these studies fed into a concurrent study of configuration concepts - area, height, wide vs. narrow span, rectangular, square, even round. These were related to various flow patterns - straight, circular, U, W, and others - and to compatible handling methods - stacker cranes vs. hook cranes, with or without gantries or jibs, cantilever cranes, conveyors, transfers, etc. The result is a single span building with hook cranes spanning 150' and supplementary gantries.

Note that all the outlined studies were progressing <u>concurrently</u>. None reached conclusion until they all did. None of the interrelated factors was allowed to arbitrarily restrict the decisions on all the others. The wide single span cost more than an equivalent two spans, BUT the number of 30 ton cranes and 5T gantries required is much less, handling costs less, WIP flow direct and unobstructed, storage area less, and dispatching reduced. The design enables operations to be dispatched in groups rather than individually. In short the plant is intended to operate as a complete system.

An offshoot of the above was an investigation into the storage and control of thousands of small parts - those 80% that represent 20% of the cost. The result was a proposal to install an automatic stacker-stores unit. Such units are not fully efficient unless they are over 30' high. Adjacent to the assembly area of the new building, a portion of the connector space (created by the need to connect with the older building) was designed to have a clear height of 40'. This kind of thing is not economic to do after a building is up; it must be planned in. Taking advantage of modern storage techniques must be planned before the architect takes pencil in hand.

Again using the stacker-stores unit, the interrelation of control and equipment design may be illustrated. The interface between control and machine occurs at the input/ output station(s). Shall the input/output be only in bulk or shall direct picking be done? The latter slows overall operation. Alternately, supplementary "pull stations" can be installed in place of some storage locations. The method and frequency of securing parts for assembly determines the number and style of the "pull stations" and the need for additional personnel. These design alternatives are all a function of production control procedures for assembly. The form of parts input (baskets, pallets, size, weight, etc.) determines the overall physical design of the stacker unit. Alternately, parts handling methods in the supplying shops may be changed to be compatible with an overall system of parts handling and control throughout the machine shops and storage facilities.

Stacker-stores units may be activated by manual keyboard, plastic locator cards, IBM cards, or direct computer control. Storage locations may be operator or computer chosen based on random, frequency zoned, first-come, etc. methods. With the aid of data communications devices the units may be literally the physical analogue of the computer maintained inventory records. In short, the means of mechanical control is a function of management control procedures.

When such modern handling, storage, and control methods are viewed in total and concurrently, the opportunity for total, analogous control of the physical flows and corresponding record flows becomes obvious. The technology is with us today; only the ingenuity of management is needed to apply it.

BUT the application of this technology must be planned before the design of hardware. Don't let the architect and contractor deliver a factory before you figure out how to run it. To illustrate, at a plant, "designed" by the financial group of a conglomerate corporation, a major portion of the raw material was to be bar stock. As designed, the bar stock could not be unloaded from a truck. Major, costly alterations had to be made to the steel structure after construction had started. Even so, the arrangement is far from satisfactory. Double handling is still required into storage. In addition, limitations in storage methods force the dilemma of uncontrolled storage with efficient handling to the bar machines or controlled storage with costly handling.

<u>Control, process, and utilization</u>. The interrelationships of product, process, and building were earlier recognized. Here the focus is on control versus process.

Universally and daily, the following discourse occurs. (PC, production control man; ME, manufacturing engineer.)

PC: Here are the drawings on part (number). Let me know the operations, times, and set-ups on 'em. Will ya?

ME: Sure. How do you think you'll run 'em?

PC: Oh, about a hundred a month, I guess.

Later:

ME: Here ya are, buddy. We figure it is best to run 'em on (machine) with a (tooling). Here's the standard times.

PC: Lessee? (Calculates EOQ) Looks like we'll run 'em about a hundred a time.

After some time, the lots are running back-to-back and the operator is getting paid for set-up on every one of them. The foreman likes it because it's "efficient"; the operator would grieve if you asked him to make something needed on the machine. Now comes expansion and the request for more of the same because it appears so "efficient" in reports. (No wonder sixteen operators are bidding on the new job.)

It's left to management to solve the hundreds of such problems in its present plant. (Some bright young IE will "make a hit" with a cost reduction project on this one.) The question here is why just extrapolate present controls/ process into an expanded plant. Why let a series of off-hand comments made years ago determine plant size, shape, and machine process. The widely published mathematical techniques for calculating plant size make the assumption that present methods are correct and extrapolate them to determine floor space.

At the time of expansion the economies of scale become a particularly important opportunity. It's time to examine all parts and products for optimum design, process, and, of particular interest here, means of control. EOQ calculations assume one ideal set-up cost and process throughout all volumes. Actually the most economic lot size should change with the process and tooling justified by the volume as well as by the volume itself. Further, methods of handling and storage justified by expanded or new product volume should be recognized in inventory carrying costs and therefore in lot size. In short, lot control methods should be designed to be compatible with a process designed to be optimum for the scale planned.

Perhaps lot control methods are no longer appropriate in the new or expanded plant. By grouping technologically similar parts or assemblies, the equivalent of line, mass production may be achieved and controlled as such. This move can result in a significantly different plant including its process and controls. Under such methods, parts are not made to inventory, but rather, are increased or decreased in flow as needed. (For a general discussion of "group technology" refer to Business Week, October 18, 1969, p. 152, "A Way to Make Diversity Pay Off".)

Long a practice in the process industries, it is now possible to design a totally integrated process, handling, and control system for fabricating plants. It is necessary to establish a control station and run conveyors from it between rows of various machines or to clusters of machinery. The dispatcher places a box of material on the conveyor and, on a console at the control station, trips a diverter for the appropriate machine. When work is completed the operator places the box on a return conveyor (over or under the dispatch conveyor) which passes through an automatic parts washer if needed and delivers the completed work to the side or rear of the control station. The dispatcher then makes the necessary records and places the work on a storage rack to await dispatching to the next operation.

(United Shoe Machinery makes a fine system of this type for light assembly. It was designed for apparel. Unfortunately, they have been unwilling to adapt the equipment to the weight of metal parts - at any price short of exorbitant. Oh, where is creative market expansion and product development? Others are entering the vacuum.)

Such conveyor dispatching can solve one of the most fundamental problems in any job shop. There is always the problem of matching machine capacity to needs and, concurrently, to orderly flow. Traditionally, management has not even tried; it has settled for machine oriented layout and organization - all lathes together, etc. With conveyor dispatching, machines may be secured in the proportions needed for a variety of parts or assemblies, located as is physically convenient, and yet operate as though in a mass production line. Any machine can feed any other machine by conveyor through the dispatcher. Thus, control, handling, and process may be integrated while remaining flexible, adaptable, and expandable.

Controls, labor, and utilization. One of the most fundamental errors made in planning plant expansion is the extension of misdirected labor controls. Historically, production management has been forced to give undue attention to the efficiency of direct labor. This has resulted in a myriad of control techniques including standard methods, standard times, incentive plans, and efficiency reports. Given the psycho-social response, this has led to large numbers of handlers, stockmen, scrapmen, chip men, expediters, sweepers, oilers, lead men and others - all to assure the operator is not deterred from constantly grinding out parts. It has led to long WIP queues and extra machinery awaiting the operator, Mills, drills, and lathes are commonly maintained set-up for the seldom used parts. Badly needed prototype, service, and other small lot parts are almost impossible to get through the system because they are not as "efficient" as commonly made parts.

In any fabricating plant, there is a tendency over the years for the over-emphasis on labor controls to cause under-utilization of machinery, floor space, and service functions at a cost in excess of the direct labor savings. Without getting into a discourse on proper labor controls, it is pertinent to recognize the opportunities expansion gives for not proportionally expanding that which is under-utilized. Here is a case where mistaken response to controls should not be allowed to determine facilities. Rather, the optimum process and service facilities, including attendant labor, should be determined and then the organization and labor controls designed to guide it properly and effectively. After all, present labor standards are, in practice, determined by the process currently available.

Further there is an opportunity here to take a hard look at service functions and design them to be effective and efficient at the expanded scale of operations. The present number of handlers, inspectors, set-up men, etc., may not be needed at the larger, reorganized scale of operations. Receiving and shipping may be better split, or alternately, combined; testing separated or combined with assembly; mechanical chip handlers or sweepers applied; automatic oilers applied; or handlers replaced with conveyors, etc. In short, there is an opportunity to correct some of the costly practices that have evolved from misuse of labor controls.

Engineering controls. During a recent investigation into the poor efficiency and motivation of a group of assemblers, gross inefficiencies were found not only in assembly but in stock handling, parts production, supervision, production control, and manufacturing engineering. Upon tracing the system, the great bulk of the inefficiency was found to be caused, simply, by the form in which the engineering department listed the parts.

As with all systems, a small error in one of the sub-systems can multiply into catastrophic problems throughout the remainder of the system - as is so well illustrated by the impact of errors in welfare and low cost housing on our urban systems of today. (The converse can also be true.) In this particular case, the engineering department lacked a view of the entire system. Production supervision was so inundated by the symptoms, that it could not see the cause of the problem. These human reactions are to be expected. It is management that is in the position to recognize the overall systems impact of various actions.

For the product of any technological sophistication, a prerequisite to the success of any of the previously discussed control systems is technical integrity in the engineering records and designs. The parts must fit, obviously, but, more significantly, the parts lists must call out the correct parts for the assembly desired- or the product "won't fly". Secondly, the parts lists need to be in terms of how the parts fit together, not their technical function; that is, they should be in terms of assemblies, not hydraulic, electrical, mechanical, etc.

The key to any computer based production and inventory control system is an accurate and complete data bank based on complete and accurate engineering specifications and materials explosions. The computer will not adjust that hole with a file; it will not change dimensions on a part because "them engineers goofed again".

Perhaps the firm has managed to overcome all errors under the "old system" by depending on the experience of operators, but in an expanding plant the "old system" breaks down with the job changes and new personnel. The "tyranny of variety" takes over, and the plant may spend years "debugging" provided it manages to avoid a complete systems breakdown.

In addition to "old system" breakdown, another aggravating factor can be anticipated. Product design changes generally result from the process design improvements done in conjunction with plant expansion. Further, process improvements may result in changes to the order of assembly. Thus, engineering changes must be timed with the phasing out of the old process and the start-up of the new. This will test the quality of engineering change procedures - particularly the ability to time changes in the computer's data bank.

The importance of effective engineering design controls cannot be overemphasized. For a plant to operate smoothly, it is technically imperative that design integrity be established and maintained. For production control systems to operate effectively, the parts lists must properly and correctly support the system data bank. The technical imperative can be recognized and planned for. This is a management responsibility; it cannot be abdicated.

Quality control requirements. It's so often ignored or tacked on later, but quality control should be given consideration at least equal to process design. If nothing else, QC facilities and/or check stations need to be designed into process flow.

Equally obvious, quality should be designed into any product or process changes precipitated by expansion.

Of more importance, the pitfalls and overlooked opportunities of superficially extending present quality control concepts should be avoided. To illustrate, one manufacturer's practice had been to test its product wherever assembled. In planning a new assembly building the original thought was to continue the practice. When it was found that one-third million would be invested in scattered, little used utilities, the practice was seriously questioned. Jumping over the long studies to the conclusion, a consolidated testing facility was installed in the new building with the following direct and indirect results.

1) less investment in better facilities
2) reduced testing time
3) improved testing supervision
4) assembly sequence change with major savings
5) measurably better supervision over a major portion of assembly

6) improved material handling

7) improved control over assembly, test, paint, and shipping flow.

In another situation, roving inspectors were determined to be unwarranted by the simple, staple product involved. The process was altered to trap all finished product at "toll gates" before entering shipping. The number of inspectors was reduced by 70%, and the responsibility for quality significantly improved, waste was reduced, and productivity slightly increased.

Quality control, too, can be a cost reduction program. It is not here germane to cover the particulars, only to point out the opportunities.

Maintenance controls. Nationally, plant engineers have done a better job than other functions in expressing their needs in new plant construction. Yet the needs warrant summary here. In short, they are access and standardization.

To minimize maintenance labor costs, to have any reasonable success in maintenance planning and standards, all equipment and utility lines must be accessible. This means layouts must leave access panels available and account for the space to remove bulky parts such as tie bars and motors. It means access panels built into walls for pipe chases, open layout for switchgear, means of shut-off for sections of utilities to prevent plant shutdown for a minor repair.

This list could go on, but it's meant to be only illustrative.

For maintenance controls to be effective, standard components need to be designed into the new plant. Finished goods inventory control has come to recognize the problems of product proliferation; the plant engineer has the same problem with spare parts proliferation. Less variety means less inventory, special tools, and labor training. It is quite practical today to standardize on electrical gear, light fixtures, motors, valves, traps, fittings, hydraulics, air fittings, drive gear, lubricants, finishes, and so on.

In order to achieve access and standardization, it is necessary to establish a control function to determine and enforce standards during the planning, design, and construction of a new plant. For the period of the project the assignment of one responsible person within plant engineering may well be done. One particular pitfall he must avoid is those "or equivalent" phrases in architectural specifications.

Not of direct connection to controls, but of aid to future cost control is the planning for reduced maintenance through long-life or maintenance-free equipment and finishes. The initial cost may be a bit more, but operating costs can be much less.

Data collection facilities. No discussion of the effect of control systems on plant design would be adequate without mention of the installation of modern data collection devices.

Almost universally the production floor terminals are designed for easy installation and simple wiring - to the point of "tack-on". The terminals may be pedestal or column mounted - out of the way of fork trucks. Wiring may be tacked on to steel work, as are telephone lines, or run in raceways with other utilities.

Location of the terminals can be anticipated at receiving, storage, checking, and shipping areas. In addition it may be convenient to place them in places of labor concentration.

In short, data collection facilities have little effect on physical plant design, but they are critical factors in the detail design of reporting and control systems.

Financial Controls

In the previous section the contention was that financial controls are secondary to technical controls. It was implied that financial controls are unnecessary.

For day-to-day operating controls, this is literally true. Production management has very little control over prices (wages); it is the number of units (hours) that must be planned and controlled.

Yet technical controls have definite limitations - particularly in the long-term - that can overcome by financial controls. Technical controls are:

1) difficult to summarize for lack of a common denominator
2) lack economic comparison from period to period as prices change
3) lack traditional acceptance in the financial markets
4) fail to compare capital consumption with periodic value added.

Unfortunately, too many managements fail to properly apply the last factor in planning plant expansion. Too many frills are included by the influential, while long-term cost reducing investment opportunities are ignored. In addition to the economic justification of the total plant, one of the three prime criteria, all design details should be economically evaluated - steel vs. concrete; type of paint, floors, heating; materials handling facilities; process; and even control systems.

To overcome the first three difficulties, the technical control system should be recognized as a superior source of data for the financial reports. Given the physical units, only multiplication, addition and summary are needed to obtain financial results. So a well designed technical control system will have been influenced by the data needs of the financial controls.

Thus we have come full circle. Financial opportunities determine the initial need for new plant and influence the design. The plant design influences the need for technical controls, and they, in turn, the plant design. Technical controls are essential for favorable financial results and are influenced in design by the data needs of the financial controls.

CHAPTER V

PRODUCT AND PROCESS

The heart of plant design is the determination of the concept or configuration of the plant's technological process. All that has preceded serves primarily to set the stage for the design of the "technical core."

The development of strategy and long range plans is necessary to determine the need for process. The development of resources enables the application of a technology to the fulfillment of a long range plan. The development of a competent management team and an appropriate management control system enables the effective, efficient operation of an optimum technology.

The reader is reminded that this discussion is still in Stage II - the design of the overall system configuration. The subject matter of this chapter should not be confused with the content of thousands of publications dealing with the design of plant components. Rather this chapter deals with the problems and methods of systems design and the resulting determination of parameters for component design.

