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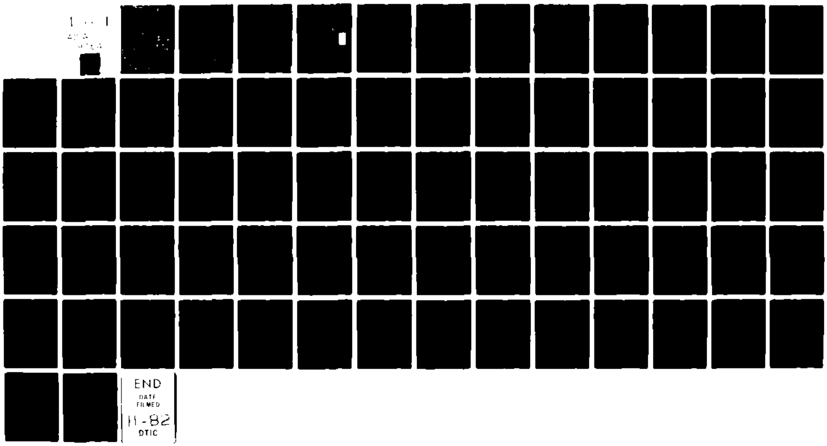

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ABSTRACT

The purpose of this paper is to develop a methodical approach to understanding and improving the productivity of an engineering workforce within an organization. Engineering workforce is, for the purpose of this paper, define as those individuals that use engineering skills to conceive, design, and/or implement products, systems, or processes in other than research and development environments.

Measurement of productivity, although very much related, is taken to be a separate issue and will not be addressed.

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PRODUCTIVITY IMPROVEMENT

FOR ENGINEERS

A Project

Submitted by

Ronald Joe Calloway

In Partial Fulfillment of the

Requirements for the Degree

Master of Science in Industrial Engineering

Purdue University

August 1981

INTRODUCTION

The concept of productivity has generated an immense amount of interest in recent years. One can hardly pick up a trade journal, association publication, text on management, magazine, or even a newspaper without finding at least one article or chapter devoted to the subject. Poor productivity, or lack of sufficient productivity improvement has been blamed for just about every woe of society including high inflation, high unemployment, low quality workmanship, and lack of industry profits. Whether productivity, or lack of it is responsible for the condition of our society is debatable, however, the fact that an increase in productivity will increase the financial position of a company is undisputed!

Although information on the measurement and improvement of productivity for the blue collar workforce has been studied, researched, and published extensively, the professional workforce has been virtually ignored. This is especially true with respect to the engineer. One possible reason for this avoidance is that the engineer's work is, by large, creative or mental in nature rather than being product oriented and does not easily lend itself to measurement. The argument follows that if the output cannot be quantitatively measured, the effects of productivity schemes cannot be assessed. I contend that this is a false argument. The productivity of an engineer is certainly more difficult to measure than that of an assembly worker and requires more effort on the part of management. Furthermore, any measurement of engineers' productivity as well as the results from intervention for the purpose of improving productivity will usually encompass a relatively long time frame. The results of the engineer's work may be subject to less strict quantitative measurement and may require more patience, but they can usually be assessed, if only on a partial or subjective basis. Perhaps more importantly, management must frequently make decisions or undertake courses of action without completely accurate foreknowledge of results. Indeed, this ability is what often separates the successful manager from the unsuccessful. However, it would seem reasonable to undertake those actions which appear to have the highest probability of causing the desired outcome. I believe this idea should be applied in an effort to increase engineering productivity. That is, determine which courses of action have the highest probability of favorably influencing engineering productivity, and the resulting organizational productivity, and apply them, whether or not a validated measurement system is available.

Another difficulty in addressing engineering productivity arises from the fact that the engineering function within one organization may be radically different from that function in another organization, both in terms of operational methods and skills utilized, as well as purpose. This lack of consistency inhibits the formation of a valid data base and often prevents the development of productivity improvement strategies in the literature that have acceptable probabilities of success. These variances in the role of the engineering function, like the difficulties encountered in measurement, should not preclude the study of engineering productivity and the subsequent development of strategies that have a high probability of improving productivity within an organization.

PURPOSE

The purpose of this paper is to develop a methodical approach to understanding and improving the productivity of an engineering workforce within an organization. Engineering workforce is, for the purpose of this paper, defined as those individuals that use engineering skills to conceive, design, and/or implement products, systems, or processes in other than research and development environments.

Measurement of productivity, although very much related, is taken to be a separate issue and will not be addressed.

WHAT IS PRODUCTIVITY?

The most rational starting point for the subject at hand would seem to be the development of a usable definition of just what is meant by productivity and productivity improvement.

With as much emphasis as has been placed on productivity, it is interesting to note that there is no universally accepted precise definition of just what productivity is.

That is, there is no single set of measures or indicators which a business can use to determine the level of its productivity. Different measures are used for different situations. There is, however, a rather clear acceptance of the fact that productivity should be thought of as a ratio concept - the ratio of the output of goods and services produced divided by the inputs or resources used to produce them. Using this ratio concept, productivity can be increased by either reducing the required inputs or by increasing the outputs. Productivity is thus defined as:

$$\frac{\text{output}}{\text{input}} \text{, or more simply: } \frac{O}{I}$$

Furthermore, the output of a function can be evaluated in two separate dimensions. The first dimension is that of quantity or efficiency. If the output of a function is increased, with other variables remaining constant, the productivity of that function is increased. The second dimension, and the less obvious, is that of quality. The quality of an output can have a direct relationship to its value to the organization. This is true, to a large extent, with the output of an engineering function. A poor design is often worthless. This rather broad and general definition will be used in this paper.

The reader should keep in mind that the only productivity improvement of any value is that of the total organization. This organizational productivity is composed of the sum of the productivities of each function within the organization which are in turn the sum of the productivities of each individual member. This can be shown as:

$$\frac{O}{I} = \left(\frac{O}{I} + \frac{O}{I} + \frac{O}{I}\right) + \left(\frac{O}{I} + \frac{O}{I}\right)$$

Organizational Productivity = Sum of Engineers' Productivity + Sum of other Functions' Productivity

The point is, that to be of value to an organization, the improvement of productivity of one individual or function must not cause a greater loss of productivity to another individual or function. If, for example, a procedure is implemented which improves productivity in the engineering function but which causes a greater loss of productivity in the marketing function, the net sum is that organizational productivity decreases.

There is one misconception about productivity which is widespread and should be addressed at this point. That misconception is that improving productivity means working harder or faster. Forcing an employee to work faster will not necessarily improve productivity, indeed the opposite may result. If increased speed is achieved at the cost of lowered quality, little, if anything, has been gained. Working smarter, not harder, seems the better recipe for productivity improvement.

WHY THE CONCERN FOR INCREASED PRODUCTIVITY IN ENGINEERS?

Since the blue collar and non-engineer workforce is often many times larger than the engineering staff, it would seem reasonable to question the validity of expending more than a minimal effort to improve productivity within the engineering function. Should not the effort be placed in the areas where the larger percentage of the labor dollar is spent and duplication of returns is possible? Although this argument does have some merit, I believe that there is a sufficient potential for returns in the engineering workforce to warrant the investment.

Engineering talent is currently a scarce resource. As our society becomes more technical, the demand for engineers increases. In addition, the increase in governmental and environmental regulations requires more engineering skills than ever before. Compliance with these regulations and the continual need to explain and justify the impact of new projects to governmental and civic groups require that less of the available engineering personhours can be utilized for design activities. There can be little doubt that technology will continue to advance significantly for the next several decades. Government influence and regulations, likewise, show no signs of reducing their impact upon the business organization. These two factors indicate that there will be a continual and increased need for engineering skills. The organization that feels this need is faced with three alternatives.

The first of these alternatives is to simply reduce the use of engineering skills within the organization. One method of accomplishing this is to reduce or stop the development of new products, methods, and processes. This would perhaps be somewhat effective in the short term, but would surely be suicidal in the long term, given the competitiveness of the business environment. An organization whose products fail to "keep up" with the needs of society is doomed to failure.

