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A Methodology for Detection of Systems Barriers To Engineering Productivity

ABSTRACT

Despite decades of research on the organization of scientists and engineers, no systematic measurement systems have been developed to guide productivity improvement. This paper presents a recently developed diagnostic tool for detecting systems barriers which suppress productivity of scientists and engineers. The methodology combines insights from classical work design with survey research techniques. The approach shifts the focus from measuring output of professionals to measuring the activities in which scientists and engineers engage and the work systems which support, motivate, and direct their activities. One application to a large design engineering unit (100 engineers) is presented. The results reveal a potential savings of $100,000,000/year (mainly in reduced warranty and manufacturing costs) by eliminating systems barriers to allow engineers to design products right the first time. The survey approach and its underlying model of workplace design appear to provide a powerful tool for productivity improvement of knowledge workers.

INTRODUCTION

Despite decades of research on the organization of scientists and engineers, no systematic measurement systems have been developed to guide productivity improvement (Schainblatt, 1982; Edwards and McCarrey, 1973). Organizational theorists have identified many socio-environmental factors that appear to foster creativity and motivation in an R&D setting (Pelz and Andrews, 1976; Ebadi and Utterback, 1984), but have not developed systematic methodologies for evaluating and improving the productivity of scientists and engineers. Economists have developed methods for evaluating the economic costs and benefits of entire research units which are useful for R&D investment decisions (Mansfield, 1981; Sandretto, 1968; Fusfeld, 1982) but these methods provide little guidance on how to change the internal workings of the unit to improve productivity--the unit remains a black box. Industrial engineers have developed systematic methodologies for measuring and improving productivity for repetitive, manual operations (Karger and Hancock, 1982) but have not successfully extended these approaches to scientists and engineers. Nor have practitioners in companies been successful in developing productivity indices for engineers and scientists (Schainblatt, 1982).

Of these disciplines only industrial engineering has a primary focus on development of productivity improvement methodologies. However, classical work measurement techniques cannot be directly applied to professional/technical workers for two reasons:

First, classical work measurement focuses on manual work in which the sequence of activities that comprise a job can be scientifically specified and are repeated over time. This allows the industrial engineer to determine how long an operation should take (i.e., performance standards) and hence plan the work (e.g., lay out workstations and balance lines); however, much of the work of scientists and engineers is neither repetitive nor manual. One might specify the optimum procedure for operating a CAD workstation, but the process of entering a design into a computer is not the primary function of a highly educated engineer or scientist.

Second, classical work measurement controls the system by comparing measured output to the performance standards. Deviations from the standard signal a problem in the system which must be corrected to achieve the known potential of the system. However, output of scientists and engineers is difficult to measure (Edwards and McCarrey, 1973; Schainblatt, 1982). It is possible to count words in written documents or dimensions specified in blueprints, but more qualitative performance measures such as quality of designs or creativity of output are often more important to organizations employing scientists and engineers. Moreover, there is generally a time lag of several years between the time something is designed and the time its success as a product is known. For example, some auto companies do not know whether a design is first rate until the car has been manufactured and used by consumers.

This suggests that a different approach and perhaps a different philosophy of work measurement must be developed for professional/technical productivity. This paper presents a recently developed diagnostic tool for detecting systems barriers (defined below) which suppress professional/technical productivity. The methodology combines insights from classical work design with survey research techniques. The approach shifts the focus from measuring output of professionals to measuring the activities in which scientists and engineers engage and the work systems which support, motivate, and direct their activities.

The paper proceeds as follows: First, the measurement of output is distinguished from the measurement of work systems which support the work activities of scientists/engineers.[1] Second, a workplace design model is presented which provides criteria for assessing work systems. Third, we describe a survey-guided methodology to diagnose systems barriers to productivity. Fourth, several applications of this methodology are described, including its application to a design engineering group of a major automotive manufacturer. We conclude with some general observations on the uses and limitations of the methodology.

A WORK SYSTEMS VIEW OF PRODUCTIVITY

By work systems we mean the managerial, organizational, and technical systems which structure, support, coordinate, motivate, and direct the work activities of engineers. Work is structured through task assignments and the division of labor. Work is supported, through tools financial resources, training, and support personnel. Work is coordinated through time schedules and direction from a project leader. Work is directed through goals and feedback on deviations from goals. Work is motivated by intrinsic rewards from doing the work and extrinsic reward systems such as salaries and promotions (Cammann and Nadler, 1976). The term system is used to denote the interrelationships between these dimensions. For example, organizational goals which state that first-time-right engineering design is a priority are empty unless sufficient time, training, support personnel, tools, and financial resources are allocated to enable engineers to design a part right the first time.

Much research on engineering productivity begins with the assumption that it is necessary, or desirable, to precisely quantify the output of individual engineers. While performance measures might aid in planning and controlling the activities of engineers, knowing that engineering performance has remained level or perhaps dropped off is of limited utility for the following reasons: First, one does not know why performance has dropped off; the task of trouble shooting the source of the problem still remains. Second, one does not know how these performance levels relate to the potential productivity of the engineers.

Consider the hypothetical example in Figure 1. Assume a company has perfected a productivity index for design engineers. In this example, management notes that the productivity of their design engineering group has dropped between time 1 and time 2. After conferring with a management consultant, they decide that their engineers would be more productive if a management-by-objective system was established. This is done between time 2 and time 3, and by time 3 productivity has improved so it is higher than it was at time 1. Unfortunately, productivity at all three time points is much lower than the true potential of the engineers.

Why might engineering productivity be so low relative to potential? A number of studies suggest the problem is not one of individual motivation but of the work systems in which engineers conduct their work (Hirsch et al. 1958; Ritti, 1971; Torpey, 1970; Raudsepp, 1964). Hirsch et al. (1958: 67) define productivity not as measurable output of engineers but as "the performance of productive work for which the scientist (or engineer) has had unique training and experience." This definition shifts the focus from measured output to the actual activities in which scientists and engineers are engaged on a daily basis. The assumption is that output is related to the percent of their time spent on activities for which they have had "unique training and experience." Though it is recognized that occasions will arise in which all professionals must do some "busy work," when a significant portion of a typical work week is spent on activities that do not require the unique technical knowledge of engineers and scientists, they are not being effectively utilized.

Based on a survey of 148 engineers and scientists in Southern California firms, it was found by Hirsch et al. (1958) that from 20 percent to 50 percent of potentially useful output was lost because of time spent on activities that did not take advantage of their unique knowledge and skills (e.g., time spent on routine clerical activity). Other sources of "lost potential output" identified in this survey included work on assignments of negligible value, duplication of effort, adjustment time to new jobs as a result of employee turnover, and inadequate physical facilities. Taken together, these researchers estimate that eliminating these sources of lost potential output could increase productivity by a factor of ten, an estimate they admit may by overly optimistic.

Similar problems are reported by Ritti (1971) in his case study of engineers in a large industrial firm. He reports that a significant proportion of engineers in this firm reported that they would "prefer to do more." Engineers in development and research laboratory settings reported a significantly higher incidence of underutilization compared to other white collar workers (e.g., engineers in sales)--29 percent of engineers in development and 38 percent of engineers in research laboratories reported underutilization.