Because of its influence on optimum corporate operations, the coverage will begin with integrated product/process design and creativity. The remaining sections deal with two basic themes - the development of an appropriate logic of production and adaptation of the physical design to human needs - plus putting all the pieces together in a process layout.

Product/Process Design and Creativity

A fundamental error made by management, engineers, and the literature is to implicitly assume design parameters that do not exist. When designing new facilities, the limitations that existing facilities would place on product and process design do not exist.

Admittedly, it is easier to obtain a new plant by copying or extending the old. Very little thought or creativity must be applied. In fact, there are a number of plant layout computer programs that will do it for you. Little management or engineering effort is required and the results are easy to understand. Furthermore, unions like it; the old standards and "understandings" still prevail.

It is interesting to note that the plant layout and building design literature implies little confidence in the innovativeness of management. It seems to say, "If management wants more of the same, here's how to give it to them in three easy steps." It is my conclusion that management's lack of interest in creative plant design has resulted in there being little offered in the way of creative approaches, either in practice or in the literature.

Only in product design and in recent years has there been widespread recognition by management of the need for true innovation.

Much has been written about the "management" of research and development. The bulk of it deals with the administrative techniques of financial control and PERT scheduling. The various treatises on creativity deal extensively with the problem solving process, checklists, and group "ideation." All of these can be useful to receptive people in the right climate.

Only Donald Schon (Technology and Change, Delacorte Press, New York, 1967) has truly attacked the near universal problem that severely limits creativity - the stifling effects of management. He coined the phrase that summarizes the problem, "propose-dispose." The employee proposes and the management disposes. Several experiences with this and creativity becomes, "Whadaya want, Boss?"

To illustrate, I was once asked to propose improvements in the manufacture of a timing mechanism. During the investigation, I proposed a score of product design simplifications. By way of the management, the proposal was referred to one of the firm's better talents in engineering. During our discussion, he pulled a prototype of a new design from his bottom drawer to illustrate a pawl design. After a long look at the prototype, I inquired why it wasn't in production. His answer, "I proposed it five years ago but they 'pooh-poohed' it". Since the management had changed in the interim, I proposed that it employ the man's ideas at a 50% saving. At this writing, still another management is trying "to turn the company around" and the design which would save half the cost of their second most popular product has not been applied. Over ten years have transpired.

Limiting this discussion to the effect on plant design, the concentration can be limited to one area - the integration of product design engineering, process engineering, and operations. According to traditional organization structure, the only one charged with coordinating these functions is the president. Seldom are all three organizations closely related. This structure leads to zealously guarded baronies exhibiting more conflict than cooperation. The manifest problem resulting from this is the too prevalent propensity for product engineering to throw its designs "over the fence" to process engineering who in turn does the same to operations. Throughout this procedure there is no explicit provision for feedback of ideas and problems from production to product design. Here the procedure has been simplified to the common three-step approach, but many firms expand this as far as research, development, engineering, process, methods, layout, standards, facilities, and finally production.

Value engineering is a growingly popular approach to overcoming this linear procedure for converting a design into a production run. Its techniques of education, analysis, and evaluation have been quite effective in dealing with the day to day design activities. It should be noted that observations in a number of industrial firms show that value engineering is only as effective as management wants it to be.

Superimposing a plant design project on a tradition of functional parochialism will lead to far less than optimum design unless conscious efforts are made to break down the traditional barriers. One effective way is to authorize the project manager to initiate design changes in product or process. Another is for the top manager to enthusiastically back the project manager's efforts to create valuable improvements through design changes. Failing this management authorization, the project manager must encourage, cajol, coerce effective cooperation among the staff functions upon which he must draw.

Why is it so necessary to overcome the prevalent barriers of management attitude and structure? The first step in the determination of optimum "outline specifications" is a thorough, creative manufacturing process analysis and development. This fundamental step is most frequently mishandled by management. Two basic approaches are common - extend the present process or design a building and then force <u>some</u> process to fit. Lack of time is often blamed, but this is just symptomatic of poor long-range planning or reluctance to make timely entrepreneurial decisions.

What is needed here is an integrated effort toward optimum product/process design for future needs. Existing product designs have probably been implicitly based on the limitations of existing capabilities and on customs. Against the rapid technological evolution currently transpiring, the acceptance of present product design as inviolate will prove inordinately restrictive to optimum process design for the future. The process engineer and/or project manager must be free to propose product design modifications where economically justified by process design innovation.

Even accepting the present product designs, the process analysis in preparation for new plant design must be recognized as different from routine, administrative process design. The restrictions of existing facilities do not exist, for new or additional ones are to be bought. The probability is nil that more of the present processes is optimum. Yet in the literature this is the universally touted approach in spite of the rapid progress transpiring in process technology.

Beyond questioning present product and process designs, there is the probability that new products are involved in the need for new plant. It is also probable that the new designs are conventional in configuration and predicated on assumptions of conventional processes; seldom is much thought put to the opportunities new processes present to product design. Moreover, it must be recognized that during the life of a plant it will probably be required to handle still further product development. Thus the project manager needs to be sufficiently cognizant of the firm's product strategy and design technology to predict the probable need for future process. He should also be free to propose process technology that may force a change in product design technology to the betterment of the firm's economics.

In brief, no presently used technology or designs need be restrictive to the initial conceptualization of the plant design. Since no process has yet been installed, there is no need to make use of existing facilities in product or process design. Not even the long range forecast of product mix need be accepted as sacrosanct; new process technology may mean new product opportunitites. The most rare opportunity to start afresh is available in the initial step in plant design. The need is for a break in tradition, a creative design of product and process jointly.

Determining Transformation Needs

For a place to start in evaluating the totality of transformation needs, the project manager should go back into the product strategy that led to the long range forecasts showing the need for new plant. It is the market and product needs that must be examined - not the product designs. Since the project manager must, by virtue of his function, make entrepreneurial decisions, he should acquire the knowledge to make wise judgements. A thorough study of the firm's product strategy is essential to gaining the knowledge necessary for making decisions concerning system optimization.

A second prerequisite to evaluating the needs for transformation is a broad recognition of the process technology available today. This may be a prerequisite to the choice of the project manager or the leading process engineer on the team. Alternately some three months of intensive research may be anticipated.

Third, the management must enjoy or create a climate that encourages significant innovation. This means that management must be openly receptive to new ideas that involve risk and uncertainty. If it insists on the certainty of the tried and true it can only expect to catch up to the competition, not exceed it. This climate is a matter of management attitude, not of proposal, control, and justification techniques. It means breaking with "propose-dispose" and "not applicable here" thinking - a difficult task for much management. It is my opinion that management would gain more by asking how to apply new ideas than by asking whether. (Some practical aids to the project manager in product/process design improvement during plant design were covered in the previous section.)

With completion of the study of product strategy, the project manager and/or team may begin the determination of the input and transformation needed to obtain the product output. To gain a grasp on the problem of determining total plant process design, one may initially, and temporarily, establish and "freeze" the input material - steel, aluminum or plastic, cast or forged, machined parts or bar stock, etc.

Knowing the material input, desired output, and, from the volume analysis covered in Chapter II, the quantity required, one may systematically enumerate what transformation is needed. To illustrate from a machinery manufacturing plant design, the input involved about all the common mill forms of metals, but particularly large plates and castings weighing from several hundred pounds to several tons, plus a myriad of purchased mechanical, hydraulic, and electrical components. These myriad materials were to be converted into a modest number of varied machines ranging from sports car size to rail car size and weighing up to 250 tons. It quickly became apparent that for any product design the transformation of a dozen basic, costly, heavy castings, plates, and weldments into semi-finished assemblies was critical to efficient operation. The thousands of remaining components accounted for a small percentage of the conversion cost.

Note that no mention has been made of how; only what has been determined. How to transform material into products involves the development of a logic of production.

The Logic of Production

The technology of mass, one-product manufacture or of mineral and chemical processing largely establishes the "how" of their transformation. Where the problem of developing a logic of production is of some import and prevalence is in the fabrication of a variety of products in one or more classes. With the market's increasing demand for individualized products, there will be a growing need to manufacture custom products by mass means.

Originating in the craft guilds, the traditional means of obtaining variety has been the job shop -- a conglomerate of specialized processes each dedicated to the skill (or guild) instead of the end product. This dedication to the means instead of the ends has led manufacturers to adapt whole product lines, processes, and even markets to the limited skills of casting, turning, milling, drilling, etc. Ignore the operator; ask a foreman what he's doing. He's running the milling department, not making your product. To paraphrase Levitt's "Marketing Myopia", he's running a railroad, not transporting goods.

As mentioned earlier under labor controls, job shop thinking leads to some fallacious approaches to cost control. Keep the machine operators busy regardless of the expenditure on indirect labor, inventories, excess machinery, material handling, etc. It also furthers make-work or "featherbedding", jurisdictional disputes, and quality indifference.

In spite of all the problems and inefficiencies attributable to the job shop, little effort has been made to change the basic approach to manufacturing variety. Techniques for plant layout, including computer programs, perpetuate the job shop while minimizing material handling. Techniques of production and inventory control, when merely added on, are only able to alleviate some of the symptoms. Quality control techniques try to keep the indifference from reaching the customer. These and other patch-work management techniques and controls have resulted in white collar employment exceeding blue in this nation since 1956.

How does one escape the job shop syndrome? Restricting this discussion to process design, there are three basic steps:

-- examine the major and/or expensive components to determine just what conversion is necessary - raw shape to finished form,

-- determine the repeating patterns that exist among the processes for these components,

-- design a limited number of optimum processes for components grouped by process requirements.

As has been widely pointed out by those interested in value engineering, a statistical phenomenon of large groups of components is that typically 20% of the items will account for some 80% of the factors under investigation. Applied here, 80% of the cost or manufacturing effort may be attributed to 20% of the manufactured components. Among very large assemblages the relative numbers will range toward 90%-10%. Applying this principle, one may "cut out of the herd" those prime components that are to be the determinants of process choice, sequence and arrangement.

Once the prime components are determined, they should be critically and open-mindedly examined to determine just what conversion is needed. For instance, must a complex shape be machined from a casting or forging; must the component be a weldment with machined surfaces; must a cylindrical part be derived from bar, tubing, cut plate, or casting; must a rectangular part be obtained from plate, strip, or structurals? Not only should the conversion in form be examined, but also the materials involved. Whether the finished component is made of steel, aluminum, thermoplastic, ceramic, or wood will have a significant impact on the choice of how the conversion will be achieved.

As each of the prime components is examined for what conversion is needed, the outline of an ideal process for it should be developed. Initially there should be no restrictions on process design by preconceptions of equipment availability. Ask the question, "What is the most economical way to obtain a (part) made of (material)?"

Next the prime components should be categorized by material and process. For any one plant the number of different materials - wood, plastic, steel - is generally limited, but the "mill form" might be quite varied - bar, strip, plate, sheet, coil, cast, forged, granule, liquid, etc. As a rule the process is most affected by the material type and shape. Categorizing the processes generally involves sorting by finished shape (cylindrical, rectangular, or complex; generated, formed, and/or built-up) or by finished chemical or physical properties. Initially, it is generally fruitful to further break down shape categories; "cylindrical" may be discs, sleeves or bearings, long shafts or tie bars, tapered, etc. Within a particular plant the number of prime components will be limited, therefore the number of fundamentally different processes will be more limited than implied by this paragraph.

As this sorting by process and material continues, the repeating patterns within the processes will become apparent. Thus, the categories may be grouped by process relationships. It is difficult to generalize about this procedure across all industry, but the common metal fabricating processes may be used to illustrate grouping. It is common to find that forgings, castings, and weldments are machined by identical methods and sequences on milling, drilling, and grinding machines. They are further cleaned, finished, and painted by identical methods. The number of processes for generating cylindrical components is strikingly limited - whether from castings, tubing, or bars. Almost totally ignored by industry are the very common and simple rectangular shapes; they are generally allowed to "find their own way" through a job shop despite the commonality of cut-off, mill, drill, and grind.

The conclusion to this analysis should indicate the need for under ten distinctly different processes. This has been confirmed by personal research in a number of plants of which the most complex manufactured several product lines with many models involving thousands of parts for each.

The next step is to develop an optimum process or production line for each group of components. The process is not to be ideal for each of the components in the group, but rather it is to be optimum for the total group. All parts need not pass through all steps in the general process; different parts may bypass unneeded steps. Further, occasionally needed steps may be performed by other production lines to avoid uneconomic duplication of machinery. The trick is to handle the vast majority of the prime components directly and most economically through product oriented processes, workmen, and supervision. By astute location of the various production lines, even the majority of the exceptions may be handled in what amounts to direct line fashion. Once the processes are determined for the prime components the remaining components may be added in, generally with little process adaptation, to determine total capacity needs. Perhaps one or two additional processes will be needed in the system; an example from the metal fabricating industry is the need to handle the thousands of low cost screw machine parts.

Looking into the activities involved in designing any one production line for grouped components, one finds some breaks with tradition. First, the limitations of volume on job shop thinking no longer apply; by grouping many part items large volumes of very similar parts have been obtained. Thus specialized equipment becomes economical for both machining and handling. Second, frequently repeated sequences offer opportunities to combine operations traditionally done on separate machinery in separate departments. Adding this to the use of numerically controlled machinery can result in outstanding savings - e.g. from 46 to 3 operations on some forgings, from 63 to 19 on particularly complex, specialized machine shafts, from an average of 12 to 1 or 2 on a variety of large diameter cylindrical components. Third, process analysis for grouped components brings out opportunities for standardization and design improvements.

For examples of the application of "group technology" for existing plants using job lot machining, see the references at the end of this chapter.

Turning from component to assembly processes one finds additional need for the application of logical analysis and integrated design. In my research leading to this discussion, three common obstacles to logical assembly process design were found. There is a too prevalent tendency to think that efficient assembly consists exclusively of long lines of operators performing minute tasks repetitively. If the volume is insufficient for assembly lines, there is a tendency to take the opposite extreme in using one assembler at his own method and pace. A variant of the latter is to assign assembly work on complex products by whether the component is electrical, mechanical, hydraulic, etc. All these approaches can be right; the problem is their misapplication.

A logical approach to assembly process design consists of breaking a product into logical entities (subassemblies) that are within the capacity of one operator to assemble without continued reference to drawings, instructions, etc. These entities should make sense - common sense - rather than be merely a function of annual volume and assembly times. This may mean more than one operator per assembly or more than one assembly per operator during the year. This approach has the advantages of minimum tooling investment while not increasing assembly time, of offering maximum flexibility for product or market change, and of compatibility with employee motivation as to be discussed in a later section.

In the process of determining the logical subassemblies of a variety of models within a product line, it may be expected that opportunities for component standardization will be found. As was outlined in Chapter II, great product variety may be obtained through the use of uniform parts mass assembled in various combinations; a limited number of parts may be used to create a vast number of models. Further, limiting the number of standardized components enhances their manufacture through expanded use of volume conversion techniques. Thus, component standardization should not only be expected but actively sought.

When an employee is charged with the responsibility to assemble a logical entity, he may be expected to be quite flexible in combining various components to produce various models. This is simply because what he is doing makes sense as a whole. He can adapt rapidly to changing market and product needs. There is no need to gamble on the amount of three month's needs of a model in order to gather enough for an assembly line run.

This logical approach to assembly process design results in significant feedback into component design and processing, and into management structure and control system design. The latter was covered extensively in Chapter IV, but the enhanced product/market orientation of supervision deserves remembrance here. The need for integrated product/process design was discussed early in this chapter; the opportunities presented by logical assembly process design merely emphasize the need.