The second alternative for an organization realizing the need for additional engineering skills is to simply employ more engineers. This has been, and is currently, the favored approach used. Demand for engineering skills currently exceeds the supply and the situation is not expected to change in the near future. This increased demand together with the relative shortage of these skills has combined to significantly increase the cost to recruit and employ an engineer. Not only has the salary factor increased, but the competition among companies has caused a considerable increase in the cost of recruiting. Although engineering enrollments during the last several years have increased, the demand for engineering graduates has increased even faster and promises to even further escalate the cost for an engineer. While a large organization may be able to easily absorb the additional cost of engineering skills, this increase in cost may be quite detrimental to the smaller organization with fewer financial resources. Furthermore, given that the increased cost of procuring engineers is acceptable to an organization, and that sufficient numbers of engineers can be obtained, another problem tends to surface. Like many other professions, engineering relies heavily at times upon experience. When several new engineers are hired by an organization, the average experience level of the function drops. This, in turn, may limit the flexibility to schedule difficult projects.

The final alternative that an organization may take when faced with the need for more engineering ability is to make better use of the existing engineering resources that it has. In other words, an organization may choose to initiate methods or techniques that will increase the productivity of its engineering function. When viewed with respect to other alternatives, this approach would seem well worth the required effort. As mentioned above, a productivity improvement approach should address not only the efficiency of the workforce, but also the quality of output. The need for increasing the efficiency is fairly obvious, the more efficient the workforce, the more projects completed. Quality of output, although possibly not so obvious, can have not only an immediate, but more importantly, a lasting effect on the organization. For instance, the poor design of a construction project can not only increase the cost to complete the project, it can harm the reputation of the firm and hinder the chances of obtaining additional work.

CHARACTERISTICS OF ENGINEERS

Although the basic needs and drives of engineers are essentially the same as for the rest of the workforce, certain characteristics may differ in either degree and/or dimension due to the nature of both the individual and the job. Perhaps if these differences are understood, the areas where various productivity improvement methods are effective will also be better understood.

The Individual: There are four areas in which the typical engineer differs from the average employee. These areas are intelligence and education, personality, value-orientation, and the relative power that an engineer possesses with respect to the organization.

The engineer clearly surpasses the average employee in educational background and problem-solving ability. Furthermore, while the typical college graduate scores significantly higher on intelligence tests than the average member of the general population, engineers and other scientists tend to attain even higher intelligence test scores, on the average, than the overall college population.[1]

There is also evidence that the personalities of engineers tend to differ to a certain extent and in certain ways. Research[2] shows, for example, that engineers, when compared with non-engineers, often have higher drives toward achievement and a preference for dealing with objects and processes rather than with people. The characteristic standing out most clearly is their tendency to be much more interested and involved in their work than most other people.

With respect to an engineer's value-orientation, a research study by Badawy[3] found that engineers are typically "organizational" or "local orientated" and tend to focus on the goals of the organization. They are interested in applying technology to the business objectives of the organization and take satisfaction in exercising authority and initiative to help achieve organizational ends. In other words, their personal goals align closely to the success of the organization and they feel the need to understand how their effort is helping to achieve organizational success. Although the value-orientation of the engineer may not differ from many other employees, the degree and consistancy to which this is present indicates that productivity improvement strategies should attempt to take advantage of this attribute.

The final, and perhaps the most significant, difference between an engineer and non-engineer is the amount of power he/she may enjoy, as an individual, with respect to the organization. Most employees derive their power from one of three bases. The trained craftsperson derives power from the fact that his/her skills are in high demand from many organizations and are transferable. This results in many alternatives, with respect to employment, being available. The craftsperson's tolerance to work situations which are less than favorable is lower than an employee whose skills are not in demand or transferable. The alternative to change jobs is ever present. This is realized by organizations and various concessions such as higher wages and a greater degree of autonomy is often offered in exchange for the employee not exercising his/her option to find a better job elsewhere. Most management and upper level staff personnel derive their power from their position within and knowledge of the organization. They often are aware of new products, policies, methods, and procedures that are valuable to a competitive organization. In addition, their knowledge of the many intricate interrelationships within the organization may make them difficult and/or expensive to replace. Other employees derive power over the organization from union membership. This is less attractive than the other two bases because it results in group power rather than individual power and offers fewer alternatives to the employee. The engineer derives his/her power from the two most attractive of these bases. Like the craftsperson, the engineer's skills are both in high demand and easily transferable to other organizations. This, in itself, provides considerable power with respect to the organization. In addition, the engineer, like the manager or upper level staff person, derives power from his/her knowledge of the organization and those areas which may allow it to be competitive. The development of a new product, method, or procedure is usually the direct result fo an engineer's work, or that of several engineers. This dual power base enjoyed by the engineer is broader than that enjoyed by almost any other employee group and results in an unusually high degree of dependence by the organization. The power/dependence relationship that exists between an engineer and the organization would indicate that job security is not as important to an engineer as to most other employees. Furthermore, there may exist certain unfavorable conditions of employment or work environment that a non-engineer would tolerate in exchange for job security but would not be tolerated by an engineer. To avoid excessive turnover of engineering personnel, the organization may desire to be unusually sensitive to these conditions.

The Job: Like the individual differences between an engineer and non-engineer, the job of an engineer also exhibits certain characteristics or differences that, if examined, may provide an insight to understanding the areas where productivity efforts can be most effective.

Engineering work is essentially creative and mental in nature. It is often complex and may deal with abstract and intangible concepts. The final drawing or report that completes a project usually does not indicate, except possibly to another engineer, what might have been a long and detailed mental process required to develop the concept. Indeed, if the work of an engineer did not require this creative and mental process, the distinction between an engineer and a technician would be insignificant. The mental effort, skill, and concentration required to develop what is often a vague concept into a rational and completed project suggest two areas of concern with respect to productivity. First it would seem only reasonable that the more experienced and better qualified the engineer, the more productive he/she could be expected to be. The engineer that has enough experience to recognize when the wheel is being reinvented can save countless hours during the development of a concept.

In addition, one who is well qualified and has a current knowledge of the latest techniques and methods can contribute the technical skills needed to ensure that the project solutions are of the quality needed to keep the organization competitive in the marketplace. Second, the environment that the engineer works in must be conducive to the concentration required by this work.

Many engineering projects can encompass a relatively long time frame. Additionally, there is usually no "one best way" to accomplish the project. Two engineers may approach the same project from two totally different directions. Both may arrive at equally satisfactory solutions, but their method of arriving at these answers can depend upon their background, experience, and possibly, the direction given or perceived. The long time frame together with the many possible approaches result in cause-effect relationships in engineering work that are hard to define. This, in turn, creates a great deal of the difficulty experienced in trying to measure engineering performance.

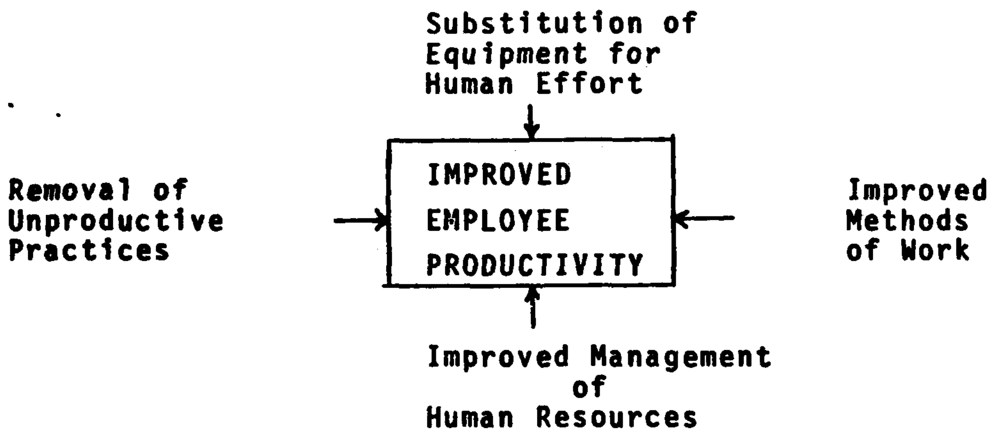
Engineering is essentially a nonrepetitive function. As one project is completed, another, perhaps completely different, is started. Thus, the job is constantly changing. This is another reason that measurement of performance is often difficult, there is usually little to use for comparison.