According to Ritti, there were two main reasons for this underutilization: First, the amount of technical support for engineers varied widely; lack of sufficient technical support was a major source of misutilization of engineers. Second, the engineers lacked influence in the overall organization--they did not have the influence to get their problems heard by top management. He notes this is not a problem of individual influence but a general management problem. According to Ritti (1971: 137):

> "..appropriate organizational therapies flow from correct problem identification. If lack of influence and underutilization were related at the individual level, the appropriate action might be managerial training in the art of allowing increased discretionary influence to engineers. But this seems not to be the case. The problem is one of the entire organization. An engineer can be given greater freedom and discretion in the pursuit of his given task, in his hours, his coffee breaks, but the definition of the technical mission and the management environment are both beyond his control. Yet it is the mission and the environment that establish the character of the individual tasks generally and determine the probability of underutilization..."

The implications of these studies are threefold: First, the productivity of scientists and engineers can be dramatically improved without attempting to measure their individual output. If work systems barriers to full utilization of professional talent can be identified and removed, scientists and engineers will be more productive without necessarily working harder. Second, many engineers will feel much more positively about their work if their potential is more fully utilized by the organization (positive work attitudes are known to reduce the likelihood of employee turnover (Dunham and Smith, 1979)). Finally, one cannot count on individual engineers or their immediate supervisors to influence top management to make the necessary system changes in large organization. Top management must be alerted to the problems and the cost to the overall organization in some other way.

What should work systems look like to effectively accomplish these ends? How can top management get the information they need to aid them (and motivate them) to make major system changes where improvements will be most cost effective? The workplace design model described below provides a set of general criteria for evaluating work systems. The workplace assessment survey uses these criteria to systematically evaluate systems barriers to productivity and their cost implications.

WORKPLACE DESIGN CRITERIA

Though traditional work measurement cannot be directly applied to work done by scientist and engineers, the underlying model of workplace[2] design is applicable. The model, developed through decades of industrial engineering theory and practice, represents any workplace as a human-machine system in which material and information inputs are transformed into outputs (see Figure 2). A work system consists of a set of core workplaces, support functions, and a management system to plan, direct, and monitor the core and support functions.[3] To achieve maximum productivity from the work system, its core workplaces must adhere to the design criteria of Table 1. These criteria as applied to engineers are:

1. Information and material inputs needed to do the work should be readily accessible. Information input is often a problem for engineers since in large complex organizations each engineer is responsible for designing a piece of an overall system (e.g., a brake system) which will often be manufactured at another location or even in another company. System features must be coordinated which requires regular communication within the engineering group, with purchasing, with parts suppliers, with assembly, etc. (Stewart and Calloway, 1982) Material input includes office supplies and parts for prototype building and testing which if not available can delay the engineer's work.

2. Machines and equipment should be accessible and in good repair. These include calculators, computer terminals, computer-aided-design terminals, and the like.

3. Tooling should be available. These include drafting tools which of course are becoming obsolete as the CAD terminal is replacing manual drawing.

4. A. Engineers should be capable of doing the work, trained, present, and in good health. Product and process technologies have been changing at an increasing pace placing demands on engineers to keep up with the latest developments. The tools to perform work have also been changing as CAD/CAM systems are coming into increased use. Training is needed to help engineers develop new capabilities for using these new technologies and keep up with changes in the marketplace.

B. Engineers should be motivated to utilize their full potential to accomplish the work as required to meet organizational goals. According to personality tests and self-reports, engineers tend to be particularly high on involvement with work and striving for advancement (Izard, 1960; Danielson, 1960). Hence, the main issue in motivating engineers is less a matter of the willingness of engineers to work hard and more of a matter of how this hard work is directed by the organization and whether this is consistent with the organization's priorities and the development of technical expertise needed by the organization. For example, many organizations reward progression of engineers along a managerial track much more than progression along a technical track, a practice that may be detrimental to the long-term success of the organization (Orth, 1957). Another common problem in organizations is that salaries are out of line with the contributions of engineers to their firms (Hansen, 1963). A third problem is lack of goal clarity. If goals and priorities of the firm are not made clear, engineers cannot set work priorities appropriately. Finally, feedback on performance is often lacking in engineering organizations. For example, how can engineers improve their performance or prioritize their work if they do not receive data on the cost and quality implications of their designs?

5. Work assignments should be allocated to provide enough time to do the work and should take advantage of engineers' unique technical capabilities. As described above, because of poor work systems, engineers often spend much of their time on routine clerical and technical work.

6. Engineers should have the authority to make routine decisions (governed by proper guidelines) on matters that directly relate to execution of their duties. In an earlier application of the methodology presented in this paper, Hancock et al. (1983) found that the productivity of engineers in a large public utility was significantly reduced because of the necessity of involving higher administrative personnel in decisions that could have been covered by proper guidelines. Hirsch et al. (1958) found that assigned responsibilities often exceed assigned authority.

7. The working environment should not damage the health of the engineer nor distract the engineer from accomplishing work. Hirsch et al. (1958) note that some of the greatest scientific achievements have been made under terrible working conditions, yet generally speaking a favorable work climate will be conducive to high output. Obviously, hazardous conditions that lead to sick leave reduce the

productivity of a workforce.

8. Output should be promptly delivered in a form useful to the client (internal or external) who requires the information and/or material. It is easy to lose sight of who the clients are and what their needs are.

The above criteria are stated as independent aspects of individual workplaces; however, in practice it is important to recognize that the elements of a "work system" are interrelated in complex ways:

First, the design criteria are highly interrelated. For example, the amount of information that must be provided (criterion 1 in Table 1) to the worker by the work system is affected by the worker's training and experience (criterion 4A). If much of the information is stored in the worker's head, it need not be provided by the system. A common problem in engineering organizations is the frequent transfer of workers (Hirsch, et al. 1958) which places a premium on retraining. During the retraining period the worker is likely to need more information to accomplish tasks.

Second, the criteria will not always be compatible. For example, criterion 5b states that the worker should have sufficient time to complete assignments, which may not always be compatible with criterion 4b on motivation of workers. Andrews and Farris (1972) found that scientists and engineers tend to be motivated by high pressure (though beyond some threshold time pressures will adversely affect motivation). This suggests that allowing just enough time to complete the assignments may provide insufficient pressure to motivate some scientists and engineers.

Finally, many workplaces are interdependent. Hence, a change in one workplace has implications for other workplaces. For example, a study of workplaces of two engineers may find that neither engineer is as productive as they can be. For engineer A, the problem is lack of information to do the job. For engineer B, the problem is lack of experience and knowledge to do the work. Attacking each problem individually would be inefficient if the information engineer A lacked were specifications engineer B failed to provide on time because of his/her lack of experience.

The general design criteria above provide a means for evaluating design alternatives; they should not be confused with the design alternatives. For example, recent evidence suggests that in R&D settings, highly formalized communication is negatively correlated to technological innovation, while innovation prospers in settings which encourage informal communication (Ebadi and Utterback, 1984). One might argue that this should be stated as a design criterion --the social environment should foster informal communication. However, this is but one design alternative that might foster productivity under some circumstances. For example, it may be less relevant in a product development setting where the primary goal is not innovation but rather getting the bugs out of the design before it gets into production. To the extent that informal communications do foster productivity, we argue that they do so by influencing one of the general criteria in Figure 3. For example, a strong informal network might help scientists get the information they need to be innovative or motivate them to try out new ideas.