Now the problems of integrating assembly and component manufacture must be faced. Oh, that it were possible to say that a direct tie (and flow) is generally practical between component processing and assembly. My research shows that industry almost never tries, and that economically doing so is limited to only one fairly common set of conditions. The conditions are:

1) the product is rather large, e.g. appliances, machinery,
2) the prime components are also bulky and/or heavy, and
3) the prime components require the great bulk of process time in their respective group production lines.

When these conditions prevail, enormous savings in handling, inventories, and space may be had by arranging the prime component production lines such that they feed directly into the appropriate subassembly areas. This approach further requires that the production control system feed sales requirements all the way back into component processing (as discussed in Chapter IV) rather than using EOQ techniques for components.

In those remaining situations in which a physical break exists between machining and assembly, integration is largely the function of a well designed management control system. As discussed at length in Chapter IV, the trick is to develop information and physical handling systems that are analogues. A review of the trade journals will reveal the variety of available handling equipment from which to choose a method compatible with the process, components, and control systems. Central to the handling method will be an efficient gathering and dissemination facility (often called "central" or "parts stores").

Out of the development of a logic or production comes a vital feedback of opportunities into:

1) product and component design,
2) management structure and control system design,
3) resource requirements projection, and
4) frequently, corporate strategy.

To ignore the opportunities is to enhance a second-class corporate status.

The logic of production carries forward into the development of process and methods designs, process layout, and, finally, overall plant design.

Creative Process Design

In Chapter II several developments in process technology were outlined because of their striking effect on facilities requirements. These same and other newer technologies also influence the development of an overall logic of production - enhancing it significantly.

As mentioned before, automation has reached the fabricating industries. Significantly, this automation has more impact on set-up than on the actual manufacture - destroying the myth that volume is necessary for low cost processing. The economics of set-up with "job shop" automation are such that flexibility in output is actually improved over the mythically flexible job shop.

Probably the two most significant developments in "job shop" automation are:

- numerically controlled machinery
- parts handling robots.

The latter, exemplified by Unimation (TM), may be manually directed through an operation once to program the sequence. Thereafter the sequence will be repeated from memory. They have wide application in parts feeding of machinery and in assembly.

Numerical control has significance to plant design in that:

1) it so commonly enables combination of many operations into one
2) it needs little in the way of separate quality control facilities
3) its flexibility reduces the need for inventories, and handling and storage facilities

4) it enables management control systems far more sensitive to assembly and market needs.

In short, its efficiency and flexibility reduce the need for physical facilities and fit well in a logic of production based on group processing and sensible breakdown of assembly operations.

Apart from the general impact of numerical control technology, there are a number of developments that have specific application but generally illustrate the utility of creatively adapting modern technology in process (and product) design. All of the processes discussed below compete quite favorably with traditional machining, principally because they (and others) have the common characteristics of being "one shot" processes and reducing material requirements, not to mention the general desirability of requiring less labor and handling.

The technology of cold forming has been greatly extended from conventional stamping, drawing, and heading to include upset forging, impact extrusion and forging, intraforming, and HERF (high energy rate forming). Where applicable, these processes make complete parts or simple assemblies in an instant with little or no loss in material. All generally require component design modification, frequently simplifying it.

The technology of extrusion has been extended to include steel. For parts with uniform cross sections, such as gears, they may be made cheaply in thousands by extrusion plus severing to length.

Thanks to the development of refractory metal dies, injection molding has been extended to high melting steel and alloys. The fine detail and tolerances traditionally limited to zinc die castings are now available in stronger metals. Thus, the machining of ferrous castings may be eliminated. (A related development is the continued improvement and growing economy of investment casting for complex components.)

Where parts need not be exceedingly strong, powder metallurgy offers real economies by eliminating machining. The technology offers whole new product design opportunities through:

1) alloying the impossible such as cermets
2) controlled porosity for lubricant entrainment
3) controlled density

Finally, there have been a number of developments in "machining". Of probably the widest use are abrasive machining and high temperature, high speed cutting.

How does a management avail itself of creative adaptation of developing process technology? First, it must ensure that its manufacturing engineers continually keep abreast of developments by means of the extensive trade literature. Second, it must avoid the "propose-dispose" approach to innovation. Third, it must encourage the product design modifications necessary to take full advantage of newer process technology. (Note the sequence of input of information, transformation into ideas, and use of the ideas.)

Two sections earlier in this chapter, material input was temporarily "frozen" to gain a grasp on the problem. Then a logic of production was developed. Within this logical framework an outline of effective, efficient, innovative processing is developed, perhaps using some of the technology cited. Then one faces the opportunities from feedback into material, equipment, and human inputs plus the opportunities offered in product design modification for economy.

The feedback from innovative process design will result in obvious demands for equipment and, correspondingly, people - considerably less than conventional if done properly. The most significant feedback will be to material input and, correspondingly, component design. For instance, a part might be better injection molded by another concern than machined on a turret lathe. So the input to the plant would be a completed part rather than bar stock. This kind of shift would significantly alter plant size, equipment, and manpower requirements.

Before leaving creative process design, it should be noted that whether or not input is significantly affected, a process well designed will require considerably less equipment, manpower, and space than conventional. The space requirement may well be so reduced that no new factory construction is needed.

Human Factors in Design

The whole science of human factors in design, or ergonomics, need not be labored here. It is covered well in the references following this chapter. The concentration will be on the difficulty in practically applying the knowledge available plus the generally ignored need for "human engineering" in the design of processes as well as machine units.

Greatly simplified, ergonomics recognizes the design of humans cannot be altered practically, so the machine must be adapted to human physiology and capability in man/machine systems. It summarizes man's activities in dealing with equipment as consisting of:

1) receiving information input from gauges, lights, sounds, or observation of the machine's operation,
2) transforming the information into guiding or correcting action, and
3) applying the corrective output to the machine through levers, knobs, etc. or manual adjustment.

The machine has an information input, transformation, output cycle mirroring the man's activities.

The problem in applying ergonomics lies in the down-right ignorance of the science exhibited by the product of a number of machinery manufacturers (that cannot be named here). It is not uncommon to find the operator of production or handling equipment:

1) unable to see the work
2) unable to see or read gauges
3) unable to reach controls with ease
4) forced into awkward or straining body contortions.

It is contended that such machinery is one of the causes of long coffee and smoke breaks.

Obtaining equipment designed to be usable by humans is a function of demanding it to the extent of refusing to buy equipment unfit for human use. Further, the buyer should not expect to pay more; good design costs no more than poor.

Beyond the development of general outline specifications for group processes compatible with human operation, the determination of specifications for individual machines is not properly a part of this second stage of design development. During Stage II the emphasis should be placed on the interrelationships of production and handling equipment as they affect human use.

In evaluating the human factors affecting the design and arrangement of groups of machinery two basic concepts need to be remembered:

1) each machine has material inputs and outputs as well as information outputs and inputs.

2) each operator is affected by neighboring handling and production equipment as well as his own.

Working from these concepts a number of questions should be answered:

1) Is there sufficient clearance among machinery to allow safe and efficient access?
2) Are work elevations proper and consistent throughout process sequences?
3) Will handling equipment physically interfere with efficient operator movements?
4) Is the operator's information input, particularly vision, interfered by neighboring equipment?
5) Will neighboring equipment distract through noise, flashing light, or effluents?
6) Is the operator's safety in any way affected, particularly, by operations out of the normal range of vision?
7) Is his emergency egress imparied?
8) Is he unusually isolated, psychologically?
9) Is necessary communication among operators and supervision impaired?
10) Are the levels of effort among neighboring operators compatible?
11) Will building or utility structures interfere with the operator's activity?

Certainly others could add to this list, but it gives the idea of the importance of human factors in overall as well as single unit design.

Many of the answers become parameters to process layout to be discussed later in this chapter. Some affect work enrichment to be discussed next.

The questions of human environment - air, light, etc. - are reserved for the next chapter dealing with the plant environmental system.

Work Enrichment

The extensive literature on work enrichment has been written under the assumption that the plant is a fait accompli. Therefore it concentrates on how existing jobs may be "enlarged" or "enriched" to improve the motivation, and productivity, of the worker.

Here in Stage II of plant design development we are dealing with jobs that do not yet exist. The opportunities for developing enriching work are limitless.

In a recent work, Michell Fein (see references) has severely criticized, and summarized, much of the work on motivation. As Herzberg did, he points out that merely making a job larger does not make it more enriching or rewarding. There is the further need for responsibility, a sense of accomplishment, and a cognizance of where this work fits into the scheme of things. The job needs to be designed such that the worker's personal motivation parallels that of the firm's goals.

In the discussion of assembly process development it was advocated that the assembly job breakdowns make "common sense". This will enhance the characteristics just mentioned. By contrast much assembly breakdown and line balancing appears as though an elementary school teacher forced the workers to write, "I will put bolt #12345 on bracket #54321", 1000 times. For a fine journalistic discussion of the response to this approach see "The Blue Collar Worker's Lowdown Blues", Time, Nov. 9, 1970, pp. 68-78.

One of the prime advantages of applying "group technology" in designing and arranging machining processes is the attendant product orientation of supervision and workers. It gives the workers the opportunity to better understand where his product fits into the scheme of things. When the techniques of combining operations and/or numerical control are used in the group, many fewer workers are far more directly responsible for quality and quantity of output. Certainly one supervisor is generally completely responsible for a complete component.

Many of the things brought out in human factors in design influence the design of satisfying jobs. Although not directly a part of work enrichment, good human engineering avoids detrimental work influences and enhances the ability of process engineers to design enriching work.

The secret to designing enriching work is empathy. Would you want to perform the job daily, as an end not a means to some other ambitious end? Would you find anything to have a feeling of craftsmanship about? If you had the job, would you "give a damn" about quality, cost, profits or anything else but payday and quittin' time?

The time to think about these things is during Stage II, the original, outline specification step in design. Waiting for detail process design during Stage III is too late; the die is already cast.

Process Layout

Process layout at this point is not the detailed plant layout discussed in the various texts. The basic difference lies in the lack of an already existing building and process. The widely advocated techniques of plant layout, including computer programs, are of little use here.

The objective of process layout in Stage II is an overall layout of the technological subsystem by areas of the right size and shape, and in the proper spacial relationship. Size is a function of equipment, people, and product derived from process prediction already covered in this chapter. Shape should not be limited to rectangular as is implied by methods of block layout within existing buildings. It should be a function of process, human, and information flow combined with effective job design and human engineering. Geometrically complex arrangements can be quite justifiable. Both size and shape will be affected by space provisions for expanding or changing future needs.

Placing the myriad areas in the proper relationship involves more than mere plotting of the importance of their relationships on charts. The "outline specifications" of a plant's layout constitute the overall picture of the physical aspects of the total plant system. To be effective as such, the plant layout must integrate the various processes, materials handling and storage, as covered here, plus management structure and controls, environmental needs, and a building configuration, as covered in Chapter VII. This is no job for cookbook approaches; in each case various concepts from the standard techniques will be found applicable, but none will solve this problem. This problem will be solved by one good, fertile, innovative mind capable of retaining and using thousands of facts and of balancing the myriad conflicting forces to arrive at an optimum general layout. But above all, this will be one capable of seeing "the big picture".

To escape from banality, how does this "great mind" work? Generally, but not universally, one starts with the results of effective process design. (Where unusually large tonnages of material are handled, process may become secondary to efficient handling. Where the process is particularly tied to the market, management controls may predominate.) The process design and product volumes are the inputs to operational relationship and materials flow analysis. This study of the interconnections and flows among operations and processes is analogous to the economist's input-output analysis. Using line diagrams, the inputs and outputs of each operation or machine group may be represented by line connections with previous and subsequent operations. The result is one or more pictoral, schematic diagrams of the relationships among operations. Simply stated, the diagrams indicate what goes where (but not yet how much) in a manner analogous to wiring diagrams. Next materials flow analysis fills out this framework with volumes of component and assembly flows derived from product volumes. The flow volumes should be expressed in an appropriate common measure (units, tons, standard containers) and may be represented in a number of ways - line width, color, numerical.

Materials handling typically represents one-third of fabricating costs, so the opportunities for designed economy are huge. Some of the economics are presumed to have been secured by eliminating handling through creative process design as discussed earlier. Nevertheless some materials handling remains within and among group processes and assembly. To account for the necessary handling and begin to determine the overall shape at this stage, the general specifications of a materials handling system must be developed for:

1) receiving, storing, and moving raw materials and purchased components,
2) moving materials within processes,
3) moving among processes, normally on an exceptional basis,
4) moving, storing, and dispersing finished components
5) moving within assembly operations,
6) moving, storing, and shipping finished goods.

For the mass, line produced product, materials handling methods are essentially established by the process and its operational relationships. For producing variety the solution doesn't come so simply.

For handling variety, some interesting approaches have been developed. The most flexible, which is quite applicable in the true job shop, is to establish dispatch/feedback conveyor systems as discussed in Chapter IV. When applying group technology, the parts within a group are expected to flow largely in a line fashion. They, and the exceptions to line flow, may be handled by chutes, slides, handoff tables, tote boses, lengths of conveyor, etc. As mentioned earlier, locating processes for similar groups in close proximity can reduce handling for parts requiring common machinery and for movements that are exceptions to the rule. Recalling the discussion in Chapter IV, getting the parts through a machine process, through a parts storage facility, and to assembly requires a handling method compatible with the storage method and with management control. Above all, it is a flexible, integrated system that is to be sought.

The techniques of material handling and plant layout are covered well in the references. The coverage missing, beyond implication, is the feedback to process design and management controls, and the effect on building configuration. Out of flow analysis and the overall materials handling system design should come a schematic concept of the final plant configuration and suggestions for process design. This concept lays the groundwork for vendor specifications, receiving and shipping, inventory facilities and control, production control, space allocation, building height, packaging methods, and often production organization. The integration of these will be covered in configuration analysis, Chapter VII.

During and following the material flow analysis, there should be a thorough analysis of the physical needs of management control systems, particularly production, inventory and time reporting. Physical inventory control points must be designed into the layout and process; otherwise, work-in-process inventories will grow like weeks - everywhere. These control points need facilities designed into the plant system, not tacked on. Employee time and production reporting lends itself to becoming an integral part of production control and the management information system, but its effectiveness depends on appropriate facilities located properly and designed into the plant system. The specifics of these problems were discussed at length in Chapter IV; the inclusion of control facilities in spacial relationship will be covered in configuration analysis, Chapter VII.

Service facilities have not been discussed at length because their determination is covered well in the references. Their problems related to management controls were covered in Chapter IV. In overall plant layout (Chapter VII), they must be located to properly serve the processes, efficiently and effectively, and their space requirements must be accounted for.

It should be noted that plant layout of this broad approach serves as an excellent check of earlier subsystems design. It puts them together and checks for fit. In the process, considerable trade-off will occur while seeking the overall optimum solution during system configuration development.

Summary

Except for the environmental factors reserved for discussion in the next chapter, all factors leading to the configuration analysis for a plant should be now available.

There should be a process layout that indicates:

1) approximate total amount of space required,
2) location, size, and shape of the various processes,
3) the general flow pattern.

In addition there should be general outlines of:

1) location and size of service facilities,
2) location and size of management control facilities, particularly inventory and quality control, plus a management control system,
3) management organization, or structure,
4) personnel required, number and skills,
5) the number and general description of equipment,
6) raw material input, types and amounts,
7) utility feed requirements,
8) amounts and types of effluent.

The listed documents should <u>not</u>, at this stage, be expected to indicate all detail for the various subsystems. This is the design of a plant, an overall system, within which the details of subsystem design will be done later in Stage III.