Engineering work must constantly deal with various interdependencies. There is interdependence between the various disciplines within the engineering fields, between the engineering function and other functions within the organization, and even between one project, or job, and another. It is not unusual for an engineering project to draw on the talents of more than one engineering discipline. For instance, a mechanical engineer designing a mechanical system may need input from an electrical engineer who is designing the electrical support system. If the mechanical system were designed independently, the resulting electrical requirement may very well exceed the available supply. On the other hand, the electrical design may depend upon inputs from the structural engineer. Engineering may interact with almost any function within the organization. For instance, the design of a new product may be based on Marketing's interpretation of customers' needs. Marketing, in turn, relies on Engineering to solve problems with existing products or to help solve a customer's special needs. Within the engineering function, the decision to start a particular project may be based on the priorities assigned to other potential projects in the queue. Also, a project that is deemed urgent may very well pre-empt another which is in progress. Thus, in the latter case, either one project or the other may be completed within a given time frame, but not both.

METHODS FOR IMPROVING PRODUCTIVITY

Given that the need to improve engineering productivity is valid, and that there exist significant differences between an engineer and a non-engineer employee, it would seem reasonable at this point to examine various productivity improvement methods and attempt to determine the degree of applicability of these toward an engineering workforce.

Sibson[4] promotes a systematic approach to the organization of productivity improvement opportunities in which four broad areas of change are identified that can have significant impact upon levels of productivity. Although this may seem to be a somewhat simplistic approach, it has the advantage of allowing a methodical assessment of various productivity improvement methods. The following diagram depicts these four broad areas:



These areas are the substitution of machinery or equipment for human effort, improving work methods, removal of unproductive work practices, and the improvement of personnel methods to help management utilize human resources more effectively. In each of these four broad areas there is a variety of more specific techniques. There is also a high degree of interelationship among the areas. For instance, use of better tools may require new work methods. Each of these areas will be discussed in turn with respect to its applicability to an engineering workforce.

Substituting Machinery for People: This method has been, by far, the most popular method of increasing productivity in the United States during the last fifty years. Perhaps half the productivity improvements in American industry during this time period have resulted from investing capital in better and more efficient equipment.[5] The rapid growth of technology has allowed the replacement of many labor hours with machines. Thus, in construction, we no longer dig ditches by hand, we use a back-hoe instead, replacing many laborers with one operator. Five-yard trucks and half-yard scoops have been replaced with twenty-yard trucks and five-yard scoops. Mobile platforms can be more economical than scaffolding. On assembly lines, we find robots replacing humans. In offices we have replaced manual typewriters and pencils with electric typewriters and calculators, and now with word processing machines and computers.

Until recently, most substitution of machinery for people has dealt primarily with the physical portion of a job. Since the work of an engineer seldom involves physical labor, there was little application possible in this area. With the advent of the computer, the potential for the replacement of mental processes with a machine was born. Calculators have all but replaced slide rules and manual computations, but this too is only a beginning. As technology advanced, the computer has become almost commonplace in the engineering environment. The extremely high cost of a computer system, often the limiting factor in applications, has made quantum reductions as the minicomputer, and more recently the micro-computer became commercially available. The result is that today the cost of a powerful computer system is within the reach of all but the smallest organization. Recent advances in the development of more efficient and lower cost input and output devices such as the Cathode Ray Tube (CRT) terminals, editors, and various simulation and conversational languages have even further increased the potential for productivity improvements in engineering.

Another recent advance in computer technology is that of computer graphics. Until this development, the use of computers in engineering was limited to those applications that involved data storage and retrieval and computations or analysis of mathematical data. Computer graphics allows communication or data flow in graphical form which is a great improvement over alphanumeric data flow which was available previously. The first important step forward in computer graphics was at the Massachusetts Institute of Technology in 1963 when a system called SKETCHPAD was demonstrated. Computer graphics technology has developed rapidly since then. Computer graphics, or computer aided design (CAD), as the terminology is often called, can not only reduce the engineering time required for many types of projects, it can also significantly contribute to increased quality of the final product of the engineer. CAD can bring numerous benefits to product conceptualization and development processes. It can enable difficult forms such as hyperbolic paraboloids, conites, hypars, and sinusoidal slabs to be drawn and rotated as needed. Some of the benefits claimed by those organizations with CAD systems in use are that CAD:

- enables computer simulation, testing, redesign and retesting of prototype parts faster and more cheaply than creating real test parts.
- Shortens design time, providing management time to consider alternatives prior to making final decisions. More designs can be completed in the same time periods.
- Relieves the tedium of doing drawings by hand, allowing designers more time to be creative and consider implications of important decisions.

Although economical use of CAD technology is currently limited to those organizations with large volume design functions, as better minicomputer systems become more powerful and less costly, and as "conversational programs" become more adaptable, use of CAD in smaller organizations is predictible. Historically, the cost of computer equipment is cut in half while the performance power increases by a factor of ten about every four years.[6]

The use of computer technology to replace engineering personhours is a viable option when developing productivity improvement strategies. It can free the engineer from many of the data manipulation and computational functions, allow more alternatives to be considered, and free him/her to spend more time on the creative and decision-making processes. A computer will never eliminate the need for engineering skills, but rather complement the engineer and allow him/her to be more productive. Many engineering functions would realize a high probability of productivity improvement if given the advantage of a modern minicomputer system. Computer graphics, or CAD, however, would only seem applicable in those applications that can justify the rather large initial investment presently required. As the cost of CAD systems is reduced over the next few years, this may become a viable option to more and more organizations.

Improved Methods of Work: The second greatest contributor of productivity improvement in the American workforce has been through the use of improved work methods.[7] Although the nature of engineering work is such that it does not seem to lend itself to standard work improvement techniques, there has been some gain and potential improvement probably exists in this area.

Standardized drawings and specifications can not only shorten design time, they can often improve the consistency of output. Reinventing the wheel serves no useful purpose. Design review and estimating costs are two areas that can often benefit greatly from a systematic approach. When reviewing a design, one of the most critical aspects, especially when the design is complex, is ensuring that all portions of the design are considered. A systematic method of review can often be employed that will help to make sure that a critical portion of the design has not been missed. This is especially needed when the engineer has little or no experience in the area concerned. The accuracy of a cost estimate often determines whether or not the organization is profitable. This is especially true with regard to a competitive bidding process. The reliability of the cost estimate is low if one or more critical or high-cost areas are missed. Again, a systematic approach can serve to ensure that all areas are considered.

Two versatile techniques that can be applied to promote a systematic approach to engineering functions are standardized computational procedures and checklists. Standardized computational procedures can increase the accuracy and ensure consistancy, while saving time, in many areas such as load factor and stress analysis. Another benefit is that the review process is also less time consuming because the reviewing engineer does not have to waste time determining the procedure used by the design engineer. The checklist is an extremely adaptable tool that is all too often overlooked. Checklists can be used for a variety of purposes such as determining equipment needed for a project, determining documentation requirements, and ensuring that all required coordination has been accomplished.

Methods improvement implies repetitive work. The fact that most engineering work is nonrepetitive should not preclude the consideration of methods improvement. Most all engineering work includes at least some repetitive functions. These functions should be identified and a methods study accomplished to determine if an improved, standardized method can be utilized.

Although methods improvement would seem to be applicable to only a small portion of an engineer's work, if that portion is identified, there would seem to be a high probability that productivity improvement could be realized.

Removal of Unproductive Practices: An unproductive practice is work that does not serve to achieve the goals of the organization. This unproductive work includes any unnecessary activity or one that has a value less than its cost. Unproductive work always results in lowered productivity. There are three general sources of unproductive practices within an organization. Collective bargaining contracts and union policies represent a principal source. Federal, state, and local government laws, rules, regulations, and activities can be another. The third type of unproductive practice is those practices which a company imposes upon itself. Since, at the present time, the vast majority of engineers are not involved with union activities and dealing with the reduction of government regulations is far beyond the scope of this paper, it is probably best to address those activities and practices that an organization may allow or impose upon itself.