A final point on the design criteria is that they define the conditions necessary to achieve maximum productivity from the engineering workforce, while most organizations are really seeking optimum productivity. That is, there may be some cases in which it is more cost effective not to "fully utilize" the productive potential of the workforce. For example, satisfying criterion 5a--giving only assignments that take advantage of the unique training and experience of the worker --is apt to lead to a very inflexible system. One can imagine a group of engineers standing around without work because few adequately demanding assignments have come up, while technicians and clerical workers are overburdened with routine assignments.

To effectively and efficiently apply the workplace design criteria, a methodology is needed which can detect deviations from full utilization of the workforce and provide data on the potential benefits of taking corrective action. In this way, one can make an informed decision on whether the costs of corrective action can be justified. The workplace assessment survey, described below, is a way of collecting this data.

WORKPLACE ASSESSMENT SURVEYS

The general workplace design model above provides the criteria by which to assess each workplace in an organization or unit of an organization. Typically, there is no systematic way of making such an assessment within existing organizations. Even if the original organizational and workplace design functioned well when it was established, there is a general trend toward disorganization unless workplaces are periodically assessed with an eye toward maintenance. Such periodic assessments may be prompted by a change of management or employee complaints. However, employee complaints cannot be counted on since people in general tend to adapt to existing conditions (Lawler, 1973:chap. 4), and as mentioned above, engineers are not particularly strong in their upward influence in large organizations (Ritti, 1971).

We propose a formal statistical approach to detecting system barriers, quantifying their impact on engineering productivity, and converting these estimates to economic terms. One could leave it to top management to note systems problems, but it is well established that people are not particularly adept at making accurate statistical inferences from personal observation (Tversky and Kahneman, 1974). Moreover, when noting specific instances of poor performance, a typical inferential fallacy is to presume the individual is the cause of the problem rather than environmental conditions (Ross, 1977). To enable management to make informed resource allocation decisions, an information system with the following characteristics is needed:

1. Periodic assessments of workplace functioning must be made to check if workplaces are functioning according to the design criteria above.

2. These assessments should provide statistical summaries so that the distribution of systems barriers can be examined. Where are the major problems? Does their severity vary by department?

3. The problems should be prioritized according to their impact on the organization. Wherever possible, systems barriers should be translated into economic terms so that cost/benefit ratios of solutions can be computed.

4. These data should be made available to management at a sufficiently high level to make major systems changes.

5. Comparable measurements should be taken before and after changes are made to evaluate whether changes are achieving their objectives.

The person doing the work may be in the best position to provide the data needed for this assessment. An "expert" attempting to evaluate the functioning of the workplace would have to take the time to learn many things the worker already knows. The quick and systematic detection of workplace deficits through questioning of employees can enable changes in the operating system and/or the organization so that the potential can be more nearly achieved. After the change, the employees can provide information to determine whether or not the changes have accomplished their intended results.

Methodology - The procedure developed by Hancock (1982) is designed to measure and identify systems barriers. This technique also provides quantitative estimates of the potential cost reduction from eliminating these deficiencies. Questionnaires are administered to the workforce (or a random sample of the workforce). Each section of the questionnaire begins with axiomatic statements (based on the design criteria above) about what the workplaces should be like and then asks workers if their workplaces are functioning as the axiomatic statements say they should. The resulting data are statistically analyzed to identify common system deficiencies which are generally outside the control of the workers themselves. (Some examples are provided in the case study described below.)

The general cycle of data collection and workplace improvement is to:

1. Develop statements of what the workplace should be like based on the general model above as modified by discussions with management and workers. The process of developing specific objectives can be a useful exercise in and of itself as it forces open discussion of how work systems should be designed to achieve high productivity.
2. Elicit comparisons from workers between the axiomatic statements describing an ideal workplace and how their workplace is actually functioning.
3. Develop statistical summaries of worker responses to determine general systems problems and convert these to economic terms.
4. Develop alternative solutions to systems problems and compare in terms of costs/benefits.
5. Take corrective action.
6. Repeat the whole process to evaluate the corrective actions and plan the next set of corrective actions.

The statistical summary (step 3) is a crucial one as this step reduces the data to a form that can be quickly grasped and processed by management. Miller (1960) classifies the various techniques used by managers to deal with information overload, including ignoring some or all of the information ("omission"), selectively taking in some information ("filtering"), storing some information to be dealt with at a later date ("queueing"), etc. If detailed data are presented to managers they are likely to use one of these techniques and perhaps distort or omit significant information. The statistical summary systematically "filters" the raw data from the survey and should be prepared by someone with the time to study the data in depth and with an understanding of workplace design.

The Axiomatic Statements - Each section of the questionnaire begins with an axiomatic statement describing what the workplace should be like. These might be almost identical to the design criteria of Table 1 or it may be necessary to change the wording to fit the organizational context. An example statement might be: "Before starting an assignment, you should have all the information you need to do the assignment." In some cases this statement may be too general. It might be preferable to specify which information the engineer should have (e.g., specific types of blueprints showing designs tried in the past, test data, etc.).

Following this statement would be a set of questions asking whether the engineer does have all the information needed to do the assignment, if not, how easily accessible is the information? Questions can also be used to pinpoint the major source of any problems getting information; for example, is it information that should be available in the library? from other in-house engineers? from a supplier? etc. Finally, a set of questions are needed to assess the impact of lack of information on productivity.

Why is it necessary to develop the axiomatic statements?

1. Axiomatic Statements Provide a Basis for Comparison - A problem in many surveys is anchoring questions against some baseline. An axiomatic statement describes how the workplace should be and is followed by questions about whether the workplace is that way. This involves an explicit comparison.

2. Axiomatic Statements are Management Commitments - Since the statements about how the workplace should be functioning are developed with management input, the statements imply a management commitment and legitimize the worker's right to "complain." Without such statements, the engineer may feel less comfortable

criticizing the organization since it may be perceived as an attack on management. In the automotive case, the questionnaire was attached to a letter from the chief engineer so, for example, management was saying through the axiomatic statements that "you should have all the information you need to do your jobs" and "if you do not, I want to know about it."

Prior Applications - Workplace Assessment Surveys have been conducted at three sites prior to the case described in detail below. The first application was to skilled maintenance workers in the production facility of an automotive supplier (Hancock, 1982). Problems detected included an inadequate budget for preventive maintenance and out-of-date blue prints. After these problems were corrected, productivity significantly increased. A second application was to assemblers in an assembly plant. After correcting problems detected by the survey, the defect rate was reduced by 50 percent and the workforce in the area was reduced by 20 percent (and reassigned to another area).

These examples on hourly workforces used traditional measures of output which are generally not available for salaried workers. Moreover, there was no control group for comparison.

The first application for salaried workers was the engineering staff of a large public utility and a control group was included in this study (Hancock, et al. 1983). The engineers were involved in the design of substations for electrical switchgear. Axiomatic statements were followed by questions asking about each aspect of the workplace described above. The questionnaire, after pretesting, took approximately 20 minutes for each person to complete. The results: Lack of sufficient information prior to starting a job resulted in 22.4 percent of the jobs having to be redone. Rework took an average of 27 hours; a normal job (no rework) took 61 hours. Lack of proper environmental impact data prior to starting a job, the necessity of involving higher administrative personnel in decisions that could have been covered by proper guidelines, and poor information flow were the major problem areas.