During the development of this technical core of the plant system, flexibility and economy are basically established. Flexibility is the function of a state of mind, a continuing criterion, of plant design. Economy is a function of optimum trade-offs and creativity.

There is no substitute for ingenuity at this stage. Yet, having innovative manufacturing engineers and/or project manager is not sufficient. There is a crying need for productive interplay among product, process, and management system design plus a receptive management.

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CHAPTER VI

PLANT ENVIRONMENT

In defining the plant as a system containing subsystems, it was recognized that the plant is itself a subsystem of the community and ecology, requiring inputs and issuing outputs. It was also stated in Chapter I that one of management's prime responsibilities is to society and the environment; therefore, one of the three criteria of effective plant design is compatibility with environmental demands.

Management has long recognized the impact of a plant on community relations. The result has been pleasing facades and landscape architecture. In addition, much has been made of the economic benefits of a plant to its community.

Since the late sixties, management has been increasingly forced to recognize the often detrimental impact of plants on the ecology. Today a prime consideration in plant design is the inclusion of facilities for water and air pollution control. A new plant is far too visible to waste time trying to "get away with" polluting the environment to even a minor degree.

More recently, management is being impelled toward grave concern for the employee's health and safety. A combination of the increasing stringency of laws and regulations and of court awards for such long term effects as hearing and respiratory problems makes inconsideration of the employee's physiological well being catastrophically costly.

Suffice it to say that management can no longer afford the luxury of ignoring the impact of a plant on its environment.

It is not the purpose of this discussion to dwell on the long list of legal and social demands on the plant. Instead, two basic, interrelated concepts derived from systems theory will be developed for dealing with plant environmental problems. It is contended that:

1) Plant environmental problems are systems problems. No plant activity may be considered in isolation; each has an impact on the ecology and human environment. Conversely, environmental control activities may not be optimally done without appropriate adaptation by the various plant activities.
2) A systems approach to product/process/environment design largely abrogates the myth that pollution control is costly. Using the best of available technology in the right combination can greatly alleviate the problem and therefore the cost.

This systems approach will be used in the remainder of this chapter to deal with the various throughputs that affect the environment. In addition human and security needs will be covered.

Air

To deal with air pollution problems efficiently, it is imperative to think of air handling as a throughput. Minimum throughput means minimum cost.

In traditional approaches to air handling the only thought to input was to that needed for building heating and with the advent of air conditioning to that needed for human consumption. Exhaust was limited to removing odors, fumes, smoke, and dust to the atmosphere. This piecemeal approach frequently leads to exhaust exceeding feed by amounts that cause a severe vacuum in a plant.

In dealing with air throughput, a place to start is with human needs. Architects recommend 4 to 10 changes per hour. This may be well for office, commercial, and institutional design but it is debated in large plants where each employee draws on thousands of cubic feet of space. For a typical 100,000 sq. ft. plant with 20' ceiling and 125-150 people, each employee enjoys some 1000 CFM (cubic feet per minute) of fresh air at 4 changes per hour. The heat load for this much air is very costly; the air conditioning load is prohibitive. Few plants actually adhere to these recommendations; my investigations indicate one (1) change per hour is typical and most of that is due to exhaust.

An alternate place to start is with exhaust requirements. Painting, heat treating, plating, welding, and other operations have (by traditional standards) large exhaust requirements. All that goes out must come in; furthermore, it must be heated or cooled on the way in. Heating or cooling causes either high cost energy consumption or high smoke pollution from low cost fuels. Air exhausted from processes must be reasonably clean so cost is added for every cubic foot that must be cleaned. The object then will be to reduce exhaust requirements as nearly as possible to the minimum input needed for a healthful atmosphere.

Painting is probably the most prevalent offender in the fabricating industries. Conventional air spray painting sends more than half of the paint into an exhause facility, usually disposable filter or water wash. Most of the solvent vapors go "up the stack". Spray booth filters or water are becoming increasingly difficult to dispose of; it's only a matter of time before stack fumes will have to be removed. To alleviate these problems, the first approach is to seek processes that don't waste so much paint and solvent.

Because of their simplicity and flexibility, two newer processes are growing rapidly. Both hydrostatic and electrostatic spraying require less solvent and avoid mixing air with the paint. Both apply better than 90% of the material to the work, greatly reducing overspray. Two other processes, dipping and flow-coating, offer still higher application rates and the facilities can be designed to retain solvent. However, they require long runs of one kind of paint to be economical. For instance, the automobile industry dip applies the base coat and electrostatic sprays the color desired.

With the great reduction in wasted paint, all of the above processes require less frequent filter or water changes and less air flow. Good paint booth design requires still less air flow by eliminating the danger of overspray escapement. Although not done to my knowledge, it is theoretically possible to reclaim the overspray from the filters or water.

To eliminate the problems of handling organic solvents, the water base coatings may often be used. Alternately, it will probably be required in the near future that solvents be removed from the exhaust by means of either stack afterburners or condensers that reclaim the solvent. Although not yet done to my knowledge, it is felt that condensers will show the greater economy and compatibility with requirements. By the proper mix of outside and plant air, varying with the seasons, condensation may be aided and plant supply air reduced. If the process is sufficiently efficient, the exhaust air may be recycled into the plant.

Another gross plant air polluter is conventional gas or stick welding. The fumes are quite toxic and, by the nature of the process, difficult to remove. To maintain a livable atmosphere, a plant built in 1970 required 125,000 CFM of air directed uniformly across a welding area 50' x 200'. (Ironically, this may prove to be a wasted investment, for the concern was concurrently altering its welding processes.)

The solution to air pollution caused by welding lies in the choice of process. One particularly promising replacement for stick welding is submerged arc welding. Herein the welding action is contained within a mound of granular flux automatically fed into the joint ahead of the arc. The process is economical, makes an excellent joint, and retains welding effluents within a flused flux. A number of other welding processes within the classes of resistance, fusion, forge and friction welding offer opportunities in air and heat pollution abatement.

The problems of smoke and heat also pertain to heat treating. Heat costs money and results in smoke, so the basic approach to pollution abatement and reduced air requirements is through heat conservation. One promising process for welding, brazing, and heat treating is induction heating. Proper coil design results in the heat being concentrated just where it's needed, so there is little wasted. Another promising process is vibratory stress relief of large weldments; this completely eliminates a large requirement for heat in addition to being more efficient. Approaching heat treating as whole one may use air from cooling chambers to feed heating chambers. By isolating a heat treating department, one may circulate the overheated air into the remainder of the plant during the winter and exhaust it during the summer -- provided the smoke producing operations (e.g. quenching) are separately treated.

A number of processes create dust. There are often clean substitute processes, but where there are not, the air should be recycled into the plant after filtering to reduce heating or cooling load.

Throughout this section the emphasis has been put on conserving air throughput by means of process alterations and recycling. There is, of course, a limit; there must be sufficient air flow to maintain oxygen levels and remove random odors and particulates.

Finally, it is strongly recommended, as the result of my investigations, that input be in excess of designed exhaust sufficient to maintain a slight positive pressure in the plant. This will eliminate problems with drafts, dead spots, and problems with exhaust system backpressure.

Water

As with air the basic approaches to fulfilling water needs are recycling and conservation.

In most industrial areas, the feed water supplies are degenerating rapidly in quality and quantity. During my tours of research, the engineer of a paper mill proudly showed me a feed water filtering facility that had been put in operation shortly before at a cost of nearly a million. "We had to do it; you'd be surprised at what we get out of the river. Why, the water we dump is cleaner than what's in the river." When asked, "Do you pump your outflow up to your inflow?", he answered, "Naw, the pH isn't quite right, and anyway we don't have any way of pumping it back."

In another case, a plastics injection molder complained that they were being forced to drill new, deeper cooling water wells because the water table was dropping. They were then dumping the heated water in a nearby stream. It was suggested that they build a lagoon in the sandy soil of the area to allow the water to seep back into the water table while cooling.

While some older plants may "get away with it" for a while, it is grossly negligent thinking to assume that a new plant will be able to dump untreated, polluted water (except human effluent to municipal sewer systems). Within the life of any plant built in the seventies, the water effluent will have to be practically as clean as distilled water.

If the outflow must, by law, be clean and the inflow should be clean, why not recycle the water through one common, therefore more efficient, output/input facility? This approach greatly reduces the treatment cost of either feed or effluent or both. Feed water, if purchased, and sewer charges may be eliminated (except human consumption). Material reclaimed from the effluent is often valuable.

To handle water efficiently there is the need for at least two systems:

- one, for human consumption and sewage
- a second, for process water
- and frequently, for cooling water

The separate use of municipal water and sewage for human needs is recommended primarily for psychological reasons. People will drink seldom pure, occasionally contaminated municipal water rather than superbly treated plant outflow. Add sewage input to the treatment facility and you can forget even suggesting it though the people may be drinking the sewage of the city upstream. The piping is simple and small - similar to house piping. Occasionally, some of the waste (e.g. water coolers) can supplement process or cooling water feed.

Process water needs vary widely from plant to plant but some generalities can be made. The first is, for anything beyond wash water, a reputable firm of consulting engineers specializing in water treatment should be employed during Stage III, detailed design.

At a minimum, a fabricating plant will have cleansing facilities that result in oily, soapy, dirty waste. In the growing number of communities that will not accept it in their sewage, or charge high rates for doing so, the simplest way to get a reusable, but not really clean, water is to settle and skim it. About 80% of the water may be reused for washing. (The sediment and scum must be dried and removed to landfill.) When emulsifying detergents are used or if, as is common, the process also involves the disposal of water emulsion lubricants, the treatment process becomes more complex, requiring expert design, but is practical.

A common problem to the fabricating industries is waste water from plating and chemical metal treating processes. The contaminates are deadly and corrosive. Each combination of operations requires its own treatment process, separate from a general water treating facility. Water conservation and recycling are necessary for economy. Expert design and competent operation are imperative. It is generally more economic to subcontract small demands for plating, because the investment is so high. For example, one small setup costing $25,000 in process facilities required $40,000 in water treatment facilities and $18,000 in corrosion resistant air exhaust facilities.

One final generality can be made. Watch the handling of floor spillage! A number of firms have found themselves in trouble when oily or poisonous floor spillage found its way into storm drainage or the municipal sewers. One firm bought a neighboring herd of cattle when a rainstorm followed the cleaning of a cyanide pot in the parking lot.

Beyond these generalities, each firm must find its own way, with the help of expert advice, to a system design that enables most economic use and treatment of process water.

Shifting from process to cooling water, the emphasis is directed to recycling and heat conservation. Since the chemical process and power generation industries have distinct problems to which considerable engineering is being applied, the concentration here will be on the "typical" fabricating plant where heat conservation has not received much attention.

As was discussed earlier, the cost of energy can be expected to rise rapidly until nuclear fusion becomes a significant factor, c. 1990. In the process of producing heat, present energy sources also create pollution for which the cost of disposal must be accounted. Therefore, the conservation of heat can be expected to be progressively more economic in the coming years.

As already discussed, raw feed water supplies are degenerating in quality and can be expected to cause corrosion and blockages. Furthermore, regulations are becoming stringent on heat pollution. Therefore, there are compelling reasons for charging a cooling system with water of the proper characteristics and then recycling it.

Why should a fabricating plant even be seriously concerned about cooling water? When all the various needs are added, a fabricating plant will be found to require a surprising amount of cooling water.

Among the common demands for cooling are:

- air compressors
- machine lubricant cooling systems
- cutting lubricant cooling
- die cooling in forming and molding processes
- condensers on steam powered equipment
- air conditioning equipment.

In conventional plant design all this water and heat has been wasted. Concurrently heat is added for the building, wash water and process water.

There are scores of places in the typical plant to which otherwise wasted heat may be profitably applied through heat exchangers. Among them are:

- employee hot water supplies
- wash and plating tanks
- tracer lines to lower viscosity or prevent freezing
- heavy fuel oil heating

- building heat
- incoming process water
- interior landscaping
- walkways to prevent freezing

Oil

To the cost of oil consumption has been added the cost of disposing of waste oil. The ecology in general and municipal sewer systems in particular will no longer tolerate indiscriminate dumping. Traditionally plants have thrown away surprising amounts of oil in the form of machine lubricants, cutting lubricants, hydraulic and quenching oils, etc. A new plant cannot consider dumping a viable long range solution.

The most economic solutions lie in reclamation. For small usage of various types, the prospects of selling waste oil to a reclaiming firm should be investigated. This will require segregated collection to retain the value. For larger usage, particularly cutting or hydraulic oils, it is often economic for a plant to have internal oil cleaning and reclaiming facilities. There are some problems with reclaiming - chemical and bacteriological contamination - that require competent design during Stage III. In addition, there is the need to adapt processes to one or a very few oils to enable economic operation.

As an economic alternative to reclamation, plants with large oil fired heating or process furnaces can consider blending waste oil with fuel oil to reduce fuel oil consumption. This is also done with spent solvents. Great care must be exercised to avoid violating emission control standards. For a treatment of burning waste oils see J. George Wills, "Don't Throw Waste Oil Away - Use It for Heating", Plant Engineering, October 28, 1971, pp. 58-60.

In planning for cutting lubricants, two current practices cannot be continued. The first is the intemperate use of mist lubrication in metal cutting. Mist lubrication when used for general, heavy cutting can literally saturate a plant atmosphere with oil fumes. Exhausting the fumes is unacceptable. In process design the use of mist lubrication must be severely limited.

The second is the intemperate use and dumping of water-oil emulsion coolants. There is no acceptable way of dumping them. In short, their supply cost remains low, but their disposal cost has become prohibitive. Waste emulsions can be put through the plant effluent water treatment facility, but it must be designed to handle them at significant additional cost. My research failed to reveal any commercially available process by which they may be indefinitely recycled. (Emulsions are particularly subject to biological contamination and become quite rancid.) In small percentages they may be burned with other oil by depending on flame heat for evaporation. In some areas, scavangers will handle them for a fee. Until the suppliers are able to offer oils and emulsifiers that will remain stable for long periods, there is no known way of using them economically without violating effluent standards.

From this outline of the problems and economics of oil handling within a plant, it should be apparent that limiting the variety and consumption of oils will result in significant savings. In the maintenance controls section of Chapter IV, one of the two principles of cost reduction outlined was standardization; this is particularly applicable to lubricants, cutting oils, and hydraulic oils. The opportunities for cost reduction are enormous. Overall studies of oil needs in existing plants have resulted in 100:1 reductions in oil varieties. The remaining varieties may be bought in bulk and are less prone to waste. A number of the oil suppliers offer consulting services for such studies; a few of them are quite effective. In a new plant design the opportunities for reduced variety and consumption are even greater. The process can be designed to minimize cutting oils. Equipment can be specified to use standard lubricants and hydraulic oils. In many applications self-lubricating materials or permanently lubricated bearings may be specified. Today's technology offers a number of ways to drive equipment without oil-demanding gears. Finally, the means of applying oils to equipment may be specified to minimize consumption and wasteful application.

Solid Waste

In attacking the plant's share of the national solid waste problem, the three basic ways to reduce cost in order of their economic value are prevent, recycle, and segregate.

Prevention, by far the most salient, is designed into the product, process, and quality assurance methods. Prevention starts with product component design. Through training in standardization, integrated design, and the opportunities offered by modern process technology, product engineers need to be made cognizant of the waste caused by component designs. Management can enhance the making of waste an active concern in product design by requiring waste assessments of any new or revised designs.

A few examples might better indicate what can be done. One manufacturer saved tons of gasket material by modifying product configuration such that progressively smaller gaskets could be made from the material punched from the hole of larger gaskets. An automobile manufacturer did much the same with clutch discs by standardizing on three clutches that could be made from the same piece. A fairly common practice is designing brackets, plates, spacers, etc. such that they are made from the scrap of other operations. Often a slight modification of size or shape will allow full use of sheet material.