Self-imposed unproductive practices are usually procedures, programs, or traditions, i.e., the way the organization does business. Often these procedures are very difficult to identify, and sometimes even more difficult to eliminate. Although existing unproductive practices will vary with different organizations, some common examples are given for guidance.

One unproductive practice which often occurs but is seldom addressed is the great number of interruptions to work that are allowed. Whether the interruption is a phone call, meeting, or a discussion about a previous project, the task at hand is put aside and then resumed when the interruption is over. Although this happens with almost all functions, it can be especially harmful to the thought process often required for engineering work. This sometimes constant start-and-stop-and-restart pattern can stretch jobs out longer than necessary and often reduce the quality of performance. Douglass and Douglass[8] present a simple solution to this problem by the concept of a "quiet time". Quiet time is time set aside during which only emergency interruptions are allowed. No meetings are allowed and messages are taken to be returned later. The purpose of a quiet time is to create an uniterrupted time for important tasks.

Meetings are often a source of unproductive time. First, many meetings are held for which no real purpose exists. A good example of this may be the daily or weekly staff or section meetings. If the meeting is held simply because of tradition and no new information is addressed or no decisions are to be made, the meeting is probably not productive. It is far better to call meetings when the need exists rather than to designate certain time periods in advance. Also, if the purpose of a meeting is simply to pass on information, a memo would probably serve the purpose just as well and at far less cost. Second, in many instances there are more attendants to meetings than are necessary for the purpose of the meetings. Often people are invited or required to attend because the true reason or agenda for the meeting is not known in advance. For an engineer to sit through a meeting in which he/she contributes or receives no necessary information is certainly unproductive. Finally, most meetings that are truely required and have the proper people attending are somewhat unproductive in that no one has bothered to plan or orchestrate the meetings in an efficient manner. The agenda, all to often, is not known beforehand so that the participants can prepare. The unfortunate result is that a meeting that could have been accomplished in thirty minutes often runs for ninety minutes or more or that important items that should have been addressed are ignored.

The quest for perfection, although admirable, is often another source of unproductive work. A characteristic common to engineers is the desire to achieve technical perfection. In many instances valuable hours are spent searching for the very best of several alternatives when in fact any one of several would completely satisfy the organizational need. There are many situations in which an adequate solution is all that is required. If the cost incurred to find a better alternative solution exceeds the benefits gained from the better solution, the difference can be viewed as being unproductive to the organization.

A final example of an unproductive practice is that of isolating the engineering function from data or input sources needed for the completion of a project. It is common practice in many organizations to require the engineers to make requests for product information through a procurement function rather than from the supplier or to deal with customer problems through a marketing or sales function rather than directly with the customer. For instance, consider the engineer who is designing a conveyor system. At some stage in the design process he will probably need to know performance or size specifications of an electric motor that will drive the conveyor system. Rather than contacting various suppliers to determine what is available and making further design decisions based on the information received, he probably will be forced to submit his request to a procurement section of the organization. The individual in the procurement section who receives the request may know little or nothing about either conveyor systems or electric motors and will probably be motivated by the cost of the motor rather than the characteristics that are important to the design of the conveyor system. The procurement person, after making the buy decision based on cost, will gather the required information on the motor selected and dutifully relay this information back to the engineer. Meanwhile, the design of the conveyor system has probably been at a standstill while the engineer waits for the necessary information from Procurement. Depending upon the current workload in Procurement, this delay could be from several hours to several days, or more! Furthermore, although Procurement may have saved a small percentage on the cost of the motor, the characteristics (size, rpm, etc.) of the motor to be procured may have resulted in a design that is substantially more expensive than that which might have occured had the engineer been allowed to communicate directly with the suppliers and select the best motor for the application. I submit that this has been an extremely unproductive procedure.

Another result of isolating the engineer is that the engineer may waste productive time, either by testing and evaluating or by some method of analysis, developing data that have already been developed by a manufacturer. If the engineer had access to the source of required data, less time might be spent duplicating the work that a manufacturer has already accomplished. Additionally, there may be a new product or item that would have improved the design, but was not used because the engineer did not have access to the manufacturer or supplier.

The potential for increasing the productivity of an engineering function by eliminating unproductive practices is awesome. The probability of success with this method depends, to a large extent, on the attitude of management and the techniques used for the identification and elimination of these practices. Many unproductive practices may have a long history and may be somewhat of a tradition. The key to a high probability of success is the involvement of the engineering workforce.

Improved Management of Human Resources: The fourth area of activity which can result in increases in productivity for the engineering workforce is better management of human resources. This implies more effective utilization of engineering talent through personnel or management policies, procedures, or attitudes which are conducive to increased engineering performance. In short, this means ensuring that the best engineer available is placed in a function that is commensurate with his/her abilities and needs, and has the proper motivation to be productive.

Implementation of personnel or management policies which are designed to be compatible with an engineering workforce can have a positive effect on productivity on two levels. The primary level of potential improvement results from the purely mechanical relationship of providing the best possible resource for a given function or task. Thus, the engineer who is qualified and experienced with regard to a particular task should be more productive at that task than an engineer who has a lesser degree of qualifications or experience. The second, and far less obvious, level of potential improvement results from creating the motivation or desire within an engineer to be more productive. Even though the engineer is more locally oriented, on the average, than most other segments of the workforce and tends to derive satisfaction from contributing to the good of the organization, he/she must be able to relate personal goal attainment with the attainment of organizational goals. The engineer will make rational decisions, based on the available information, concerning his/her actions that will contribute to the attainment of personal goals. Personnel policies often send signals to the engineer which do not allow him/her to relate personal goals with those of the organization. For the purpose of productivity improvement, it is imperative that the engineer be given signals which show that the attainment of personal goals (promotion, higher salary, etc.) are directly related to the attainment of organization goals. The most obvious method of relating personal to organizational acheivement is through the use of various rewards for behavior which benefits the organization. To be effective, these rewards must fullfill valid needs of the engineer.

There are several areas within the personnel management function which have the potential to send proper signals to the engineer and thus contribute to productivity. It may be argued that some of these signals or rewards increase the engineer's satisfaction with his/her work environment rather than fullfill valid needs and therefore may do little in terms of true motivation which would lead to increased productivity. However, in view of the many employment opportunities currently available to an engineer, satisfaction with the work environment may be viewed as a need and may result in less turn-over of engineers. The necessity for replacement of a productive engineer who has decided to exercise one of these alternative opportunities (quit) will surely have an adverse effect on the organization's productivity.

The following sections list those areas which seem to have potential for responding to the needs of engineers, for providing the best human resource for a given task, or both. Each has the potential for increasing productivity.

(1) Recruitment and Selection: Probably no other area affects the productivity of engineers as much as the proper recruitment and selection of personnel. Position specifications should be carefully developed so that the recruiter or interviewer has a good picture of the qualifications really needed. In addition, information about the job should be communicated as accurately as possible so that the candidate himself/herself can do a more effective job of selection. Jobs that are oversold or glamourized often lead to later disillusionment and either to resignation or undesirable defensive behavior, neither of which can be considered productive.

Another important factor as far as productivity is concerned is the consideration of near-term and strategic or long-term recruiting effectiveness. Those brought into an organization are usually brought in to fill a specific job. The ability of the candidate to fill that job is of near-term critical importance. Typically, the employment and recruiting process is designed solely to make sure that a properly qualified engineer is recruited to fill a particular job. Experience requirements, knowledge requirements, and selection process all tend to be geared to evaluating the candidate's suitability for the immediate job opening. However, engineering requirements for a company are subject to change, either because of project completions, market shift, or advancement. When any of these happen, the engineer may be required to fill another position. Typical recruiting processes do not take this important factor into consideration. Selection procedures and selection criteria should evaluate the long-term needs of the organization and the likely positions or types of work that will be required of the engineer in the future. There should therefore, be a balance of criteria in the selection process for evaluating the candidate against the near-term needs of the job and in the more strategic long-term criteria as well. Employment decisions then consider the potential productivity of candidates over their entire estimated work life in the organization. The degree to which the organization is building its engineering assets to meet not only its near-term needs, but also its long-term needs obviously has an effect over a long period of time on the level of work effectiveness.