After attempts were made to correct these situations, a second set of data were collected using the same questionnaires. The increase in productivity (based on a comparison of the second questionnaire to the first questionnaire) was 9 percent, or the equivalent of 26.1 full-time employees. Since the workload was increasing, this meant that additional workers did not have to be hired resulting in annual savings of over $600,000. The same questionnaires were given to engineers at a comparable control site. At the control site changes suggested by the questionnaire were not made. Productivity at the control site did not improve over the same period in which productivity improvements were detected at the experimental site.

A CASE EXAMPLE OF ASSESSING ENGINEERING WORKPLACES

Background - Like many other firms of the 1980s, a major automotive manufacturer was concerned about the productivity of their engineering staff. In the midst of the downturn in sales in 1982, the chief engineer of a large product engineering group initiated a productivity improvement program for the 100 engineers in his unit and delegated responsibility to one of his engineering managers. Business was slow so this was a good time to clean house. Since staff (primarily support staff) had been recently cut back, productivity improvement was a high priority. Technological productivity tools were added including additional CAD workstations and terminals at each engineer's desk which through a mainframe link would provide computer mail service. In the fall of 1983, a workplace assessment survey was conducted to assess system barriers to productivity.

By the time recommendations from the survey were developed, the probability of management action on the recommendations was very low for three reasons: First, business had picked up considerably and the engineers in this unit became so involved in new car programs and firefighting of old car programs that acting on the recommendations was not a high priority. Second, the engineering manager responsible for the productivity improvement program, who had been highly committed to acting on the survey results, was reassigned to head up a new engine program. Responsibility for the survey shifted to a different manager who had not been involved in earlier phases and hence was not as highly committed. Third, the corporation began a major reorganization which demanded much of the chief engineer's time and created feelings of uncertainty among engineers in the unit. A common feeling was: Why should we improve this organization if we do not even know if it will be here after the reorganization?

This section describes the steps taken to design and conduct the survey and the survey results. Though many of the recommendations were not immediately acted on, this case illustrates how the methodology can be used to diagnose system barriers and the types of recommendations that are apt to follow from this diagnosis. We suspect that many of the problems detected in this engineering organization are very common throughout U.S. industry. Before describing the survey design and analysis, a brief description of the product engineer's job in the auto industry is necessary background.

The Product Engineer's Job - The product engineers in this company (and generally throughout the auto industry) have some input into design of a new car model in the concept stage and perhaps even earlier on occasion. However, their primary function is to make the product work. By the time they come into the picture full force, many design decisions have already been made. Since automobiles are a "mature product," product engineers are more concerned with fine tuning of designs than radical innovation.[4] Engineering assignments are highly specialized, generally focusing on a particular component system (e.g. exhaust system) and the coordination of its design among different models.

The larger organization unit of which this engineering group is a sub-unit is responsible for the manufacture of small-, medium-, and large-size cars.

However, they do not actually make most of the component parts of the car, nor do they assemble the cars. Most components are made either by other parts of the corporation or by outside suppliers. In general throughout the auto industry, component parts are made by many supplier firms (Liker and Wilson, 1983).

The significance of these arrangements for understanding the survey results is that product engineering does not take place solely within the unit surveyed. For example, a design engineer within this unit who is responsible for brake systems of a new car will not design a brake system from scratch but is likely to be concerned with things like how piping is routed through the particular car body of the new model year. This person will work with engineers in an internal or external supplier who may have decades of experience in the design and manufacture of brake systems. Hence, the typical design engineer in the division studied spends a large portion of a work week coordinating information flows (including test results done in-house). Establishing a good network of contacts is very important in this job, and engineers interviewed claimed that this could be more important and take more time to develop than the technical expertise needed to do the job. In addition to information gathering and coordinating, design engineers also serve a control function since they must approve any engineering drawings or changes.

Pretest Interviews - In preparation for the questionnaire design, two groups of three engineers were interviewed. In these interviews we asked for descriptions of a typical work week and their reactions to how well their workplaces matched the workplace design criteria above. There was considerable agreement among the engineers interviewed that the workplace was deficient in a number of important respects. In general, there was agreement that because of inadequate support staff and difficulties getting information needed to do the design, inadequate time was devoted to new product designs. This resulted in excessive use of engineering changes to correct deficiencies in original design.

As a result of these preliminary interviews with engineers and discussions with management, the questionnaire was drafted. It was then pretested, redesigned, and pretested a second time to estimate completion time. The questionnaire took about two weeks to design and pretest and about 20 minutes for each engineer to fill out. In the fall of 1983 the questionnaire was administered. The data were analyzed and recommendations provided within one month of the time the survey was conducted.

The Questionnaires - Questionnaires were sent to 100 engineers with a cover letter from the chief engineer explaining the rationale behind the project and urging them to fill out the questionnaire. Of these, 81 were completed and returned (in some cases after several phone calls and additional questionnaires were sent out). There was little variation in the response rate by department. It appears that non-response is largely random. For example, a number of engineers could not respond before the deadline as they were on vacation; others had been transferred.

To assure anonymity, the engineers were to return the questionnaires to a locked box and only the outside researchers had access to the questionnaires. The engineers were asked to write their names on the questionnaires, and 61 of the 81 gave names. Clearly some of the engineers desired anonymity.

All of the engineers surveyed were project engineers responsible for product design. The average tenure at the corporation was 12 years, but the tenure at the current job was considerably less. On average, the engineers had been at their current job for four years. Additional analysis of data on career patterns revealed considerable job rotation, a factor that has implications for training and motivation as discussed below.

The presentation of results is organized around the main workplace design criteria described above. From the preliminary interviews it was discovered that not all of the design criteria were a concern for this group, and hence several were not covered in the questionnaire. More specifically, there was no evidence that material acquisition (#1), availability of tools and machinery (#2 and #3), authority relative to responsibility (#6), the working environment(#7), or the removal of material output (#8) were problematic. On the other hand, there was general agreement that information and time were both in unacceptably short supply--a pattern that reinforced itself over time as excessive attention was devoted to "fighting fires."

Results

A. Lack of Information - Professional/Technical staff deal largely with information. The product engineers surveyed are central nodes in networks of tremendous amounts of information. At the least, they must receive information from supervisors on the nature and scope of their assignments, other product engineers within the company about related components and car systems, internal component manufacturers or outside suppliers who will actually produce (and may largely design) the component, test engineers who are testing prototypes, persons in the assembly plant who are trying to fit their components into the car, and warranty information on repair rates. If they are working on a new car line that has not yet gone into production, assembly information and warranty data may not be available (although these may be available for similar carlines). However, the typical product engineer is working on several carlines that are in various stages of development so that each information source is likely to be necessary for at least one current project (Liker and Wilson, 1983).

The questionnaire was used to assess the degree to which obtaining the information needed for design was problematic, as well as pinpoint which information sources were particularly problematic. That is, we asked the engineers what percentage of time they succeed in getting the information they need (from a number of specific sources) to do their work in sufficient time so that their work is not impeded. The degree to which a particular information source is problematic depends on three factors: 1) How often is information needed from that source? 2) How easy is it to make contact with the source when information is needed? and 3) How often is the source able to provide the information once contacted?

The results are summarized in Table 2. Design engineers most often attempt to contact other design engineers from within the division to get information (23.5 percent of the time). They are least likely to attempt to contact technicians or individuals from assembly plants (3.3 percent and 4.3 percent respectively). When coupled with the data on the success rate in getting through to these people and actually receiving the information they request, this provides very useful information on problems with information flow.