Chip making is a great waste of material. It is not uncommon to find components designed just slightly too big for a standard material size. Or a component nominally requires, say, 1/2" stock, but the tolerances are too tight to use it. There are cases where a slight size modification will allow the use of pipe or tubing instead of solid stock. Beyond these simple modifications, earlier discussion outlined a number of "one-shot" processes that form rather than remove material.

During the design of a new plant, the project team is quite liable to become cognizant of situations that will cause inordinate scrap. It should be within the purview of the project manager to bring these conditions to the attention of product design and to suggest alternatives. Value analysis techniques can also be of help.

One of the most productive activities a quality control organization can perform is ferreting out the causes of waste. In designing the plant organization, this function along with other quality engineering should be included in the quality control group. Mere inspection is not productive; cost reduction through quality engineering is.

If waste cannot be prevented through product/process design, recycling is the next most economic method. The most obvious method along these lines is remelting plastics and metals. Unfortunately not all opportunities for remelting are met. Much material is wasted because virgin material is arbitrarily specified; even if it is, scrap can be used for setup and test runs.

Broadening the concept of recycling, processes can often be designed to remelt or rework the scrap from other operations. Small, clean melting crucibles can be coupled with machine molding to productively use scrap including chips. The process may not be economic with new material, but it certainly could be using "free" material. Similarly, new products have been developed to make use of waste material; an example is chipboard from sawdust.

Much of the solid waste in a plant results from the packing of incoming materials. Simplified, bulk packing is available if specified. With some thought and planning, incoming containers and packing can be used for shipping product. Scrap wood shavings have been used in packing. Paper waste can be shredded for packing.

Finally, for waste that must be disposed, segregated collection is a practical procedure. It's only a matter of time until segregated waste disposal is regulated, so why not profit by it in the meantime. Most plant wastes, being in some volume, have a moderate value - if clean.

Chips are a chronic problem and their value is commonly wasted. To be of any real value chips must be segregated by material and separated from cutting oils. (The oil is reclaimed.) Adequate technology and equipment are available on the market.

Paper products are another large source of salable waste. To maintain value it must be segregated into corrugated, chipboard, kraft, white (clean and printed), etc. and uncontaminated.

Glass as yet has little value but enough to warrant segregation to prevent it contaminating other waste.

A problem will be to keep vending machine and cafeteria waste from contaminating valuable waste.

In the case of burnable wastes for which no outlet can be found, there is available incineration equipment that can be integrated into building heat or the steam system.

To benefit the most from the economics of solid waste use and disposal, the facilities and procedures must be designed into the plant. From a review of the problems and solutions it becomes apparent that many functions are involved in effective waste control and disposal - product and process design, production supervision, quality control, and building design. From this it is also apparent that the project manager is responsible for the development of a waste control and handling system for the new plant.

For a comprehensive discussion of disposal technology, see Chiagouris, Geo. L., "Methods of Solid Waste Disposal", Plant Engineering, Dec. 23, 1971.

Human Needs

Heating, Ventilation, and Air conditioning (HVAC): Much of this duplicates and overlaps the earlier discussion on air, but HVAC is not entirely dependent on air flow. Furthermore, people have needs that are not entirely satisfied by ecology oriented air flow.

The only time heat need be supplied entirely by heated air intake is when process exhaust closely matches the amount of warm air needed for building heat. When process exhaust is excessive, using building air is wasteful and subjects many areas to hot air blasts. It's better to provide specific air intake to enough large users to bring general input and output into balance.

The minimum requirement for warm air feed is that needed to maintain a minimum turnover based on the ratio of plant volume to personnel. Any additional heat required is better and more economically provided by one of the radiant forms. Radiant heat is significantly more comfortable to people. They will feel warm at ambient temperatures from 4° to 8° less than with warm air. Less humidification is required. On the market there are a number of gas and electric, ceiling and wall radiant heaters. There is also material for wall and floor, water and steam fed radiant heating that can employ spent process steam or the heat from cooling water.

One can also employ radiant heat by having the required hot air supplied through floor ducts and registers. They may also be used to bring in cool air in the summer. My research revealed a few such systems. They reminded me of Oriental heating methods where hot flue gas is directed through floor tiles from a fire on one end of the building to a chimney on the opposite end. It occurs to me that hot stack gas might be so directed in a plant. It might also be easier to clean the cooled flue gas at the far end of the floor ducts. Hot stack gas from waste incinerators might also be so directed.

An obvious need, seldom fulfilled, is humidification of warm intake air. It adds to comfort and reduces the ambient temperature required for comfort.

Shifting to the summer, one should at the least employ the type of two-speed air feed units which can pump much larger volumes of air in the summer than they can heat in the winter. They are standard equipment. Unfortunately, architects usually mount them on the roof where they take in sun and process warmed air. It is my contention that the intake units should be placed around the periphery of the building and supplemented by roof exhausts.

For those plants requiring significant cooling water, the roof may be used as a spray reservoir. The water is cooled by spraying and further evaporation from the roof keeps the plant cooler. This does, of course, require dirt filters and supplementary water. Depending on snow load requirements which vary with location most roofs can handle 2" to 4" of water without special support. Coupled with hot water heating in the winter a complete heating and cooling system is created.

No discussion of HVAC would be complete without consideration of summer air conditioning. Progressively more manufacturers are recognizing the detrimental effects of heat and humidity on productivity. So far AC has been concentrated in labor intensive operations. Despite the contrary myths, and excepting forging, casting, and heat treating, it is practical to air condition fabricating plants. First, processes that require considerable exhaust air must be provided with special air intakes (also an aid to heating). Second, hot processes and other large heat sources may be water cooled. Third, the roof may be water cooled or insulated (an aid to heating). Finally, air cooling can be limited to a 20° F reduction which provides good dehumidification and a noticeable, healthy difference from outside temperature.

<u>Light and color</u>: Here we are dealing not only with the physical needs of seeing but also with aesthetic and psychological response.

Starting with source light requirements my research indicates 60-75 foot candles is a good compromise between light level and cost in general fabricating. Below 50 causes visual errors and over 100 brings out the dark glasses.

Examination of a number of lighting/cost studies leads to three starting points in fixture specification. For fixture elevations of:

1) over 30', try metal halide for good economy and color balance
2) 18' - 30', high intensity fluorescent strip fixtures
3) 10' - 18', medium intensity fluorescent strip fixtures

In all cases high voltage, generally 277V, will lead to economy in circuitry, power consumption, and replacement.

Examination of lighting arrangements leads to the conclusion that more electrical engineers need to design light instead of economical electrical circuitry. Circuitry will be designed to be compatible with daily operations only if emphatically specified - in detail. This refers to night lighting, section lighting, switchgear locations and complexity, etc. In addition electrical engineers seem to like fixtures aligned in military fashion, regardless of what interferes with or is below them.

Starting with a skeleton of basic light requirements, the lighting system needs to be "fleshed out" with color and daylight. Where plants were earlier dependent on daylight, contemporary design goes to the opposite extreme. Excluding daylight causes negative psychological responses that override anything gained by preventing window gazing by employees. (Design enriching work and there'll be no need to daydream.) Since windows are costly to install and maintain, and are not necessary, daylight can be admitted through one of the translucent polyester fiberglass wall systems and through translucent roof openings. Skylights, unless superbly installed, are troublesome to maintain, but at least necessary openings, such as fire blowouts, can be specified translucent.

Color starts with the ceiling. With fluorescent lighting 20% uplight is strongly recommended, so reflective ceilings are necessary to avoid wasting it. White is common and most efficient, but very light blue has been used to create a skylight effect. In spite of the complexity of plant ceiling structure, painting can be economical (10-12¢/sq. ft.) if properly planned. All ceiling construction must be complete including pipe and conduit. (Lighting fixtures may be hung later if desired.) The floor needs to be virtually unobstructed - prior to equipment installation. Then, using plastic floor covering, rolling scaffolds, and hydrostatic spraying the entire ceiling and structure are sprayed. Later the cost will be higher because of the necessity to cover equipment and maneuver scaffolds. Since virtually all overspray from hydrostatic spraying is a powder by the time it falls, the method has been used without floor and/or equipment coverage, but there's the danger of contaminating machine ways and lubricants, and a small percentage does stick.

For reasons of cost, it is common for companies to forego painting the walls and columns. Although the need cannot be objectively proved, this writer contends that subdued, aesthetic decoration of building features is a worthwhile investment in employee environment. The color(s) should be light for good reflection and easy on the eyes. Green is a common choice, but being common it does not "say anything" to employees. My research indicates a mild negative response to tan and brown. The paint chosen should be long-lasting for low maintenance and should result in a smooth surface for easy cleaning. Economical hydrostatic spraying may be used.

A great variety of colors is used on equipment. Beyond being light and easy to clean there is no significant reason to limit choice. (One firm, employing many women machine operators, allowed each employee to choose any color for her machine. Wow!) It is often desirable to color code equipment by organization or function. It is widely advocated that pipe and conduit runs be painted according to function, but this is unnecessarily expensive. They should first be spray painted along with building features; then it is only necessary to color code, by tape or paint, those fittings used to branch or change direction plus an occasional coupling in long straight runs.

Some general criteria should be summarized. Color choices should begin with very light on the ceiling and become progressively darker to medium tones on the floor. Glare should not be tolerated. The color scheme should not be distracting except for safety warnings. There is a debate between quiet, subdued decor and the colorful, "say something" schemes.

Noise: Between the Walsh-Healey Act and the Occupational Safety and Health Act of 1970, industry can no longer tolerate sound in excess of 90 dB and should plan for less. This is difficult when so many common machines create 80-125 dB.

It is not the purpose of this discussion to detail the design specifications for saws, drills, mills, presses, compressors, blowers, pumps, conveyors, etc. Suffice it to say that noise specifications are to be an integral part of detailed equipment and process design in Stage III.

The intent here is to emphasize the need for noise abatement design in the total plant, for sound output from many sources accumulates.

Noise abatement begins in the overall process design. There are often alternative process sequences that are strikingly different in noise generation. For example, compare manual hammering with pneumatic nail setters; change the welding method to alleviate chipping; incorporate noisy cutoff operations into pressing or turning where noise attenuation is already needed; flood cutting action with coolant; eliminate "hammer fits" in assembly. One of the easiest ways is to reduce the number of operations by combining as covered in Chapter V; this especially reduces materials handling with its attendant banging noises. Materials handling itself is quite subject to noise abatement by using sound deadening pallets and containers, belt instead of roller conveyors, composition instead of metal chutes, electric instead of gas trucks, etc. Of course, an outstanding way is to minimize handling for economy and noise abatement. The process might well be so arranged that the use of sound barriers is facilitated. Sound can sometimes be "exhausted" by astute use of air flows or water cooling.

The essence of noise abatement action during process design is the edict: prevent by eliminating, combining, or simplifying the sources of noise. Whatever the process there will remain large sources of noise energy. If few and isolated, noise attenuation should be designed into them in Stage III.

For plants where the process is expected to be generally noisy, acoustical engineers have made available many ways of attenuating noise. The techniques are based on two approaches, reduce reflection and reduce conduction. If you've ever tried to find a rattle in your automobile, you're familiar with conduction. In plants there are three primary trouble areas - utility runs, floors, and steel structure. Preventing conduction is accomplished by the use of flexible connections where utility runs interface equipment and resilient mounting of equipment and/or utility runs to the floor or steel structure. Sound and vibration isolation also mitigates sound creation from resonance and vibration induced chatter in machining components - a quality problem.

When the above approaches are insufficient to reduce noise to acceptable levels, one must turn to the more costly techniques of reducing sound reflection. Perhaps the simplest aid is hanging sound baffles from the ceiling. (They must be designed in conjunction with air flow systems.) The ceiling may also be insulated with one of the spray-on or panel type sound absorbing materials available. Another relatively economic method is to employ a resilient floor (to be discussed in the next section).

Finally, and most expensively, sound absorption may be designed into the walls. In lieu of plain concrete block or metal sheathing, there are a number of materials and wall constructions that will absorb varying percentages of sound. For heavy or load bearing construction there are slotted concrete blocks (e.g. Soundblox). The manufacturers of metal buildings and paneling offer a variety of sound absorbing constructions. Sound absorbing materials may be substituted in conventional construction methods. As a last resort wall configuration may be altered to break up sound or barrier walls may break up the process.

Turning from the abatement of process created noise, my research indicates that the most prevalent offender among building and utility facilities is air intake and exhaust design. Air blowers and duct work rumble, roar, screech, whistle, rattle, and crack. Until 1969, the design and manufacturing philosophy was build cheap and move "a lotta" air. Following the advent of stringent noise regulation, the reputable national manufacturers have been bringing out equipment designed to mitigate noise. The common approaches have been toward larger blowers with lower velocity and reduced turbulence. Problems remain, however - the connecting ductwork by local suppliers and, at this writing, an inadequate supply of acoustical expertise among architects and HVAC engineers.

There is no substitute for thorough advance planning in sound abatement. It's cheaper to prevent than cure; it's cheaper to substitute materials, processes, or configurations than to replace. After the fact, tack-on solutions are costly and never quite satisfactory. The first prerequisite to adequate planning is obtaining acoustical expertise through employment, the firm of architects and engineers, or consulting specialists. The second is recognizing that an integrated, systems approach gives the best results; recognize the relationships among process, equipment, building facilities, sources, conduction, and reflection.

A final admonition is to watch for charlatans among the acoustical experts. The rapid and enforced interest in noise abatement has attracted them.

Personnel facilities: Since the details of personnel facility requirements are well covered in building codes and in the plant engineering and layout literature, this discussion will be limited to some significant relationships of personnel facilities to other subsystems.

The question of convenience will elicit a debate among any group of plant supervision, engineers, and administrators. First, labor codes generally require a toilet facility within 200' to 300' walking distance from any employee. Beyond this, installation is costly. Scattered vending machine locations may reduce break times, but they have the disadvantages of installation cost, litter, and contamination of segregated waste. More than one cafeteria is justified in only the largest of industrial complexes.

So often it's the little oversights that give so much trouble. Emergency egress and maintenance passageways have often served to integrate men's and women's locker facilities. In a two story toilet complex built to conserve floor space in a high ceiling plant, the women were to be assigned the upper level until I reminded the management that production would be frequently interrupted among the men in the vicinity of the open stairway leading up. In another plant, they were having troubles with production among a group of women assemblers until it was discovered the women's location gave them full view of the men's room every time its door opened; a barrier was constructed opposite the doorway. It is not uncommon to find:

- toilet facilities opening onto eating facilities,
- sound pervious walls between men's and women's facilities,
- doors that open blind onto truck frequented aisles,
- toilet partitions without doors
- hand lavoratories inconveniently farther from the door than the toilets
- unnecessarily exposed piping
- water seepage in below ground locations.

Relative to cleanliness and aesthetics, I have found during my research that a reliable estimate of the management's attitude toward labor and the strength of the union may be obtained by a visit to a factory men's room. As I feigned need, a number of management guides endeavored to lead me to the privileged men's room. Cleanliness is particularly enhanced by astute design. In toilet facilities, it is strongly recommended that all fixtures and partitions be wall and ceiling mounted so that:

- the unobstructed floor presents no cracks to gather dirt

- the unobstructed floor can be mopped completely, quickly
- the fixtures are easy to clean
- piping is hidden in a "chase" that allows easy maintenance and expansion if 30" wide
- floor coverage materials are applied economically
- general appearance is enhanced.