In addition to ensuring that the long-term engineering requirements of an organization are fullfilled, a well planned recruitment and selection program also serves to provide for the needs of the engineers it is acquiring. If an engineer knows that the organization's need for his/her qualifications will end at the end of a particular project, there is little or no incentive to expend more than minimal effort to ensure that the project is completed with the necessary quality or within the necessary time frame. In fact, it would be in the best interests of the engineer to keep the project going as long as possible! Just as detrimental is the situation where the engineer is hired based on a special set of qualifications but after perhaps one year finds himself/herself working on a project in which he/she is not interested or has insufficient qualifications.

Unless an organization is currently unusually diligent with respect to long-term planning of engineering requirements, there is a high probability that such planning could significantly improve the long-term productivity of its engineering function.

(2) Utilization: Another area that is closely related to the selection process is that of utilization. Although better utilization is inherent in almost all productivity improvement methods or techniques, the idea is so important that a separate discussion is probably worthwhile.

The most productive engineer is one who is working in his/her area of specialty. Although the economics of the situation preclude this from being totally possible, there is evidence that better scheduling of engineering resources would allow a better matching of abilities and requirements. Studies[9] have shown that engineers often feel that they are working out of their specialties far too often. If an engineer is performing a task that could be accomplished more efficiently by another engineer, or more cheaply by a lower paid employee, such as an engineering technician or clerk, it would seem rational to believe that the potential for an increase in productivity exists.

The opposite situation can also be detrimental to the productivity of an organization. If, for example, an unqualified person is tasked with a function that could be better performed by an engineer, productivity can suffer. The attempted isolation of the engineering function cited above seems to illustrate this point well. Requiring a procurement person to make a decision for equipment which will affect the design of a conveyor system can cost far more than the savings accrued from not using the engineer.

A far less obvious result of poor utilization of the engineering workforce is the effect it has on the motivation and attitude of the individual engineer. There are three situations that can have a negative effect on the engineer's motivation and desire to be productive. The first situation is when an engineer is given a task or project that is obviously far below his/her level of ability or competence; an example of this might be routine clerical duties. The engineer has spent a good deal of time, effort, and money acquiring engineering skills. If he/she is denied the opportunity to use those skills, there may be self-doubt as to the value placed on his/her service to the organization. The engineer may feel that the organization is questioning his or her competence as an engineer. The result is that the engineer's motivation to further the goals of the organization is severely reduced. A second situation is that which arises when an engineer is given an assignment that is outside or above the level of his/her competence. In this instance the engineer is made to feel incompetent. Since the need for technical competence is strong in an engineer, he/she will surely become very frustrated. This frustration can also lead to lowered motivation and a reluctance to accept challenges with future projects. The third situation which can have a negative effect on an engineer's motivation is when the discretion needed to complete a project is not allowed. Again, the example of Procurement making decisions for the engineer is given. The reputation of an engineer is often based on the quality of his/her output. If the engineer is not allowed to control that quality, the relationship between achievement and rewards is lost. The engineer will then look to other areas of recognition that can be controlled, such as punctuality. The effect is a lowering of desire to be productive in the primary areas of work.

Better selection of engineers and scheduling are two methods of improving utilization. Another, perhaps less obvious, method is that of modifying the design of the organization. The matrix organization is a hybrid organization in which individuals from various functions are grouped together to form project teams. Although the original functions remain intact, individuals are assigned to a team for the purpose of completing a particular project. This type of interfunctional grouping can be very effective for the completion of an unusually large or complex project. It has the advantage of reducing the communication barriers that may exist between functions and, in effect, pools individuals from various functions. Since several technical specialties are working for one project manager, better control of these resources is possible and utilization of personnel can increase. One disadvantage of the matrix organization is that each team member is usually responsible to both the project manager and to his/her functional manager.

Better utilization of engineering personnel is basic to any productivity improvement program in this function. Techniques may be as simple as devising better scheduling or as complex as development of new organizational structures. Whatever technique or techniques are employed, if engineers can be better utilized, productivity will increase.

(3) Salaries: No area attracts more attention or arouses more emotions than the matter of salary administration. Not only the absolute level of an engineer's salary, but its relation to salaries paid to other engineers, both within and outside the company, can have a profound effect on performance. Although most engineers earn a respectable salary, monetary rewards have come to be regarded as a symbol of status and progress within the company as well as recognition of individual performance. There are few rewards quite so meaningful as an increase in salary. One

of the characteristics of an engineer cited above was that engineers tend to have a high inner drive toward achievement. The salary of an engineer is probably the most obvious and convenient method of measuring his/her progress within an organization. Even if salaries are treated as confidential information, they are usually common knowledge among the engineers. If one engineer is receiving a higher salary than a second engineer, added prestige and power are only possible if the second engineer is aware of the difference. Promotions in title or responsibility are almost meaningless without an associated increase in salary.

One problem which has grown in recent years in that of salary spread, or lack of it, within the engineering work-force. The shortage of qualified engineers, along with inflation, has caused the escalation of beginning engineers' salaries much faster than the salaries of established engineers have grown. Although the rate of increase for a new engineer's salary fluctuates with both the supply and demand present at the time and with inflation, there is a clear trend toward narrowing the gap between a new engineer's salary and that of an engineer who has been employed by an organization for some time. To compound this problem, salary increases for experienced engineers have been all but cancelled, in real buying power, by recent inflation effects. The result is that an experienced engineer who has been employed by an organization for a number of years, and is quite satisfied with his/her periodic salary increases, discovers that the new engineer recently hired is earning a salary that is just below his/her own. He/she may reflect that his/her progress, up to now, has seemed to be excellent. All feedback he/she has received, either from appraisals or other means, has indicated complete satisfaction with his/her work by the organization. However, if the organization has placed a value (salary) on his/her services that is virtually the same as for a new engineer, something must be amiss! His/her prestige and perceived power with respect to both the organization and the new engineer is immediately diminished, as is the desire and motivation for performance. At this point, the engineer may, as a defensive measure, attempt to shift his/her salary reference point to another organization. He/she will most assuredly be able to find at least one organization that employs a salary structure that is higher, or at least perceived to be higher, than his/her own organization. That will become the new reference point and the engineer in question will probably remain quite dissatisfied until his/her salary is appropriately adjusted, or until the option of changing jobs is taken. No matter what happens, the productivity of the organization will suffer. The competitive position in which organizations find themselves when trying to procure new engineers simply does not allow a reduction in salary increases offered. Therefore, at some point management must make the decision to substantially raise established engineers' salaries, or risk extreme dissatisfaction from this group.

In order for salary to have a positive effect on productivity, the relative level must be related to contributions or performance. This poses two problems. The first is the necessity of maintaining sufficient flexibility in the salary structure to permit the salary to fit the individual and yet enable management to retain control of salary expenses. The second is the problem of determining the value of the individual's contribution and satisfying him/her that the evaluation is a fair one. Many companies have attempted to deal with the first problem by the use of formal salary structures for engineers. The typical structure includes a number of classifications which are really levels of professional work. Each classification has, in turn, a number of salary or merit ranges which provide for individual ranges. This system has the advantage of a formalized structure which allows a fair amount of control by management while still allowing an engineer to see progress based on individual effort. Within the system, the engineer can progress from one classification to the next as his level of competence and responsibility increases, and also within the classification by recognition of time (maturity) or merit.

The second problem of determining the value of an individual's contribution and satisfying him/her that the evaluation is fair is essentially one of developing an appraisal system. There is an increasing effort to tie salary increases to these appraisals or performance evaluations. Although this is probably the most effective means, with respect to productivity, of administration of salaries, the concept of performance appraisals is one which merits discussion separately and will be addressed in the following section.

Contrary to the beliefs of many contemporary individuals,[10] salary administration probably has as much effect on the motivation of the engineer, and therefore on productivity, as any other concept. The potential for productivity improvement from more effective salary administration would be indicated if an organization is experiencing high turnover rates for engineering personnel.