As an example, of the time spent trying to contact people to get information, other design engineers are contacted 24 percent of the time. Of these attempts only 50 percent succeed and of these successes the design engineer contacted can supply the information only 64 percent of the time, on average. Hence, of the total time spent on information gathering attempts from design engineers, only 32 percent was spent productively (50% x 64%) and 68 percent was spent unproductively. In all, 16 percent of all information gathering time was spent on unproductive attempts to gather information from other divisional design engineers (68% x 24%).

Since this information was provided to the chief engineer whose formal authority did not extend beyond his organizational unit, we totalled the unsuccessful attempts to get information from all sources within his unit. The results: Of the time design engineers spend trying to gather information, 66 percent of the time is spent attempting to contact individuals within their own unit (including drafting personnel, supervisors, etc.). Of this time 60 percent is spent unproductively, i.e., failing to contact the people or failing to get satisfactory responses. In all 40 percent of all information gathering time was spent on unproductive attempts to gather information from other people within the division.

Clearly, lack of information prior to starting a job is a serious source of inefficiency for these design engineers. The implications: First, engineers are wasting time on unproductive attempts to get information. Second, they may be going ahead with design work without the information they really need to do the job right. The economic costs of lack of information prior to starting a job are discussed below.

B. Time Availability and Allocation - How much time do engineers need to do their work? It is generally not possible for an outside expert to specify exactly what the activities of an engineer should be, let alone how long each should take. Typically, only the person doing the work knows exactly what he/she does. Hirsch, et al. (1958:67) define what scientists should be spending their time on as follows:

> "It is readily apparent that such jobs as non-routine technical work, non-routine designing, and technical data searching do require the scientist's unique training. It should be equally clear that routine technical work, routine designing, drafting, personal time, routine laboratory work, and other nontechnical activities do not require this special background. Between these two obvious extremes are activities which utilize the scientist's background to varying degrees."

These researchers used this definition to make best guesses about which activities in a survey use the scientist's time efficiently. Our approach relies on the knowledge and judgement of the person doing the work. First, we developed a list of common design engineering activities (based on interviews in the pretest phase). Second, we developed an axiomatic statement (design criteria) describing how engineers should be using their time as follows: "In order to use your time most effectively, you should not be doing things that (1) do not aid in your work, and (2) could be done just as effectively by someone at a lower level within the organization." Third, the questionnaire asked the engineers to estimate the percentage of time actually devoted to each activity (in a "typical work over the last 3 months") as well as the percentage of time that should be devoted to the activity (based on the axiomatic statement of how they should spend their time). Finally, the engineers were asked to whom the excess activity (if actual was more than should) could be delegated (e.g., secretary, technician, etc.). In short, based on criteria stated in the questionnaire, the engineers told us what percentage of each activity was efficiently utilizing their time.

Time can be thought of in terms of availability and allocation. To get more time to work on a new design, an engineer can work overtime increasing the total time available to do work or reallocate time within a fixed work week. An example of the latter would be to spend less time on engineering changes for parts in production, thereby freeing up time for new product design.

There was general consensus in preliminary interviews that time was a problem. Engineers typically worked more than a 40-hour work week, and 60 hours or more was quite common. Management agreed that this was the case and had no desire to see engineers taking still more work home. Yet there was also general agreement that too much time was spent on engineering changes and other "fire-fighting" activities, while too little time was spent on new product design. As a consequence, as the deadline for a new product design approached, it became a short-term activity--a job to get done by the deadline, rather than a first-rate design activity. This problem of time allocation can be characterized as a vicious cycle. As long as new product designs are not done right the first time, they will become problems to fix downstream eating up time that could be spent on designing future products right the first time.

Time Available for Design - A recent general cutback in personnel in the corporation had dramatically reduced support staff. At the time of the survey management assumed the engineers would claim they needed more help, but they had no systematic way of estimating how many additional support staff were needed so the time of the design engineers could be shifted to new product design.

The survey revealed that a considerable portion of the design engineer's time was taken up by activities that could have been delegated to support staff, in particular secretaries and technicians (see Table 3). Fully 81 percent of a typical work week (on average) was being devoted to activities other than engineering design, including mail handling, filling out forms, telephoning, attending scheduled and unscheduled meetings, writing letters, searching the building for other people, and photocopying. Not all of these activities could be effectively delegated. For example, on average, engineers spent 23.4 percent of their time on "uncreative paperwork," of which they felt 10.5 percent had to be done by themselves. Yet, the remaining 12.9 percent could be delegated to a secretary.

Other questions about specific activities broke down the 19.2 percent spent on "other engineering activities" still further. Included in this category were trips to various places, including plant visits, the prototype lab, the electrical lab, production sites, etc. Of these various visits to places many could be handled just as effectively by technicians, according to the design engineers, and this would result in an additional time savings of 10.5 percent of a work week.

In all, the design engineers reported spending 12 percent of their work week on activities they felt could be adequately handled by secretaries and 21.5 percent of the work week on activities that could be handled by technicians. According to these estimates, one third of the work week could be claimed for new product design with increased support staff, more than the total amount of time currently spent on "engineering design work."

<u>Allocation of Engineering Design Time</u> - Of the time spent on engineering design work, what percentage was devoted to new product design as compared to engineering

changes? The engineers were asked how the precious little engineering design time they had was allocated between engineering changes, new product design, and other activities. They were asked how they should allocate their time to get the design right (or as close as possible) the first time.

The results (Table 4) showed that of the total time spent on engineering design, 32 percent was devoted to engineering changes and 26 percent was devoted to other engineering activities not related to new product design. This leaves 42 percent for new product design. What should this distribution look like? The answer--70 percent should be devoted to new product design, an additional 28 percent.

C. Selection, Training, and Motivation - These three issues are discussed together since they are so closely linked. For example, one way of getting highly trained and motivated engineers is to select engineers with the educational backgrounds needed and career ambitions consistent with the goals of the organization. Once selected, some special training may be needed as technology changes or to fill in specific gaps in the individual's background. If the engineer is highly motivated when hired, the organization need only maintain that high level of motivation, as well as channel it in the directions demanded by organizational needs. On the other hand, poor selection procedures place a heavy burden on the organization to train and motivate the engineer.

These issues are the most difficult to address through a self-administered questionnaire. While other issues examined require the engineer to assess aspects of the external work environment, selection, training, and motivation call for some degree of self-assessment. As Peters and Waterman (1983) note, though ability tends to be normally distributed, the vast majority of people view themselves as above average. Also, as noted above, people tend to adapt to situations as they exist. Hence, engineers may feel they are more than adequately trained and motivated because they are either misperceiving their own abilities and performance or their standard for comparison is their own organization. That is, as long as the engineer's peers are not far superior in knowledge, ability, and performance, the engineer is apt to feel his or her own capabilities and performance are up to standard. The power of performance standards for repetitive, blue-collar work is that some external standard exists for comparison, and supervisors don't have to rely solely on worker's self-assessments of performance.

The questionnaire included an axiomatic statement that the engineers "must have sufficient training and experience so that you know what and how to do your job." Questions following asked if the engineers felt they had enough "training and experience to accomplish your assignments" and, specifically, "what percentage of assignments you are asked to accomplish do you feel qualified for?" The results showed 83 percent of the engineers felt they "often" or "always" had enough training and experience, 15 percent "sometimes" felt this way, and only two percent felt they "seldom" or "never" were sufficiently trained or experienced. On average, the engineers felt they were qualified for 88 percent of their assignments.