Tile and glazed block are not recommended because they are expensive and result in dirt collecting cracks. Today's market offers polyruethane and epoxy coatings that provide economical, continuous surfaces for walls and floors that are as impervious as tile. From the wide color choice tasteful decor can be obtained. All corners should be rounded and blended for easy cleaning. Economical suspended acoustical ceilings are recommended for cleanliness, aesthetics, light reflection, and noise abatement.

Many of the above specifications apply to locker rooms and cafeterias. Additionally, it is often convenient to locate locker rooms over toilet facilities so that economy in piping and space utilization is realized. (Locker room location will also be discussed in connection with security.) Using slope top lockers mounted flush on raised curbs prevents litter collection and eases floor cleaning. Using movable, sound barrier walls between men's and women's can allow adjustment to changes in the male/female ratio if the lockers are arranged to allow it. Cafeteria design is a problem in itself, largely directed by local health codes, but the aesthetic and cleanliness specifications outlined above apply.

All these recommendations imply added construction cost. They are worth it! The above recommendations plus floor drains (often code required) enable cleanliness with less than half the janitorial manhours required with conventional design. Beyond paying for themselves, these design criteria aesthetically improve the human environment.

Health and building code requirements for ventilation of employee facilities are varied but high. Incorporating them into the general HVAC system can result in substantial savings. General plant air, conditioned and cleaned as presumed from previous discussion, can be vented into employee facilities through door and/or wall louvers by providing exhaust capacity to move sufficient air against a slight vacuum. Thus, the required air serves a dual purpose by being a part of general plant ventilation and fulfilling requirements for employee facility venting. Heat and/or cooling are used "twice" (except that facilities located along outside walls may require enough radiant heat to offset the coolness of the wall).

A prime consideration in the location and sizing of employee facilities is their lack of flexibility. Relocation of facilities with significant plumbing is prohibitively expensive. For long term economy it is recommended that they be located outside of prime space, away from potential process relocations. In most layouts there are convenient, yet clear of production locations for employee facilities - along a wall with other permanent facilities, in a corner, in the space between two plant buildings, or on a mezzanine over productive space. For economy in piping they are best located in back-to-back or stacked complexes. Astute arrangement can enable any necessary future alteration of the proportion allocated between the sexes. Provision for expansion may be accomplished by "stubbing in" piping for fixtures to be added later.

Floors

Floor specification is so critical to future plant operations that it is given special consideration here. Architects will tell you that choice of floors is the most important decision in building specifications.

Floors bear the brunt of all operations; they support the loads of process equipment and material; they determine the safety and speed of employee and vehicular movement. Floors are the building feature most subject to breakdown and are most difficult to repair. Like roadways, when built right they last indefinitely; when remiss, maintenance starts with first day of use.

With rare exception modern factory floors are constructed directly on earth. Thus good floors start with good bearing soil thoroughly compacted. On this, architects recommend at least 6" of quality concrete. The inclusion of roadwire is debated; when recommended it is only expected to prevent shrinkage cracks. (The use of heavier reinforcing, perhaps tensioned, and perhaps thicker concrete for heavy load bearing, is a different proposition.) Concrete of 6" on compacted earth can be expected to support most machinery, medium height pallet racks, and vehicular traffic. Such construction is commonly employed as the general specification supplemented with heavier equipment foundations on an exception basis.

Continuous or strip pouring of the concrete if often touted for economy, but the method has some distinct disadvantages in factory construction. The extremely large sections are particularly subject to shrink and vibration cracking under dynamic load. Should it be necessary later to open a part of the floor for alterations, the resulting stress relief will cause cracks to open and gradually propagate over wide areas of the floor. The large sections carry noise and vibration over wide areas and have been suspected of resonance. These disadvantages are overcome by using checker-board pouring in sections of about 2000 sq. ft. This method is widely recommended for better quality work. Stresses are smaller and confined to a smaller area.

Vibration propagation is reduced even with standard joints; by using a vibration dampening material in the joints, vibration and noise may be isolated. Obtaining special grades, slopes, or constructions in exceptional areas is facilitated. Future alterations affect much smaller areas.

Since floors are by their nature inflexible to future change, building flexibility into underfloor utility runs requires some ingenuity. To facilitate maintenance and alterations the basic need is to have reasonable access to the utility run. One method is to install a commercially available duct system into the concrete. Duct systems are expensive, generally limited to wiring, and weaken the concrete floor. My research has shown them to be economically justified only in offices, testing, and laboratory areas. A second method is to build plate covered trenches into the floor. Their cost is justified when a number of utility lines are to follow the same path; they can be designed to fulfill fire water drainage requirements. Rarely, underground tunnels are justified for heavy usage or in conjunction with conveyor systems and/or employee passage. One ingenious method observed was the use of 4" and 6" transite pipe laid immediately below the floor and terminating in what amounted to plate covered holes in the floor. This method was also used in lieu of the general practice of "stubbing in" pipe and conduit for planned additions.

Finally, where not obstructed by material handling equipment, the whole problem can be avoided by using the roof structure to carry utility lines; the roof structure must be strengthened accordingly.

On a solid base the next consideration is surface. A common practice is to merely float (smooth) the base concrete. It's cheap but subject to wear, dusting, and spillage absorption. Resin concrete fillers prevent dusting and absorption, and are easy to clean, but they are slick and do not prevent heavy wear and chipping. Expense limits the heavier epoxy and polyurethane coatings to situations subject to chemical spillage or where cleanliness is imperative. Branded floor construction is available wherein a top layer of special concrete is heavily worked to present a very dense, hard, smooth surface. Such surfaces are largely impervious and dust free, have excellent wearing and cleaning properties, and add to the strength of the floor. Another top quality factory floor is obtained through the use of end-grain, impregnated wood block. Their resilience offers some often desired advantages - reduced breakage of dropped articles, sound and vibration absorption, and warmth and leniency on employee feet and legs. Their coarse surface prevents slipping, but presents problems in absorption and cleaning. Being like cobblestones, they can readily be removed to alter or place small utility lines, but improperly installed blocks will just as readily lift out if they become water soaked.

The choice of floor materials and construction is an optimum trade-off among a number of variables. The first, of course, is cost, but cheap is only so if the floor meets the demands placed on it. The other variables are:

1) strength to carry all static and dynamic loads except especially heavy machinery requiring special support
2) resistance to wear as needed, where needed
3) resilience and damping properties
4) absorption, dusting, and cleanliness characteristics
5) human needs - warmth, color, safety

It should not be construed from this that a single choice must be made; a plant may well require more than one floor type.

Safety and Security

Although the forces had long been building for a change, the Occupational Safety and Health Act of 1970, called "OSHA", has precipitated a break in two time-honored traditions of management. Naming some nice, innocuous, longtime employee as safety engineer no longer means an adequate safety program. Second, the employment of a retired policeman or engaging a detective agency no longer suffices for security.

The rapid growth in societal concern for consumer and employee safety has led to strict safety legislation and codes plus punitive court awards in damage suits. Concurrently, there has been an alarming increase in theft - property and information - and in destructive rioting and vandalism. It would be presumptuous to think these few paragraphs offer a panacea for management's safety and security (S&S) problems. The only hope is to show that competent S&S planning and design will prevent or alleviate many of the problems. For maximum economy, it is contended that an integrated, or systems, approach is necessary to competence.

Historically, man's greatest fear has been fire. The modern result is a profusion of national, local, and insurer's fire codes to which OSHA has been added. Unfortunately, these codes conflict in many ways. It is common to find something required in one section and exempted in another. These conflicts must be resolved, or occasionally waived, in view of the unique characteristics of each plant. These characteristics can change radically with seemingly negligible changes in process or layout. Before OSHA the codes encouraged a property protection orientation in design; now design efforts must be more people oriented.

The first step in determining fire protection requirements is to determine the flammability of products and process. For brevity, this discussion will be limited to "typical" products of low to moderate flammability, and to "typical" processing - molding and/or machining plus assembly and packing. In such widely prevalent circumstances the primary concerns are with flammable dust and fumes (as from solvents and oils) and with human carelessness.

Next, products and processes are examined for ways to mitigate flammability. Today, because of property protection, safety, health, and just human considerations, dust and fumes must be conducted away. (For environmental reasons they must also be trapped.) Since dust and fume handling facilities are generally complex (explosion-proof circuitry, elaborate controls, and internal fire facilities), they should be eliminated, combined, or simplified wherever possible. Elimination, or at least lessening the hazzard, may often be done by modifying the product material or by substituting less flammable, say, solvents required in processing. The number of facilities may be reduced by combining locations through process method or sequence modifications. The facilities may be simplified by arranging the layout to reduce ductwork, fittings, and blowers. Sources of ignition, such as torches, may be replaced by safer heating means - e.g. induction in lieu of flame brazing. Processes requiring heat or flammables may be replaced by those that do not, such as vibratory stress relieving or water based adhesives.

Those fire protection facilities determined to be essential should be integrated into the general plant design process. Just because fire codes require a certain level of protection, the fire facility configuration should not dictate process configuration; e.g. materials handling techniques should not be dictated by an arbitrary sprinkler pattern. The proper design is the result of the optimum economic trade-off between process and fire facility configurations. In short, fire protection facilities are to serve the plant - not be served by it.

It is felt pertinent here to stop listing what and how for a moment and concentrate on when and who. S&S planning and design should be an integral part of the overall manufacturing system design project running concurrent and parallel with the activities outlined in Chapter V. There should be a constant interplay (feedback) among S&S, product, and process design. To accomplish this charge effectively and creatively, there is the need for at least one truly competent, safety-oriented engineer, free to act as "check and balance" on product and process design. Here, competence means more than being able to read codes and yell, "Think safety!" It means the ability to create ingenious, economic substitutes for designs causing safety problems or unnecessary costs. It means that S&S activities should be a positive force instead of a necessary evil.

Before leaving fire, there are three secondary points that need to be made. OSHA now enforces much more emphasis on employee warning and egress. In plants, this means not only firedoors but also clear egress from among machines. This factor needs to be incorporated with other human factors discussed in Chapter V. Secondly, the little oversights can be costly. For instance, the scattered use of cleaning solvents or occasional use of certain cutting oils can change a plant's classification from low risk to hazardous. Thirdly, special storage facilities for flammable liquids need special consideration concurrent with - not an afterthought to - process design and layout. Bulk storage and pipe handling can mean economies in S&S as well as in purchasing and handling.

There are a number of areas in which plant arrangement, S&S, and people interface. A group of them may be likened to traffic engineering, for the safety engineering concepts are quite analogous to highway safety. First, aisles need to be designed for smooth traffic flow as follows:

1) size as needed (interstates, boulevards, and side streets),
2) layout straight or gently curved, clearly marked, with clearances for <u>both</u> pedestrian and vehicular traffic,
3) clearly mark intersections, round the corners, maintain clear visibility or provide 45° mirrors,

4) design for "rush hour traffic" around time clocks and exits,
5) employ surfaces that provide good traction,
6) employ snow and dirt removal grates at entrances,
7) employ lighting levels of at least 15 foot candles,
8) employ safety colors on all potential obstructions,
9) employ traffic signs,
10) above all, avoid blind corners and entrances.

There is traffic engineering to be employed among machinery. Slippery floors, emergency egress, and clearances for personnel and handling equipment have already been outlined. Further, machine projections should be avoided, guarded, and/or clearly safety painted; utility lines should be below floor or dropped vertically from the roof structure. Areas around data collection devices can present traffic problems. Finally, as a part of job design, the individual's traffic pattern needs explicit consideration.

A number of plant arrangement/S&S problem areas can be grouped under employee carelessness. A subgroup relates to utilities. Utilities are too often complacently assumed to be safe because of code requirements. A prime example is the frequently observed practice of conveniently locating switchgear or gas valves dangerously close to vehicular traffic. One forktruck collision with a distribution panel or gas control can be catastrophic to a plant. Another is the location of disconnects or starters such that the equipment cannot be observed for clearance while operating the switch. Positive lockouts should be specified for all disconnects. (Maintenance men in one plant employ bright red personal tags with the admonition, "LEAVE THIS DAMN SWITCH OFF, or my ghost will haunt you. __(signed)______".) Switchgear is too commonly located in places subject to dirt, chips, water, and oil splash. In high bay plants, an excellent location for main or area switch gear is on special mezzanines; they retain the floor for productive space and keep unauthorized personnel out.

Waste collection systems are another area in which employee carelessness can be a problem. The problem of vending waste, already mentioned, can be alleviated by vending machine location and by providing frequent receptacles for personal waste. Containers for flammable waste should be brightly color coded and clearly marked - FLAMMABLE. Openings to liquid receptacles, and to some extent to solid waste receptacles, can be designed to discourage throwing in personal waste. Personal waste receptacles should be placed near all segregated waste receptacles. Trenches and floor tracks should be covered to prevent trash accumulation. These recommendations may seem expensive, but one cigarette in a chip bin can start quite a fire and/or explosion;

plastic coated vending cups can ruin the recycle value of paper waste.

People and materials handling equipment clash, often disastrously. Eliminate or shorten it by modifying the process. Locate it over, under, or aside out of the way. Provide adequate guards and automatic shutoffs to stop it when obstructions, human or otherwise, are encountered. Ceiling height and overhead mounting heights must be adequate to provide sufficient clearance. Provide safe and orderly storage facilities. Avoid layouts that encourage people to climb over or through conveyor systems. Designing a safe material handling system has a significant impact on overall plant configuration. One factor involved in keeping it safe is the use of warning colors and alarming noises.

The earlier discussion of light and color is extended here to emphasize safety. Adequate light is an obvious factor in safety. Earlier, color coding and the debate between subdued and colorful decor were discussed. For reasons of human response and safety, the writer advocates the following criteria. The general decor should be light and clean, but subdued and restful. Color coding should be limited to that necessary and should use colors that are distinct but not distracting except for hazardous waste containers and equipment. The remaining colors, used for warning, should be truly alarming. Common practice is to use red or yellow, but being common, they suffer from mental filtering as with disagreeable odors or extraneous sounds. Particularly with vehicles, luminous fuchsia or chartreuse and/or psychodelic patterns are recommended. Warning signs should be colored and worded to be truly striking - FINGER SNATCHER, or PURPLE PEOPLE POUNDER, or WE PAINTED THIS CONVEYOR RED SO YOUR BLOOD WON'T SHOW.

Staying with people but shifting the emphasis to security, raises the question of design and location of employee facilities. If employees must bring lunch pails and heavy coats into the work and storage areas, theft losses can be anticipated. An alternate is to provide personal lockers near the plant entrance. If eating facilities are near the lockers, it is practical to restrict lunch pails from the plant.

To illustrate what can be done with employee facilities in tight security conditions, a complex of facilities designed by the writer will be drawn on. A manufacturer of small, valuable, hazardous products was building a plant with secured loading dock on the east, offices on the south, and parking lot to the west. The southwest corner of the building was chosen for employee facilities. The office window decor was extended around the southwest corner for aesthetic reasons in the cafeteria located there. Doors in the north wall of the cafeteria opened onto a wide passageway leading from the parking lot to the plant by way of guard facilities at the plant end of the passageway. North of the passageway opposing stairs led to men's and women's lockers located on the second floor. Next was a first aid room opening between the stairwells. Men's and women's toilet facilities opening onto the plant were located north of first aid. By this design the employee could enter the building and leave off personal gear before entering the work area of the plant. At lunch or breaks he passes the guard to reach his personal locker and/or the cafeteria. Personal gear, except purses, was restricted from the plant.