(4) Appraisals: Another area that has potential for influencing productivity is the use, or misuse, of an appraisal. Most organizations use some form of appraisal system for engineers. Unfortunately, most appraisal systems in use are not especially conducive to the improvement of productivity. The most common system used is for the immediate supervisor to rate the employee which usually results in an overall point score. This is reviewed by the next higher level of management. The supervisor is then supposed to review it with the employee. An alternate version of this is for both the immediate supervisor and the employee to rate the employee's performance and then compare and discuss the results.

An appraisal should perform two functions. First, it should define what is expected of the engineer, and second, it should provide a measurement of how well the engineer is accomplishing these expected requirements. The engineer receiving the appraisal expects two questions to be answered. First, "How well am I doing?", and second, "What are my chances for promotion or a merit increase?" All too often the appraisal accomplishes neither its intended functions nor answers the engineer's questions.

An inherent factor in ensuring that an appraisal system contributes to productivity increase is that of feedback. Studies suggest that for performance feedback to be effective, it must help the individual to understand his or her progress in moving toward clearly defined goals.[11] Many appraisal systems tend to inhibit the process of proper feedback.

Some appraisal systems simply do not allow sufficient feedback. There is usually very little effort made by upper management to ensure that the appraisal is throughly discussed with the engineer. A direct face-to-face discussion between the engineer and the supervisor is absolutely essential to ensure that the engineer understands the reasons for the ratings. If these reasons are not understood, performance simply will not improve. In fact, a decrease in productivity is almost certain if the engineer, because of lack of understanding, feels that the appraisal was unfair.

Another difficulty with the feedback process occurs when the appraisal is designed such that a large percentage, if not all, of the rating is developed from personal attributes such as attitude or punctuality rather than from actual performance factors. This is often the case when one set of appraisal criteria is used for the entire organization. Since these non-performance criteria are the areas that the individual is rated on, he/she assumes that they are the most important aspects of his/her job, and tries to improve on them rather than on performance, which should be the real concern. Thus, an engineer may become very punctual, which will improve the rating, but probably will not become more productive. If feedback consists of the wrong data, productivity improvement should not be expected.

There is a tendency for many appraisal systems to concentrate on negative feedback rather than on positive factors. This aspect encompasses far more than simply the verbal reinforcement at the time the appraisal is discussed. Positive feedback results from a sense of accomplishment that a person feels when predetermined goals are reached. Most appraisals tend to reflect the areas where an individual has failed to meet general standards or where improvement is needed. This is negative feedback. In these cases, defined goals have not been predetermined. If, on the other hand, an individual is able to measure progress with respect to predetermined goals at the time of an appraisal, positive feedback results. This would indicate that an integral part of a successful appraisal system must be the defining of these goals. The best time to set these goals would seem to be at the time of the previous appraisal. Furthermore, if the engineer concerned can be involved in the process of setting these goals, a form of personal contract results between the engineer and the supervisor. Since the engineer has agreed to the goals, he/she is certainly aware of the areas where improvement or accomplishment is needed. This, in turn, makes the job of the supervisor much easier at the time of the appraisal review. The appraisal review becomes simply a discussion of the progress made with respect to the goals that both the supervisor and the engineer had previously agreed to and the mutual development of new goals for the next period. Studies seem to indicate that difficult but attainable goals are more effective than simple goals of "do your best".[12]

Finally, the one most important factor needed to make an appraisal system effective for increasing productivity is the proper relationship between appraisal results and organizational rewards. If the appropriate rewards, such as salary increases, promotions, etc., do not go to those individuals with the better appraisal ratings, the appraisal system will have little or no effect on productivity. A good rating on an appraisal, by itself, is usually not sufficient to warrant the effort needed to increase productivity. The validity of the appraisal can only be maintained by a direct and visable relationship with appropriate rewards.

A well designed and executed appraisal system, if coupled with appropriate rewards, would appear to have the potential for increasing engineering productivity. This is one method of matching the goals of an engineer with the goals of the organization. It would seem reasonable to believe that the probability of increased productivity resulting from appraisals would increase as the relationship between appraisal ratings and rewards becomes more direct and visable.

(5) Promotion: Promotion is one of the most tangible means with which an organization can provide recognition and incentive to an engineer. Although incentive and recognition do not necessarily result in improved productivity, the lack of these will certainly reduce an engineer's desire to perform at his/her upper limit, and may be cause of an unusually high turnover rate. The engineer, in turn, is seeking promotion. Not only is promotion seen as recognition of achievement, which is important to the engineer, but a promotion is virtually always accompanied by an increase in salary.

Promotion from an engineering workforce can present special problems in that promotion usually includes an increased amount of administrative work at each higher level. Some engineers, by reason of ability, are simply not logical candidates for increased administrative responsibility. Others do not desire to move away from the technical aspect of the job. In either case, promotion through normal lines of advancement is eliminated as a device for recognition and incentive if the best interests of the organization and of the engineer are served by leaving him/her in a technical position. Indeed, promotion into an administrative position may gain the organization a poor administrator at the expense of losing an outstanding engineer. An outstanding engineer does not necessarily make an outstanding, or even good, administrator.

From the engineer's point of view, frustration may result from the fact that, as an administrator, he/she may have to deal with situations and problems for which he/she has not been trained. In addition, increasing involvement in administrative duties will probably leave the engineer little time for updating professional knowledge. Combined with the fast pace of changes in many engineering fields, this may accelerate the process of professional obsolescence by which the engineer loses his/her vitality as a professional.

In order to reduce the negative impact of engineers' aspirations and inappropriate promotion decisions, some organizations have established a parallel promotion system. In the parallel system, a new and distinctive line of promotion is established, consisting of a progression of engineering positions without the addition of administrative duties. In setting up this system, positions and titles are created to correspond to the administrative levels of the organization, and the pay and prestige of the new positions are equated to those of the corresponding administrative positions. Typically, this dual system includes higher non-administrative positions for three or four steps, extending from a position equal to an administrative position one level above the engineering workforce to a position equal to or just below the level of department manager.

The dual promotion system has the potential of offering a solution to the problem of providing the recognition and incentive of promotion to an engineer without sacrificing the individual's technical abilities by burdening him/her with administrative duties, however, it does have some shortcomings. First, these dual positions are not always on the same salary level as corresponding administrative positions, and second, and probably more important, they are often not perceived to carry the same prestige as an "equal" administrative position. One method of dealing with the latter problem is for the company to give as much publicity as is practical to the parallel system, both to potential candidates for these positions, and to the workforce in general.

There is no easy solution to the problems that promotion from an engineering workforce creates. To provide the incentive and recognition that is required to procure and maintain a viable engineering workforce, a visable potential for advancement must be present. The use of a parallel promotion system would seem to have the potential for providing at least a partial solution, and therefore have a positive impact on productivity, if the organizational structure will allow the new parallel positions to be real advancements with appropriate increases in both salary and responsibility that are implied by the term promotion.

(6) Supervision: An area which is closely related to that of promotion is supervision. Except for recruitment and selection, probably no other area affects the productivity

of an engineering workforce as much as the quality of supervision. The major problem in this area is the determination as to what personal qualities enable a person to provide the kind of supervision best suited to engineers. There is one faction which believes that recognized technical ability is the only important quality; at the other extreme is the belief that anyone with manageral ability can supervise engineers. Of course, the obvious choice would be a person with both abilities. Unfortunately, this is seldom realized. Part of the problem is that there is seldom an attempt to impart managerial skills to an engineer. In order to provide knowledgeable and effective management for an engineering function, engineers with administrative potential must be identified and developed for the role. Assigning an unknowledgeable person to supervise an engineering function does a disservice to the function. Assigning an engineer without management skills does a disservice to everyone, especially the new supervisor!

In reality, the technical interaction that is required between the engineering workforce and the supervisor leads to the rational conclusion that the supervisor should probably be someone with engineering experience. Almost all organizations recognize this requirement and as a result, virtually all engineering supervisors are drawn from the engineering workforce. The principle consideration for an engineer to enter into a supervisory role almost always is his/her "success and standing as an engineer". In many cases engineers demand that they be supervised by an outstanding engineer. One problem stems from the fact that neither the engineer or those who are responsible for guiding the engineer into a management position understand the difficulties of the transition. As a result, an engineer who has been promoted to supervisor is often left to flounder in a new environment for which there has been little or no preparation. The ineffective supervision that results can have a disasterous effect on the productivity of the engineering function.