On the other hand, a considerable portion of the engineers (72.5 percent) felt that the specific responsibilities and requirements of their positions were not made clear to them when they first started the job, and the majority of these engineers (78.5 percent) said, as a result, their work suffered at least to "some degree."

Interpretation of Training Data Based on Preliminary Interviews - To put these responses on training and indoctrination on new assignments into perspective, a broader view of the organization of this (and many other) engineering organizations is needed. We note, however, that this broad view comes more from open-ended discussions with twelve engineers and managers than from statistical analysis of the questionnaires.

As currently set up, the organization rewards managers significantly more than engineers. By rewards we mean pay, prestige, and other "perks." These provide incentives for ambitious young engineers to direct their energies toward promotion to management ranks. There are pros and cons to this system from a selection, training, and motivational viewpoint.

An important recruitment criteria for this organization is "high management potential" which may or may not coincide with the highest technical expertise. Young engineers with high management potential tend to be highly motivated as evidenced by a willingness to put in long hours that are not compensated in the short term. On the other hand, placing a premium on the development of managers has the unintended consequence of devaluing the significance of first-rate engineering. This organizational reward system assumes that a good manager must be a generalist to understand the overall system. Specialized technical competence is therefore not rewarded in the same way as general competence. Those persons who are not picked as high potential, or who were at some point high potential employees but were passed over for key promotions, are the ones who make up much of the long-term design engineering staff. They become the specialists because, in a sense, they have been designated by the system as mediocre.

The implications for the development of highly trained engineers are apparent. First, the "best and the brightest" are pulled into the management ranks. Though they will guide the direction of future generations of engineers, they will no longer be designing parts themselves nor directly training future generations of engineers. The establishment of effective mentor-apprentice relationships is apt to suffer. Second, high potential candidates are rotated through jobs to facilitate generalist training. This prevents them from developing in-depth technical competence on any one component or component system--a factor that may contribute to the high need for information from others described above.

The survey included data on the average number of years engineers had worked at each of the jobs they held. On average, engineers worked at a job for three years. However, the distribution was skewed. A number of senior engineers had been at the same job for many years; presumably these were not high potential employees. Among junior engineers job rotation was much more frequent. About one-quarter of the engineers surveyed were in a different job every year and another quarter rotated jobs on average every two years.

Even if technical competence could be mastered in a single year, the implication is that one-quarter of the design engineers left their jobs as soon as they got on top of it and another quarter spent half of their stay in a job learning the ropes of the job. One young "high potential" engineer put it this way:

> "I've had six assignments in my five years here. I started in brakes, then went to emissions, then went to emissions certification, then went to design of basic engines, then took a corporate job in bumpers, and I've been in bodies for one year. Now I am about 90 percent comfortable where I am, which means I'm ready to leave."

A direct consequence of this lack of continuity in jobs is that great demands are placed on the organization to quickly orient new entrants to jobs. As the survey results summarized above indicate, the organization does not provide adequate orientation. One engineer described the process of expediting high priority engineering changes in this way: "A novice will miss bases and have to learn by failure. We don't get oriented." Getting oriented in this case is not a matter of acquiring technical expertise but organizational expertise--knowing who to go to for what and how to expedite without being given the run around.

Despite these observations, the engineers surveyed think they are adequately trained and experienced to do their jobs well. One explanation for this apparent contradiction is that these engineers are accustomed to getting by with minimal technical knowledge and rely heavily on the expertise of others. According to our preliminary interviews with engineers and management, "others" include experienced draftsmen, engineers of supplier firms, engineers contracted from outside consulting firms, and the "car designers" of corporate staff. This places the "design engineers" in the role of coordinating information flows and controlling what gets on blueprints, as opposed to creative designers. We suggest this arrangement is not optimal, particularly in a period of rapidly changing product and process technology.

Economic Impact Analysis

A key part of the methodology is the estimation of the costs to the organization of systems barriers. What are the economic impacts of poor utilization of engineering design staff? To design this portion of the questionnaire it was necessary to identify the major cost variables for this organization. Some of the costs are internal to the engineering unit and have already been mentioned in the discussion of time use. For example, one can compute the percent of an engineer's time used inefficiently and multiply this by his/her salary. These internal costs are often the primary focus of "efficiency" studies. However, the more substantial costs of poor design are downstream, external to this particular engineering unit, as follows:

First, in the production and assembly stage, poor design means higher production costs, including idle time waiting for engineering changes and the cost of scrap from parts that have not been designed to fit with other parts. Moreover, parts that are not designed to optimally fit the manufacturing process will cost more to produce (e.g., more direct labor hours and perhaps more expensive equipment and tooling).

Second, in the distribution stage, poorly designed component systems will fail more frequently leading to higher warranty costs and ultimately customer dissatisfaction that reduces sales.

The questionnaire asked about short and long-term costs due to "lack of time," "lack of information," and "other reasons." The short-term focus was on engineering change requests (ECRs). The preliminary interviews suggested that ECRs were often made in haste in response to a "crisis." Since "normal" procedures for ECR processing could take several weeks, engineers spent considerable time and money circumventing these standard operating procedures. The long-term focus was on the downstream costs of insufficient attention to new product design which include processing of additional ECRs, plant problems, and warranty costs.

A. Excess Processing Costs of ECRs - The questionnaire asked the engineers to think back to the ECRs processed over the "last six months" and consider how these were processed. On average each engineer processed 25 ECRs in that period. In virtually all of these cases, they were forced to circumvent normal procedures either because they lacked time (in about 80 percent of the cases) or information (in about 20 percent of the cases). The costs of circumventing normal procedures over the six-month period were estimated to average $68,660 per engineer.

There was general agreement by the design engineers that few of the ECRs would have been necessary if they had sufficient time and information to do the original design to their satisfaction. On average, they estimated 24 of the 25 ECRs would have been unnecessary.

B. Cost of Incomplete Original Design - Over the "last six months" each design engineer worked on an average of 12 different design programs. Of these, none were given sufficient attention according to the design engineers. The number one reason --insufficient time--accounted for 64 percent of the cases in which insufficient attention was given. The second most significant source of insufficient attention was lack of information which accounted for 22 percent of the cases, while lack of training accounted for 9 percent and other reasons accounted for less than five percent.

What are the economic consequences of incomplete designs? For the designs done over the "last six months," the biggest estimated cost was for additional warranty costs estimated at $193,500 per engineer. Second were plant problems created by the inadequate design estimated at $115,240 per engineer. A close third was the costs of processing additional ECRs, an estimated $115,000 per engineer. "Other" costs were estimated at $74,224 per engineer.

The total decrements due to poor organization are $137,320 per engineer per year for extra ECR processing and $847,480 per engineer per year for incomplete designs. Since there are about 100 design engineers, this amounts to $98,480,000 per year. Lack of time accounted for most of these extra costs, followed by lack of information. Clearly, any steps which can improve the organization have the potential of very favorable economic returns.

One can think of a number of reasons to doubt the accuracy of these estimates. For example, there are is probably some double or even triple counting of costs. The costs incurred are probably not independent across engineers. Some are working together or on related projects and each might be claiming the same warranty repair costs in their estimate. Another source of error is the possible double counting of ECR processing costs, since separate questions were asked for the costs of short-cutting normal ECR procedures and the costs of processing additional ECRs due to inadequate attention to original design. Finally, these were clearly difficult questions to answer as less than one third of the engineers attempted to estimate the costs of circumventing normal ECR procedures and only about half of the engineers answered the questions on the costs of incomplete designs. Part of this difficulty was due to lack of cost data provided to design engineers. According to the survey, only a small fraction of design engineers routinely got information on the costs of processing ECRs, the costs of new product designs, and warranty costs attributable to the area.