In dealing with overall plant security, our emphasis shifts outside the building. We are primarily interested in preventing property from leaving and destructive forces from entering. The plant designer's major contributions to security are through lighting and land design. For brevity, this discussion is limited to an outline of major criteria developed from research into security problems. First, segregate offices, docks, and general parking. (Internal docks are recommended.) For economy, integrate security lighting with architectural, office, dock, and parking lot lighting. Severly limit normal entrance and exit; alarm all emergency exits; limit and alarm openings such as windows and waste hatches. Use adequate fencing to

1) maintain segregation of offices, docks, and parking
2) control and limit pedestrian and vehicular

traffic to observed routes

3) prevent unauthorized entrance or egress
4) protect employee automobiles as desired
5) protect large land areas from abuse or arson as desired

Construction criteria for fencing should include:

1) sturdy and lit compatible with security techniques
2) clear of trees and brush which obstruct view and form excellent fence bridging
3) snow storage provided next to parking and separate from fences to prevent damage and simply walking over the fence,
4) alarmed emergency and maintenance gates.

Integrated Building Control Systems

It should be noted that there are commercially available integrated safety, security, and building operational control systems that will perform about any building function conceivable. As exemplified by the JC/80 system (new in 1972) of Johnson Service Company, these systems can operate heating and cooling equipment; start up processes that require warm-ups; operate lighting, doors, even toilets; operate protection equipment and give warning, even by areas; silently note intrusion and even plot the path of the intruder; notify public authorities, security personnel, and/or management; and even tell you if the guard is asleep.

If desired, building control systems can incorporate a complete security system including alarms, television viewing, sound and magnetic sensors, door and gate controls, and even voice communication with remote doors or gates at night.

Safety alarms may be included, such as conveyors striking an obstruction, processes becoming overheated, or equipment being overloaded.

Design details of these systems are unique to each set of circumstances, so they are here left to development in each plant design project.

Epilogue

On January 1, 1972, subsequent to the development of this chapter, Business Week made public Dow Chemical Company's integrated approach to pollution control. In an article, "Dow cleans up pollution at no net cost", p. 32-5, and in an editorial, "It pays to be clean", p. 56, Dow's philosophy that pollution is waste and their activities to convert waste into profit were described. Also reported were a number of conflicting views. Although not stated as such, this writer interprets their effort as a "total systems approach", at least in the area of pollution control. Dow is the only large firm known to be taking an integrated approach. Further this is the chemical industry which has been recognized throughout this discussion for its history of superior, if enforced, plant design efforts and its unique problems beyond the scope of this general approach.

In general manufacturing, or fabricating, the only near "total systems approach" known was that applied during 1970-71 in the design and building of a plant for Package Machinery Company of East Longmeadow, Mass. There the theories and concepts underlying this chapter were tested, applied, and confirmed.

CHAPTER VII

CONFLUENCE IN SYSTEM CONFIGURATION

Recalling the basic steps of the systems approach as adapted to manufacturing systems design in Chapter I, the need, criteria, and resources were determined in Stage I. Stage II has consisted of conceiving, determining, and outlining three major subsystems and now the determination of the total system configuration.

Determining the plant configuration is critical to the economic viability of the small to medium size manufacturer; it cannot absorb an inefficient plant as a large firm could. Although not critical to the survival of a large firm, it would be fair to state that at least the reputation of its management in the financial markets would be impaired by an ill conceived plant.

The whole purpose of all the hard work and planning outlined in Chapters II through VI lies in the fact that known needs and effective systems design prevent the costly errors of guesses and assumptions in determining the "outline specifications". Stated in another way, effective planning and systems design are prerequisite to effective configuration analysis and design.

Since poor plant design is so commonly blamed on architects, engineers, and other outside professionals, it is felt the relationships of management to architect/engineers should be explored prior to the treatment of configuration analysis. This is particularly true since their services are most frequently misused at this point.

Effective Use of Architect/Engineers

Management and plant engineering literature and conferences are studded with references, often sarcastic, to the ineffectiveness of architectural/engineering (A&E) design. Upon critical examination, these complaints almost invariably concern the incompatibility of building design with plant processes.

To overcome the incompatibility, are we to expect the architect to become competent in the manufacturing firm's process, products, management controls and structure, planning and strategy? If so, we can expect a much longer and more costly relationship. To avoid duplication he had better be also the project manager - and just possibly the president of the company.

When challenged at conferences, architects can justifiably admonish management to better determine needs and be explicit in specifying the needs. It is interesting to note that Vitruvius, the Roman architect, wrote nearly 2,000 years ago that architects should "be familiar with such matters so that before building is begun, precautions may be taken, lest on completion of the works the proprietors be involved in disputes. Again, in writing specifications, careful regard is to be paid both to the employer and to the contractor. For, if the specification is carefully written, either party may be released from his obligations to the other, without the raising of captious objections."

To better understand the current situation, let's review for a moment the typical procedure for engaging an architect. First, friends and associates are contacted for references. "How did you like your architext?" Factories are viewed in ignorance which leaves aesthetics the only criterion. Construction costs are compared on a square-foot basis regardless of end use.

Next a few recommended A&E firms are called in to make a presentation. The basic question put to each is: "How cheap can you design a building about (size) that looks good?" This question immediately specifies a warehouse or gymnasium, not a plant. After several presentations and some discussion, an A&E firm is picked - let's fact it - on reputation and personality.

This approach coupled with vague concepts and specifications makes management almost entirely dependent upon the architect's innate ethics and talent in management psychology rather than his competence and ingenuity as an architect.

Upon being employed, the architect first develops a number of "preliminary" designs to try on the management. After some haggling over the costs of various aesthetic renditions, a concept is chosen and the A&E is commissioned to complete the design. Many critical decisions are considered only after A&E's ask questions about height, floor loading, HVAC, utilities, etc. Most of the answers are guesses designed not to delay the project. Under these conditions, the A&E firm's professional reputation is at stake, so they over-design to prevent catastrophic liability. Since the fee is a percentage of construction cost, the management naturally tends to question the motive of over-design.

By now the reader has probably deduced this writer's contention that customary relationships between architects and manufacturing management are inefficient and ineffective. While architectural freedom may work well for institutional and commercial structures, it leads to high cost, design failures, and discord in plant design. The fundamental reason is that in plant design, the building is not the end, but rather the means of supporting and protecting the manufacturing system.

Explicitly, how can one avoid the pitfalls of customary client-architect relationships? First, recognize that the A&E firm is merely a part of and a service to the overall plant design project. An effectively managed project involves a myriad of both internal and external professional personnel. Second, profitably employ the A&E firm much earlier in the planning stage than is customary (as discussed in the next section). Third, in the process of configuration development, remove the uncertain liabilities from the A&E and encourage ingenuity.

There is, of course, the question of compensation and contractual relationships. It is recommended that the A&E firm be employed on a basis analogous to management consultants. That is, they should be engaged to design the structural and utility <u>subsystems</u> of the total plant system and adequately compensated for this service - even to the extent of offering special compensation for particularly economic approaches. This writer would rather pay $100,000 in fees for an unconventional $1,000,000 structure than pay a "cheap" 4% of a conventional $2,000,000.

Consulting arrangements are not entirely new to architects. A few such arrangements with competent architects were determined to have existed - satisfactorily. Usually their compensation amounted to less than the usual percentage arrangements, because liability for uncertainties was alleviated - though measured risk remained - and costly, random development of many "preliminaries" was replaced with outlines of a few truly probable designs.

Configuration Analysis

Configuration analysis is the confluence of all the planning, analysis, and design work that has preceded within the three major subsystems - management, process, and environment. The effort within the subsystems does not end with the beginning of configuration analysis, but rather continues throughout the "preliminaries" and on into the "outline specifications". Here it should be emphasized that communication - feedback - is expected to have been quite active among all subsystems during the preceding work; in short, the work should not have been done by three groups provencial. Thus, configuration analysis does not begin at a point in time, but rather gradually evolves from subsystem analysis into total systems analysis.

Configuration analysis is defined as the concurrent determination of total space requirements and overall shape of the structure. Configuration analysis pulls together the physical volumes required by the subsystems while arranging them in the proper spacial relationships. It must also account for probable additions and future changes in product mix, process technology, services and employee requirements.

Reviewing the process layout and summary sections of Chapter V, and picking up the threads from a different point of view, we find that preliminary process layout is the backbone of configuration analysis. The various process groups are sized based on machine, man, and material volumes. These groups are then arranged in the proper spacial relationships. By material flow analysis, a handling system is developed to tie the groups together. The overall shape is not expected to be some common geometrical shape at this point. Rather the graphical representation will resemble a complexly shaped puzzle with many open spaces.

To this "puzzle", the volumes required by management control systems are added within and among the process groups. This will result in some modification of the size and shape of process groups and will fill some of the open spaces. Next employee and other service facility space requirements are added. Here many of the remaining open spaces and odd corners may be used profitably. However, flexibility for future process changes should not be sacrificed by improper location of such permanent facilities as toilet rooms merely to save space.

Here, if not sooner, competent A&E services need to be brought into the project. Already there may have been questions concerning: floor loadings, machine foundations, structural support of conveyors and cranes, spaces required for electrical distribution and pipe chases, effluent and exhaust transmission, etc. Certainly, questions are imminent concerning: air flow and equipment, drainage systems, fire walls and extinguishing systems, secure entrance and egress, adaptation to land, and cost of alternate building types.

Into the layout of process and management control systems, environmental and utility requirements are fit. The HVAC system should be outlined by the A&E first, because it is the most difficult and will tolerate little modification without detrimental effects on air flow. Next the effluent and drainage systems are sketched in. Then the electrical, liquid, and gas services are threaded in. Finally, those safety and security facilities not already part of the above systems must be placed. Modification in process group and control station size, shape, and location result, of course, from the inclusion of environmental facilities.

At this point we have a spacial concept of the ideal plant configuration. As a practical matter the "building" is probably, as yet, hypothetical; for its complexity would make its construction prohibitively costly. Nevertheless, we are much closer to an optimum building than by way of the conventional method of choosing some rectangle of near appropriate area and then forcing the contents to fit.

Management, if it wants optimum return on investment, now has a systems analysis problem of major porportions. The optimum overall design configuration is the most economic composite of:

(1) building shape to

    a. process flow pattern

    b. materials handling needs

  - c. receiving and shipping needs
  - d. employee needs
  - e. utility, service, safety and security needs
  - f. management control systems requirements
  - g. environmental control requirements
  - h. height needed for product, process, or handling methods
  - i. roof, column, and floor load requirements
- (2) building size to
  - a. production volume and mix
  - b. process and product volume requirements
  - c. storage requirements
  - d. receiving, packing and shipping facilities
  - e. employee, office, utility, service, safety and security needs
  - f. short term expansion estimates
  - g. trends in product and process technology
  - h. planned equipment additions following initial operation
- (3) structural design to
  - a. structural support of processes and handling methods
  - b. economic future expansion
  - c. flexibility to meet changing needs
  - d. noise, light and environmental requirements

e. fire, safety and security needs

f. maintenance economics

g. aesthetic and social values

At first glance, it would appear that the vast number of economic alternatives caused by the possible permutations of so many variables would make solution of this configuration problem practically impossible. This is not true. First, some common sense geometrical shape will probably be found most economic. Second, the preliminary layout and the requirements probabilities developed by earlier product, process, flow, storage, control system, environmental, and social needs analyses will have established effective parameters to guide "homing in" on a relatively few viable alternatives -- provided these analyses have been handled properly, not parochially.

The mechanics of this decision process require that the A&E roughly design at least the structural portions of buildings that comply with those few configurations determined by management to be truly probable. Then at least the structures of the buildings are "costed out". Rather rough estimates are generally quite satisfactory; only close competitors need "sharp pencil" estimates. These estimates are an input to economic comparison and trade-offs. To them must be added the estimates of equipment investments and operating costs that vary with building configuration.

Finally return on investment analyses are made on each of the alternatives.

Within the framework of purely economic analysis, management must apply its own best judgment, goals and value systems, for many decisions on aesthetic, ethical, social, and uncertain factors must be made. It must also make a searching evaluation of its decision in relation to its very long term strategy, objectives and policies.

An illustrative case. The Package Machinery Company, of East Longmeadow, Massachusetts, found that it needed high, wide bay construction in order to handle large, heavy components and products on large machines. Previous analysis and preliminary layout had revealed the probable square footage and height needs plus additional uncertain needs. The president decided to accept the risk of providing for the uncertain needs; thus a magnitude of building was determined. At this point, A&E services were called upon to design and price the variable portions (mainly structurals and skin) of three distinctly different configurations:

(1) circular

(2) two parallel bays with 80' craneways

(3) one wide bay with 150' craneway

Circular configuration would have been ideal for process flow and material handling, but construction costs proved prohibitive. A number of construction alternatives were prohibited by the need to connect the new with existing facilities. Use of geodesic and laminated beam domes required the essence of two guildings - the internal one to merely support crane systems. In addition, the circular building would have been difficult to expand at a later date.

Although resulting in much lower operating costs, the 150' bay initially appeared uneconomic because of higher construction costs and the excessive costs of 30 ton cranes to span 150', so design work on two parallel bays was initiated. However, further research revealed a quite competitive European crane design; and an American crane manufacturer decided to rise to the challenge of providing 150' cranes at a reasonable cost. Now the total investment cost of the wide bay came within $10,000 to $20,000 of the parallel bays; this difference was more than offset by operating savings. So, at the loss of some structural design work and some time, the design of two parallel bays was stopped and the one wide bay design initiated.

Outline Specifications

The choice of configuration and related guidelines constitutes completion of Stage II. The decisions should definitely be recorded in "outline drawings", architectural renderings, and "outline specifications".

Some research has culminated in a competent method of preparing and presenting "outline drawings". First, prepare a small scale, say 1" = 25', layout showing intended use by areas. Polyester is recommended for the durability of this drawing. Make a number of transparency copies on sepia or polyester. On one layout, outline power requirements by location. On others, outline drainage, HVAC, communication, fire lines, overhead conveyors, etc. as far as is needed. Copies of these can be provided to the A&E, plant engineering, plant layout engineering, government agencies, management, or anyone else who has a "need to know".

Recalling Vitrivius' 2,000 year old comments, there is a crying need for managements to be explicit in writing their "outline specifications". Being specific in general specifications does not preclude later addition and modification to detailed specifications as detailed plant layout and equipment "specs" develop in Stage III.

Management cannot be expected to determine the specifics of general specifications without the aid of explorations in cost, codes, and physical limitations in conference with its A&E firm. It must realize, however, that the backbone of "outline specifications" is adequate development of plant needs: power requirements by process and area; air makeup by process; employee facilities by number per sex, codes and management policy; floor and structure loads and type; bay dimensions; fire, safety, and security needs; aesthetic rendering; and all the other needs of the management, process, and environment subsystems.

Going into the development of all specifications would require a book longer than this one, but there are some generalizations that warrant treatment. H.E.B. Anderson in "Construction Problems and Practices" (Plant Engineering, Nov. 11, 1971) reported on a survey of completed plant buildings. His and my mutually corroborating research point to the discouraging incidence of roofing and HVAC problems in operating plants. Among all the possible failures, management can fully expect two, leaks and short make-up air, unless they are assiduously avoided.

There are a number of unusual specifications that can be of particular value to an operating plant.

(1) To aid future adaptability of the plant, there is a need for easy access to utility runs. Pipe lines should use plugged tees instead of couplings (pointing up on air lines). Valves should be provided at all branches. Switchgear should allow for additional circuits. Busduct and wire raceways are superior to mazes of conduit.

(2) All equipment arrangements, process and building, must provide for ready maintenance access.

(3) Oversized, looped compressed air trunk lines are decidedly superior to large tanks near the compressor.

(4) Avoid load bearing walls; partitions may be moved.

(5) Avoid "or equivalent" clauses if standardization is potentially affected.