If the difficulties, and the reasons for them, that an engineer encounters when making the transition for engineering to supervision are understood, perhaps the organization can better choose and prepare the individual for the role.

The transition from engineer to supervisor usually occurs at a time when an individual has achieved an outstanding reputation as an engineer and has every indication that success will continue. He/she is now entering a new profession where the chances of success have completely different probabilities. He/she was at the top of his/her engineering profession, but now will be at the bottom of the management profession. The new supervisor rightfully feels insecure and fearful of making wrong decisions.

The engineer, as a new supervisor, must now view problems and make decisions from an organizational viewpoint, and not from that of a professional engineer. This is especially difficult for the engineer who has practiced several years and/or is not prepared for this change.

The engineer, who is now a supervisor, may fear that he/she will lose the direct control he/she formerly had over his/her work. As an engineer, he/she probably worked by himself/herself and achievements were directly the result of individual effort, but now achievements must be the result of the work of subordinates. The new supervisor is at the mercy of these subordinates and their inefficiencies and may therefore attempt to protect himself/herself by endeavoring to gain expertise in each subordinate's specialty. Since this is impossible, he/she may try to become directly involved in all projects. As a result of this effort, the new supervisor is probably uncomfortable, gets in the way of subordinates, and finds that the day is simply not long enough.

The new supervisor finds that he/she must devote a great deal of time to activities that were previously ranked low in importance or value. Most engineers view a typical supervisor as a bureaucrat and paper shuffler who is an obstacle in the way of engineers trying to do their work. This situation can, and often does, occur when the new supervisor is not adequately prepared and trained for management responsibilities. Rather than admit defeat, he/she immediately develops work habits designed to protect the position. He/she becomes a bureaucrat enmeshed in paper-work, so busy that it is impossible for him/her to be removed from the position, or so he/she thinks!

An engineer is trained and experienced in making decisions based on theories and laws governing the behavior of the physical world. In the new role, as a supervisor, he/she must deal with intangibles, with rules and regulations made by people, and with the vagaries of human nature. Certainty has been replaced with uncertainty. There is little wonder that the unprepared individual is confused, often unhappy, and usually ineffective.

In addition, there are seemingly endless administrative problems and questions that appear daily such as how to discipline, how to requisition supplies, how to get a raise for a subordinate, etc. Organizational politics and mounds of paperwork of questional value also appear as obstacles to success.

As seen from the above paragraphs, the successful transition from engineer to supervisor seems doubtful, at best, if the organization does not provide adequate preparation for an individual. It is acknowledged that a change in supervisors for the engineering function does not usually occur frequently. However, if a change occurs and the organization has not prepared by providing orientation and training in management skills for the successor, a profound negative effect on the productivity of the engineering function will surely be experienced.

(7) Professional Development: There are many reasons why an organization should be interested in the continued

professional development of its engineers. In the first place, technology is increasing so rapidly that the knowledge and skills of an engineer can easily become obsolete without frequent updating. Second, the rapid increase in the number of sub-specialties and the trend toward specialization require people who can establish effective liason among specialties. This is especially important for those engineers who will someday move into management. Third, a four-year engineering program simply cannot provide an individual with the breadth and depth required for most engineering positions in the organization. The engineer's formal training and background do not usually match the diverse needs of a particular department. In general, professional development programs increase an individual's capability to do productive work. They also represent a way of providing incentives.

Some developmental need can be met by careful and selective job rotation. Often a new engineer is put into a training program and transfered through several departments for up to a year, or more. This can not only broaden the engineer's knowledge but can give him/her the opportunity to assess more carefully his/her interest and aspirations for a career.

Another method of providing for professional development of engineers is to offer some type of plan where an engineer can further his/her formal education. Typical of such a plan is one which pays for part or all of the costs. This may include tuition, books and supplies, and commuting costs.

These plans usually require that the individual take courses on his/her own time and that the courses are in some way related to his/her work. It should be noted, however, that non-technical courses may also serve to further the engineer's professional development, and his/her value to the orgainza-tion. Communication, public speaking, planning, and other management related subjects can be beneficial to both the engineer and the organization, especially if the engineer is deemed to have the potential to move into management at some future time. Leaves of absence are sometimes granted to allow an individual to fulfill a university's residence requirements. Advanced seminars, subscriptions to journals, and maintenance of a good technical library are other ways in which the continual development of an engineer can be facilitated.

Yet another means of professional development for an engineer is through association with professional societies. Active participation in these orgainzations is useful from not only the standpoint of individual development, but also from the standpoint of professional status, and increased interest in work. These society meetings can help the engineer keep abreast of new developments which can, at least indirectly, contribute to an increase in productivity. In addition to the crossfeed of information that professional societies can provide, they can often help fulfill some of the social or group needs of the engineer. Social interaction with others of similar background and with similar problems seems basic to human nature. Blue collar workers fill some of this need through association with unions. Professional societies can provide the engineer with the social gratification of interacting with others who understand the technical jargan and share common interests of the profession. The primary means of encouraging participation in professional societies are the reimbursement of membership dues and allowing employees to attend meetings and other functions on company time.

Professional development of the engineering workforce serves to increase the capability and the inclination of the engineer to be more productive. In addition, a well planned professional development program helps to provide a professional atmosphere in which to work, which in turn should help to reduce the turnover of engineering personnel. Productivity increases resulting from this approach will be long-term and gradual, but, due to the residual effect, should be cumulative over time.

TWO IMPORTANT CONCEPTS

At this point, the reader may expect that the procedure for implementing productivity improvement actions should be forthcoming. Unfortunately, the nature of an engineering function precludes a simple, predefined course of action. As mentioned above, one of the major difficulties encountered when addressing the subject of engineering productivity is the lack of consistency from one organization to another.

Perhaps even more discouraging is the fact that the engineering function within an organization may also be inconsistant over time. This somewhat dynamic situation is, at least partially, responsible for the problems encountered in trying to measure the productivity of this function. The reasons for the differences between organizations are essentially the same as those for the change within an organization. The existance of an engineering workforce is based on the need to investigate and determine solutions for problems, usually technical in nature, that develop within an organization. These problems differ from one organization to another due to differences in organizational purpose and require that the engineering function of a particular organization be structured and staffed to meet a particular set of needs. Within an organization, as one problem/solution set, or project, is completed, another is started. Furthermore, as the financial picture, product line, available technology, or a host of other environmental factors change, so may the problems addressed by the engineering function. This can result in changes in the structure and staffing of the engineering function that is not unlike, when viewed over time, the differences between organizations.

The differences between organizations, and within one particular organization over time, constitute another set of variables which simply do not allow one course of action or productivity improvement strategy to be predefined which would apply to more than one engineering function in one particular time frame. This somewhat unique nature of each engineering function requires that a unique productivity improvement strategy (course of actions) be developed for each function. However, there are two basic concepts which can guide and should be used in the development of such strategy. These concepts are participation and contingency theory. The importance of each warrants discussion.

Participation: A participative approach to productivity improvement for an engineering function can significantly increase the probability of success for an organization. A participative approach is one which allows individuals to contribute ideas toward the solution of problems affecting their organization and their jobs.

Productivity improvement occurs as the result of a change process. For a change process to occur, a modification of tasks or thought processess must take place. If individuals are allowed to participate in the formulation and implementation of these changes, there will be greater acceptance than if the changes are imposed.[13] This is especially true for engineers who normally enjoy a great deal of independence with respect to their work. The quality of decisions made with respect to productivity improvement will probably be better if these decisions are developed through participation.[14] An engineer is usually well educated and is accustomed to working in a creative atmosphere. Participation can bring together or tap this reservoir of knowledge, experience, skills, and creativity and may identify areas for improvement which would not be obvious to management. Participation can also help align the engineers' goals with those of the organization. If the engineer is involved in the formulation and implementation of changes, he/she is more likely to be committed to their success. Thus, the engineer's goal is to achieve the organization's goals and the probability of success is significantly enhanced. Finally, participative processes leave those who are involved with an awareness and knowledge of the situation, an indication of what may occur, and a readiness for change.