In defense of these estimates, they closely matched independently generated management estimates within each category. Moreover, even if the costs are overstated by a factor of ten, the potential savings from better organization are considerable.

SYSTEMS BARRIERS AND WORK ATTITUDES

Given that engineers tend to be highly involved in their work (i.e., are motivated to do a good job), one would expect the system problems identified above to be very aggrevating and frustrating. Work is apt to be experienced as one hassle after another. The survey results confirmed this suspicion.

The engineers were asked whether they agreed or disagreed (along a seven-point Likert scale) with a number of statements about their work and workplace (see Table 5). Included in this list were three items measuring feelings that work is a hassle. In all, 84 percent of the engineers agreed that "getting my work done is an uphill battle," 84 percent agreed that "if they would only get this place better organized, getting my job done wouldn't be such a headache," and 65 percent agreed that "most of the time this job is one hassle after another."

It might be argued that these engineers simply liked to complain. Perhaps general morale was low for some reason other than system barriers and they were apt to complain about anything they were asked to evaluate. However, the response to questions about general job satisfaction suggest otherwise. Questions asking whether they found their work meaningful, they cared about doing their work right, they felt satisfied with their jobs, etc., all yielded much more favorable reactions compared to the questions about workplace hassles. At the worst, 34 percent of the engineers disagreed that "this is an excellent place to work," and at the best, only 11 percent agreed that "it's hard on this job for me to care very much about whether or not the work gets done right."

That engineers report feeling hassled does not prove that the systems barriers detected by the survey were actually the source of this negative attitude. Strong proof would require a controlled field experiment in which some of the systems barriers were removed and a follow-up survey was conducted which showed a decline in these negative feelings toward work organization (a matched control group in which the workplace changes were not made would strengthen the research design). Unfortunately, the company surveyed did not feel the time was right for making major system changes. However, correlations between work attitudes and the various systems barriers at a point in time provides suggestive evidence that the systems barriers were a source of negative attitudes.

Correlation coefficients in Table 6 show the relationship between systems barriers and the indices based on three domains of work attitudes--work hassles, meaningfulness of work, and job satisfaction.[5] A positive correlation indicates that those people who reported the systems barrier (e.g., lack of information prior to starting a job) also reported negative work attitudes. We see that not all systems barriers were equally important to the engineers.

Lack of time to design products right is at the top of the list as a source of hassles (r=.35), feelings that work is not meaningful (r=.36), and dissatisfaction with the work, job, and workplace (r=.54). Note that this was also the major source of excess costs. Other sources of negative work attitudes are lack of information because of difficulties contacting people, lack of support staff, and the necessity of bypassing standard procedures to process engineering changes (correlations range from .08 to .34). Finally, the problem of poor indoctrination into new assignments has a modest relationship to negative work attitudes. (This was not an immediate problem for most of the engineers and perhaps for this reason was not as salient in their minds as lack of time, information, etc.) These problems are of course interrelated. For example, lack of time on engineering design is largely due to the lack of support staff and time spent correcting past design deficiencies through engineering changes.

As expected, these system barriers are a major source of dissatisfaction for engineers, a result consistent with other surveys of engineers (Danielson, 1960; Ritti, 1971) and surveys of white-collar workers generally. The first concern of a national sample of white-collar workers (Staines and Quinn, 1979) was that the work they do is meaningful and interesting. Beyond this, three of the most important aspects of their job are: 1) "I have enough information to get the job done," 2) "I have enough authority to do my job," and 3) "I receive enough help and equipment to get the job done." Hence, for white-collar workers, removing systems barriers to getting the work done is tantamount to improving general satisfaction with the work and workplace.

Recommendations to Management - The survey provides an analysis of the systems barriers to productivity and estimates of their cost impact. This is an efficient way of collecting data which provides some direction and motivation to problem solving. Nothing inherent in the methodology leads to any particular solution or even a particular approach to problem solving. For example, the data analyst might propose solutions, productivity experts such as industrial engineers might devise solutions, or a task force might generate ideas to improve the workplace. Recently the nominal group technique has been proposed as a way of generating ideas on productivity improvement for knowledge workers (Conn, 1984). The workplace assessment survey can provide guidance to such groups on where changes are likely to be most effective in improving productivity.

In the automotive design engineering case, we worked with top management to generate a set of proposed system changes. These are of interest as examples of the types of solutions that can come from such a process and also since we suspect these problems are widespread throughout much of U.S. industry. The proposed changes were as follows:

1. Devise methods by which people can contact each other within the time constraints necessary to do the work. A computer mail system became fully opera-

tional after the survey was conducted, but we suggested organizational solutions might be considered in addition to technical solutions. One excellent suggestion from an engineering manager was to place a moratorium on meetings for three hours each morning. During this time, every engineer would attempt to remain close to his/her phone and work on new product design.

2. Increase secretaries and technicians to relieve design engineers of jobs that can be adequately handled by support staff. The survey provided estimates of the portion of engineers' time that they spent on such duties providing a basis for estimating the additional staff needed. The results showed 12 additional secretaries and 21 technicians were needed. At the time of the survey, only eight secretaries and eight technicians were assigned to support the 100 design engineers.

3. Change the method of indoctrinating engineers into new assignments so that their duties, responsibilities, and background information (e.g., past designs that have been tested) are appropriately covered. Set a minimum time--such as one year --where a newly assigned engineer must be under the direct supervision of a more senior engineer to provide a "tutoring" environment.

4. Provide more information to engineers concerning the cost of their work, so that they can formulate their needs for support and organization in economic terms, and so that these cost estimates can be used to substantially improve the quality of the design processes of the group.

5. Every ECR should be reviewed to determine if its basis is inadequate original design. This information should be used to make major changes to new product design review and processing.

6. Change policies on rotating engineers through design jobs. The engineering organization needs depth. "First of class" car systems will not be designed by inexperienced engineers. At least one top-notch engineering specialist should be available for each major component system.

7. Develop a system of review for new product designs at key milestones in the design process (including prototype stage). A possible format is the seminar in which designers present their designs to experienced engineers for in-depth technical comments and criticisms.

8. Develop a "dual ladder" which substantially raises the ceilings on promotions and compensation for design engineers and makes this track competitive with the management track. For an example of a dual ladder system set up at General Mills, see Wolff (1979). In general, this appears to be a difficult program to implement to the satisfaction of all parties.

CONCLUSIONS

Traditional work measurement assumes the best way of doing a job can be determined by scientifically analyzing the tasks required and routinizing the work. The system is monitored and controlled by measuring output and comparing this to the known potential of the system. In the case of engineering design, the assumptions of traditional work measurement do not apply. Hence, a different approach and philosophy of work measurement is needed. The workplace assessment survey does not focus on measuring output, or specifying predetermined activity sequences, but rather on assessing systems barriers from the viewpoints of those people doing the core work of the organization. System barriers which suppress productivity levels are statistically detected and associated economic costs estimated. A controlled experiment on productivity of engineers in a large public utility (Hancock et al. 1983) demonstrated that workers' expertise can be used to improve productivity. The primary system barrier in that case was lack of information.