(6) Provide floor level truck entrance for economical construction and equipment moving.

(7) Provide wall hung personnel fixtures to reduce janitorial time (time recorders, water coolers, telephones, etc.).

(8) Provide adequate corner and column protectors near vehicular traffic.

(9) If concrete floors are used, provide broomed finishes near docks and outside entrances. Provide snow and dirt grates with drains inside entrances. Provide heated bottom seals on doors subject to freezing.

Looking Forward

Now that Stage II, the outline specification of the manufacturing system, has been completed, it is advocated that the management initiate an integrated design and implementation project, Stage III. This project, done in conjunction with the A&E firm, involves the detailed design and specification of:

(1) detailed plant layout and materials handling design
(2) detailed process design, job design, and equipment specification including human factors
(3) utility and service facility design
(4) environmental control systems design
(5) detailed building design and land layout
(6) detailed management control system design
(7) necessary product design modification

The project also involves the implementation of:

(1) management planning and development
(2) manpower planning and training
(3) financial planning and development
(4) continuous economic evaluation of alternate design composites
(5) continuous plant engineering evaluation (maintainability, reliability, and standardization)
(6) continuous evaluation of safety and security factors
(7) continuous review by quality assurance personnel
(8) continuous employee communication about plans to allay their fears of change
(9) corresponding market planning and development

(10) evaluation regarding strategy, policies, and ethics

(11) evaluation of the fulfillment of aesthetic and social obligations

A comprehensive development of the activities during Stage III is beyond the scope of this dissertation; the techniques necessary within each of the design disciplines are readily available. Each discipline, however, has given only superficial coverage to the "spillover" among the disciplines. The first five listed subprojects (layout, process, utility, environment, and building design) are so closely related that there must be constant liaison among them. This and other liaison will test the calibre of the project management with a challenging dilemma - encouraging creativity yet integrating the design of the various subsystems into the total plant system.

The long lists of design and planning work make obvious the large number of manhours and disciplines needed. The resulting number of people involved presents a major problem in management, scheduling, and coordination. To prevent the project from lasting forever, the management through the project manager must schedule and follow-up hundreds of subprojects. PERT or CPM techniques are of value here; so are frequent, but brief and organized, coordinating and reporting conferences.

The evaluation and review activities listed need to be set up early. The necessary personnel (e.g. quality assurance and plant engineering) need to be consciously included in the appropriate conferences and decisions. The problem here is to adapt the available leadership, communication, motivation, and evaluation techniques to guiding and integrating without stifling creativity. The encouragement of ingenuity rests with the management's ability to avoid using evaluation as a barrier to innovation and to welcome radical ideas (see Schon, op. cit.). Because the skill is not prevalent, it is recommended that competent economic evaluation services be provided to the other disciplines as a continuing adjunct to the project.

Manpower and management development should begin as soon as broad outlines of manpower requirements become available from process and layout design. The process will determine the technologies needed of the employees and supervision. The type, sex, etc. of employees will feedback into facilities design, process capability, training needs, supervisory needs, administrative needs, etc. These feedbacks are ignored by writers on plant layout or building design. Employees are thought of in terms of quantity not quality -- in terms of parking spaces, lockers, and seats in the cafeteria and toilet. Organization theorists implicitly assume the plant facilities are already fixed.

To implement a major expansion obviously requires financing. Thus the financial personnel should have access to the magnitude and timing of cash needs as the project progresses. They should also be able to influence timing and guide economic evaluation. Note that magnitude of investment is not accepted as a restriction; a well planned expansion can obtain funds. However, the cost of capital will feed back into the plant design process to influence the man versus machine decisions and the excess capacity decisions. In contrast to this current liaison approach, the literature describes the analysis of a number of completed alternative plans. This ignores the cost of planning many alternatives and the economic assumptions made by the designers that may have eliminated the optimum method from those being analyzed.

If the company expects to be effective in the use of cost accounting, now is the time to develop techniques appropriate to the total plant system. The organization and process being designed should feed into the design of cost controls and the control system needs should feed back into organization, process, and production control system design. This is in contrast to the literature which implies after-the-fact procedures development and physical alteration as needed.

Now is the time to design the production and inventory control systems for the new plant. Production and inventory control require physical facilities as well as bytes in a computer tape. To avoid being tacked on they must be designed into the layout, process and building. Since much of the information needed in production and inventory control is of common interest to accounting, purchasing, sales, etc., one begins to see the opportunities offered by the chance to design an integrated physical facility and management information system. Again, the literature implies little or no influence on physical facility design.

When the design of physical facilities is firm and the drawings are complete, one may call Stage III complete, although some administrative procedures work is still in progress. Drawings and specifications may be let for bid, builders engaged, and construction begun. Construction and installation, which may be called Stage IV, is defined as outside the scope of this problem in multiple systems. The effectiveness of the design through Stage III will, of course, have a significant influence on the efficiency of construction, installation and Stage V, the initial start-up.

Looking Back

Throughout the development of this methodology of facilities planning and manufacturing systems design, there has been a definitive forward progression of information and decisions, BUT each subsequent step produced a distinct feedback that modified all previous conclusions. In short, no segment of a plant may be optimally designed in isolation.

The progression of information and decisions and the major feedbacks are summarized in the flow chart at the end of this chapter. To prevent confusion the thousands of feedbacks that are the result of daily interplay and liaison among the necessary professional personnel are not shown. Only the major inputs, transformations, output, and major feedbacks are included.

Note the forward movement of facilities planning guidelines from Stage I into manufacturing systems design in Stage II. Subsequently, the general specifications developed in Stage II progress into and permeate the detailed design project, Stage III. BUT design activities in Stage III produce a modifying feedback into the "outline specifications" and into the engineering and administrative disciplines called upon to aid their development. While the evaluation activities in Stage III use strategic criteria, the results of evaluation studies often cause modification in strategy or market tactics.

It must be recognized that decisions made in plant design set corporate tactics and strategy for years to come. Management abdication of planning during plant expansion is gross irresponsibility; yet, too commonly, management does allow outside builders, consultants, architects, or developers to ineptly, in ignorance, set future management tactics. A literature search and examination of company practices reveals nothing to refute this contention. Without aid, only a few, generally the largest, most successful companies avoid the pitfalls, having benefited from more frequent experience. Calendar time is no excuse for management abdicating its responsibility. Building "something" to fill as yet undetermined needs will result in years of expensive rationalization before the plant gets fully "on stream". The axiom, "Haste makes waste", is particularly apropos here.

Although plant location has been defined as outside the scope of this treatment, it must be recognized that location has a significant influence on building and ancillary facilities design. Obviously, strategy, product, process, etc. affect plant location. Equally obvious is the vital impact of plant location on the logistical strategy of the corporation.

During the many steps of corporate and facilities planning, there are a number of points at which, quite properly, a decision <u>not</u> to physically expand deflects planning efforts from the analysis and decision process covered in this discussion. My research indicates that the great bulk of "starts" should not be expected to "make it" all the way to a decision to build. Instead, the revamping of existing plants would be the more economic way to achieve expanded capacity. For these circumstances, and the many cases in which owner/management does not desire expansion, there is a crying need for further development of the technology of adaptation (or modification).

In view of the nation's "crisis in productivity", there is a broad need for renovation of great numbers of plants - whether crowded and indicating the need for expansion or not. Many individual plants and whole industries are finding themselves unable to compete with the low cost labor and modern technology employed by our major foreign competitors. I submit that our long term economic health will depend in large measure on the degree to which we renovate, modernize, non-competitive plants and industries.

Many of the techniques outlined in this discussion are applicable to plant renovation. In addition, the trade literature offers scores of "trick of the trade" articles every month. Yet nowhere is there a rational, orderly treatment that puts together all the bits and pieces of the technology of renovating old plants to increase their capacity and/or productivity. Particularly, in the literature and in practice, corporate planning and plant layout methods are not adequately interconnected.

Reviewing the techniques outlined in this discussion, it is believed the procedures of Facilities Planning, Stage I, covered in the first three chapters, are conceptually applicable to the situation calling for rennovation. It is contended that what is needed is a logical, organized approach to manufacturing systems renovation to parallel the Manufacturing Systems Design, Stage II, covered in the latter four chapters. Thus there exists an outstanding opportunity for someone to make a significant socio-economic contribution by developing an integrated technology of industrial renovation.

There are two socio-ecological concerns of some import that bear on the subject of this dissertation. The first is the validity of the economic growth syndrome. Herein, discussion of this question was limited to:

1) pointing out that only 5% to 10% of industrial concerns are prepared for auspicious expansion (the remainder cannot or do not want to)
2) establishing socio-ecological compatibility and socio-economic adaptability as two of the three universal criteria for evaluating the need and design of expansion.

Regardless of whether general growth is valid or not, there will be individual growth, and death, among all open systems, biological or economical. Thus, the question resolves to which industrial systems should grow. Which are socio-ecologically beneficial and which are not? There is a lack of definitive socio-ecological criteria by which government and industrial executives may evaluate plant expansion, replacement, and abandonment. In view of the growing social demands on industry, there is a critical need for the development of such criteria.

The second social concern of pertinence is the degree to which industry is responsible for social welfare and urban development. The basic question is how industry should create jobs in depressed areas, particularly urban ghettos. Since plant location has been defined as outside the scope of this discussion and it is contended that urban industrial development is largely a plant location decision, only brief mention of the problem was made in the section on the relations of plant location to corporate strategy in Chapter II. Some chronic restrictions on the location of industry in urban areas were cited, but there is the need for further sutdy of the factors that discourage industry from locating in just those areas which need it the most. The earlier discussion of renovation also applies here in that there is a need for developing the means of revamping existing urban industry to ensure its viability.

While reviewing the scope of this treatment of systems design, it is well to recall that techniques and illustrations were generally limited to the design of a "typical" fabricating plant rather than:

(1) utilities - gas, electric, telephone, etc.

(2) transportation - terminals and exchange facilities

(3) process industries - chemicals, primary metals, etc.

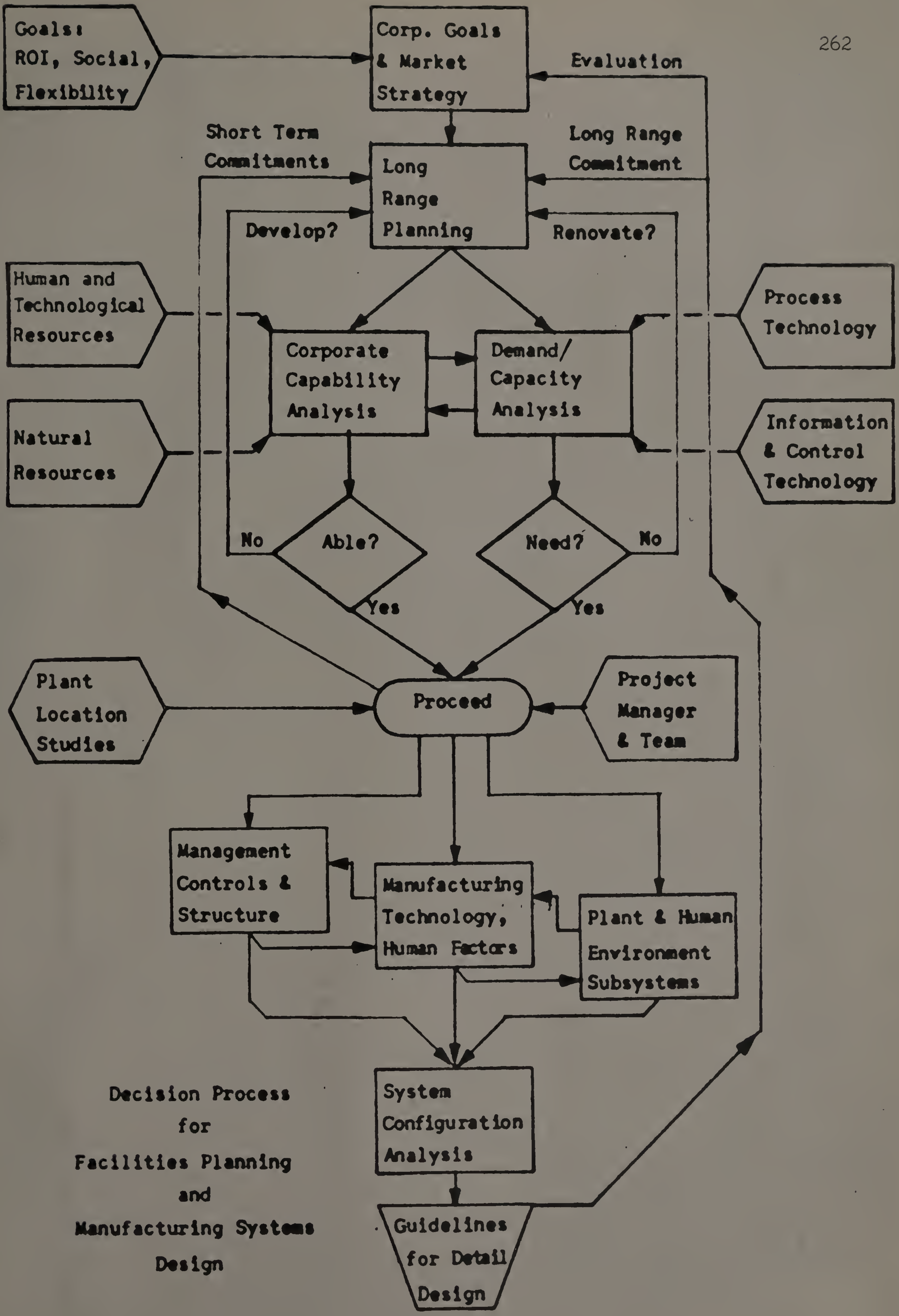
(4) distribution - warehousing, retailing, etc.

(5) services - hospitals, repair facilities, etc.

This is not to say that similar problems do not exist nor that the techniques are not applicable, but merely that these industries are outside the scope of this particular treatment. In view of the "crisis in productivity" there remains the need for developing the methodology of systems design for these industries - both in renovation and in new construction.

During the course of this dissertation, several innovations in management technology have been presented, but perhaps the most significant point is the distinctive definition of a plant as a total, living, open system. This concept is the essence of this discourse.

Finally, it is contended that manufacturing systems design is not a problem in architecture or engineering. It is a problem in systems design for management and only management can solve it.



Decision Process
for
Facilities Planning
and
Manufacturing Systems
Design

Glossary of Special Terms

Capability Analysis: The study of resource availability and corporate ability to transform those resources into goal satisfying output.

Configuration Analysis: The determination of the internal arrangement of a total system by assembling optimum subsystem designs and then suboptimizing them by "trading off" small sacrifices in some areas for large gains in others to obtain an optimum, integrated system.

Demand/Capacity Analysis: The determination of the capacity needed of plant processes to fulfill marketing demands.

Group Technology: The grouping of parts and/or products by the technology required to manufacture them. See "Logic of Production" in Chapter V.

Material Flow Analysis: The study of the direction, amount, and type of material flow required within a transformation system.

Operational Relationship Analysis: The study of the sequence and connections among the operations within a transformation system.

"Outline specifications": Architectural lexicon for specifications written to guide detailed design of structures.

"Preliminaries": Architectural lexicon for drawings of overall concepts of buildings as yet not designed.

"Trade-off": See configuration analysis.

Abbreviations

A&E: Architectural and Engineering

CFM: Cubic Feet per Minute of air flow

EOQ: Economic Order Quantity

HVAC: Heating, Ventilating, and Air Conditioning

OSHA: Occupational Safety and Health Act of 1970

ROI: Return on Investment

S&S: Safety and Security

WIP: Work in Process