There are many participative processes ranging from surveys to informal discussions to structured group processes and committees. The scope of this paper does not allow the development of the various approaches, however, current literature abounds with this information which the reader can, if necessary, easily acquire. The participative method(s) to be used must depend on the size, complexity, and resources of the organization. A word of caution is probably required at this point. For participation to be effective, the goal must not be simply to convince individuals that they are participating in the decision process. It must be more than just an effort to obtain approval of decisions already made by management. Management must acknowledge and accept the risk associated with increased influence and control by employees. The basic reasoning underlying any participative approach is that individuals have a need for recognition. The objective is to develop feelings of a common commitment to organizational goals and to promote constructive cooperation.

Contingency Theory: Although the uniqueness of each engineering function precludes the development of a fixed strategy of techniques or methods to be used for productivity improvement, the concept of contingency, or situation theory, may provide a means for solving this apparent dilemma.

Contingency theory acknowledges the unique and dynamic nature of organizations. Furthermore, it asserts that there is no one specific method or style of intervention that will be successful in every situation, but that success will depend upon the matching of management style, the situation of the organization, and the characteristics of the members of the organization at a given time. Ivancevich, Szilagyi and Wallace[15] describe the contingency approach to organizational change and development as follows:

> "Therefore, the domain of change and development is filled with contingencies that need to be considered. To cope with the endless stream of contingencies, we suggest that managers think of organizational change and development as a continual series of stages. Two of the common threads needed to face this steady set of change forces are an ability to diagnose the environment, the individuals, the groups, and the total organization and an openness to make modifications in plans when the diagnosis suggests that they are needed..."

Carlisle[16] describes four steps or parts that constitute a methodology for utilizing contingency theory. The first three are not necessarily sequential but serve as prerequisites to the fourth:

"(1) A manager must know of or be familiar with the various concepts and techniques of management that are available...

(2) The manager must be knowledgable of the tradeoffs involved when he selects any particular concept or technique for application...

(3) The manager must know the situation to which he is applying the technique.

(4) The manager must not only know the techniques, and the particular *situation* before him but also skillfully match the tradeoffs of the techniques with the needs and demands of the situation..."

In simple terms, contingency theory suggests one should assess the situation, determine the desired changes, look at available alternatives, determine tradeoffs or interrelationships, and <u>use what best fits the situation</u>. This is precisely the strategy which is being suggested as a course of action for effecting improvement of engineering productivity. The value of contingency theory is that it provides the theoretical framework to assist the organization in this process.

Initially, the reader may feel that the embracing of contingency theory does little more than allow graceful admission of a lack of knowledge required to define a course of action for the organization. However, one must realize that the subject matter at hand is, by its very nature, filled with uncertainties. A predefined course of action will not reduce those uncertainties, it will simply reduce the probability of a successful change process. The concept of contingency theory does not represent a lack of knowledge, but rather allows the insight that permits the organization to utilize the available resources and to exercise discretion as to the appropriateness of a technique or method to the situation.

DEVELOPING A PRODUCTIVITY IMPROVEMENT SCHEME

The above sections of this text have attempted to present an argument for increased engineering productivity, to explore some of the variables that can influence the outcome of a productivity intervention, to survey various methods or techniques that appear to have potential for improving the productivity of an engineering function, and to review two concepts that appear to be basic to the development of a productivity improvement program for this function. I believe that these are essential prerequisites for any rational attempt to increase productivity. Management must truely believe that there is a valid need and a reasonable potential for the improvement of engineering productivity. For this improvement to be realized, a change process must occur within the function. As Morris[17] points out:

> "Top-management legitimization, sanctioning, support, and continuing involvement are critical to the success of a change process."

This is simply not possible if management does not believe in the cause. The characteristics of the work group form a portion of the variables that affect the outcome of intervention attempts and must be understood if one wishes to increase the probability of successful change. These variables help define the cause-effect relationship between an intervention action taken and the resulting change that occurs. The better the cause-effect relationship is understood, the less uncertainty or risk one experiences with each action. The various methods to techniques surveyed serve to provide possible alternatives for the organization wishing to effect a productivity increase within an engineering function. As with most any problem set, the alternatives must constitute the basis for the best final solution. The more complete the alternative set, the higher the probability that the optimum solution will be found. Finally, the concepts of participation and contingency theory provide a means of increasing the probability of successful intervention and a theoretical framework for the intervention process, respectively.

Although the specific methods or techniques to be applied must depend upon the situation at hand, one can rationally forsee a sequence of actions or events that must be accomplished to effect the desired goal of increased productivity. It may be helpful to consider the need for productivity improvement as a problem in need of a solution. This problem-solution context is more familiar for individuals to work with and is especially helpful when the participation approach is used. The following are given as general steps or stages needed to effect productivity improvement.

(1) Determine need: Both management and the engineers must be convinced that a valid need for productivity improvement exists, and that this need is greater than the effort that will be required to effect a change.

(2) Determine area(s) of need: This stage may be accomplished in conjunction with the previous stage. A recognized deficiency was probably the initial reason that productivity improvement was made an issue. To simply state that productivity improvement is needed is like telling the doctor that one is sick. Before diagnoses can be made or corrective action planned, more specific data must be identified. For instance, is there an increasing backlog of engineering work, is there a problem with the quality of output, or is the cost of operating the engineering function too great for the organization to tolerate? Once the areas of need are identified, they should be ranked in order of importance to the organization. Each area should be treated as a separate problem, recognizing that interdependencies between problems exist.

(3) Determine root problem(s): Once the areas of need have been determined, one should examine those areas and attempt to discover the root cause of the problem. For example, if output quality has been identified as an area of need, is the poor quality caused by incapable engineers, by poor supervision, by the use of outdated methods or poor equipment, or by a combination?

(4) Identify alternative intervention actions: If the root problem(s) are known, the number of alternatives that must be considered is considerably reduced. Nevertheless, there may be several alternative actions that have the potential for improving the situation. For example, if incapable engineers have been determined to be the cause of poor quality output, several alternatives may be available to the organization. Professional development in the form of short courses or seminars may be one option. Computerizing certain computational aspects of the job and thereby reducing the manual computation requirement may be another. Scheduling changes (better utilization) can help ensure that the more capable engineers are assigned the more demanding tasks. Better recruitment and selection of engineers may provide a long-term solution to the problem.

(5) Assess the situation: At this point the overall situation of both the organization and the engineering function must be evaluated. What time frame is available for a solution? What is the financial situation of the organization, is capital funding available? How detrimental is

the current problem area to the success or survival of the organization? What is the historical background of the current problem? In short, what are the variables that affect the current problem, and what are the parameters that the solution must recognize?

(6) Evaluate each alternative: Each alternative must be evaluated with respect to the current situation, to its potential for solving the problem, and to the interrelationships of effects if used in conjunction with other alternatives. In addition, the effects on other departments within the organization must be considered. If an action resolves a problem in Engineering, but creates one in Marketing or Production, the trade-offs must be assessed. This is the most crucial aspect of the whole process. The skill, experience, and foresight of the decisionmaker(s) at this stage will determine whether or not the resulting intervention is successful.

(7) Pick the best alternative(s): Once each alternative and each combination of alternatives have been assessed, the best should be chosen. The situation prevailing at that time will determine which alternative(s) constitute the best decision for the organization.

(8) Monitor results and feedback: Once the chosen alternatives have been implemented, the problem situation must be monitored to ensure that the intervention actions taken have had the desired effects. If the results are not favorable, modification or fine-tuning may be required.

CONCLUSION

There seems to be great opportunity for increasing productivity within the engineering function. The highly technical and creative nature of the function, while making quantitative measurement of output extremely difficult, if not impossible, need not preclude indentification and correction of low productivity aspects of the function. A greater understanding of the total situation and a greater adaptation of existing techniques, methods, and procedures will be required for successful intervention, however, the benefits that an organization can accrue would seem to justify the added effort. There are few functions that are as basic to the survival of an organization operating in a competitive environment as that of engineering.

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