The second application of this methodology to an engineering workforce was to a design engineering group of a major U.S. automotive manufacturer. The systems problems detected in this automotive organization can be summarized as follows: First, because of deficiencies in support systems design engineers spend about one third of their time on routine clerical and technical work. Second, of the time they spend on engineering design a major portion is on engineering changes (i.e., rework) and because of time pressures this usually involves side-stepping formal bureaucratic mechanisms. Third, engineering design work is hampered by difficulties getting information needed for the design. Fourth, fast-track engineers are frequently rotated into new positions for which they are not properly trained or oriented. Fifth, because of lack of time, information, and training, new product designs are released before they are well tested and fine-tuned which results in the need for rework downstream. Finally, design engineers do not get feedback on the cost and quality impact of their work, and hence can only guess at the costs to the organization of inadequate product designs--without feedback on the downstream cost and quality impacts engineers cannot rationally prioritize their activities.

Management was not surprised by these results, though prior to the survey they had no way of quantifying the severity of the problem or its economic consequences. Steps taken to correct these problems included substantial increases in support staff and a computer mail system with a terminal for each engineer. At the time of this writing, the chief engineer was reluctant to make more fundamental changes in the organization since the corporation was in the process of reorganizing and the implications for his engineering group were uncertain. Our recommendations on changes in compensation practices (i.e., dual technical and managerial career tracks) were of great interest, but this required a change in corporate policy. In this instance we had identified a system problem that was beyond the authority of the chief engineer.

A number of general conclusions can be drawn from this research. First, the workplace assessment survey is an efficient and cost-effective approach to the identification of general systems problems that suppress the productivity of professional/technical staff. Second, the survey can be used to estimate the cost implications of these systems problems which provides management with a means of prioritizing resource allocations and motivates management to take corrective action. Third, some degree of tailoring is probably needed for each organization. The questionnaire used at the public utility would not have been appropriate for the auto company, even though design engineers were surveyed in each case. It is also likely that separate questionnaires need to be developed for different functional groups (e.g., design engineering, test engineering, sales engineering, etc.). Fourth, it is difficult to get accurate information on motivation and training when these data involve self-assessments. Wherever possible, questions in this area should focus on the work environment <u>external</u> to the human (e.g., training, compensation, and promotion policies). Fifth, survey data is not enough, in and of itself, to assure that major systems changes will be made, even if those changes have highly favorable cost/benefit ratios. Research on managing change (Nadler, 1977; Zaltman and Duncan, 1977) suggests that involving those persons affected by the changes in the design and implementation of the new systems increases the chance of successful implementation. In some cases, personnel from interdependent organizational units (e.g., purchasing, assembly, parts suppliers) should also be involved in the changes. Finally, technical productivity tools (e.g., CAD, finite element analysis, etc.) will not be fully utilized without good workplace design and functioning. For example, in the case studied it is hard to imagine that the design engineers could find the time to become skilled at a CAD workstation. Organizational approaches to productivity improvement should supplement or, ideally, complement technological improvements.

FOOTNOTES

1. Thusfar, the survey methodology described here has been applied to two engineering design groups, but has not been applied to engineers or scientists in an R&D setting. Hence, we use the term "engineers" throughout the paper to refer to design engineers. While we believe the basic concepts apply to scientists as well as to design engineers, actual application of the methodology is apt to be different because of differences between the organizational contexts and different orientations of scientists and engineers (Ritti, 1967; Badawy, 1971).

2. "Workstation" is a term that generally refers to the physical layout, machinery, equipment, and tooling of a specific and fixed work area. Recently the term has been applied to microcomputer "workstations." "Workplace" as used here is a more general term which includes the workstation, the human, the work environment, and inputs entering the workstation.

3. "Core work" is defined by Hancock et al. (1983: p.263) as "work that directly adds value." They note this is harder to identify in service organizations and for these "it is helpful to think of the "value-added" work as the work that constitutes the main services of the organization." Supportive work is defined as the work that enables the potential of the core. In the context of engineering productivity, engineers provide the core services of the engineering organization, while draftsmen, secretaries, and technicians are a support service.

4. Abernathy and Utterback (1978) describe the historical development of the auto industry in the United States. As the industry "matured," product designs stabilized and long production runs to achieve economics of scale became the dominant mode of production. As a mature industry, large capital investments in dedicated technology make radical product innovations costly. Process innovations to cut cost tend to take precedence over product innovations. The high degree of specialization among product engineers has been described by Ritti (1971) as a main reason why engineers feel underutilized and frustrated in their jobs. About the only way they can become responsible for a major component system (e.g., an engine) is to be promoted to project manager status.

5. A Hassle Index is based on items 1-3, in Table 5. Items 6-9 of Table 5 (taken from the Job ~~Hackman~~ Diagnostic survey, Hackman and Oldham, 1980) are all substantially correlated with each other and with item 10 ("overall this is an excellent place to work"), so these are averaged below to create an index of job dissatisfaction. The inter-item correlations range from .45 to .65 and there are no discernable patterns to the correlations. Items 4 and 5 were averaged to form an index of "meaningless work" which correlates at .75 with the job dissatisfaction index.

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Table 1

General Workplace Design Criteria For Full Utilization of Workers

	WORKPLACE ELEMENT	DESIGN CRITERIA
1.	Inputs	The worker should have the materials and information (including data and task assignments) necessary to do the work before he/she starts the work. Otherwise, he/she should be able to find and promptly obtain these materials and information when required.
2.	Machines and Equipment	Should be accessible and in good repair.
3.	Tooling	Should be available in the proper quantity and in good repair.
4.	The Worker	A. Should be capable of doing the work, trained, present, and in good health. B. Should be motivated to utilize his/her full potential to accomplish the work as required to meet organizational goals.
5.	Work Assignments	A. Work assignments should be appropriate to the level of training and experience of the worker. B. The worker should have sufficient time to complete all tasks required to complete the assignment (including training time).
6.	Authority Structure	The worker should have the authority to make routine decisions (governed by proper guidelines) directly related to executing his/her job duties.
7.	The Working Environment	Should not damage the health of the worker, nor distract the worker from accomplishing the work.
8.	Output	Should be promptly delivered in a form useful to the client (internal or external) who requires the information and material.

Table 2

RESULTS OF INFORMATION GATHERING EFFORTS BY DESIGN ENGINEERS (N=81)

Information Source	(A) % Effort Devoted to Source[a]	(B) % Successful Contacts[b]	(C) % Satisfactory Responses[c]	(D) Success Rate (B x C)
Within Chief Engineer's Unit:				
Drafting personnel	14	74	73	54%
Test Engineer	13	54	59	32%
Supervisor	12	64	76	49%
Technician	3	70	62	43%
Other Design Engineer	24	50	64	32%
Subtotal	66%	59%[e]	67%[e]	40%
Outside Chief Engineer's Unit:				
Assembly Plant	4	49	64	32%
Other Corporate Personnel	18	55	67	37%
Other Person or Source Outside Corporation	12	60	74	41%
Total	100%	60%[e]	68%[e]	41%

[a] Base is total time spent trying to collect information over the "last six months."

[b] Percent of attempts that lead to contacts in sufficient time so that work is not impeded.

[c] Percent of contacts that lead to satisfactory responses.

[d] Success rate = successful contacts x satisfactory responses.

[e] Averages weighted by the "%Effort Devoted to Source."

Table 3

PERCENT OF "TYPICAL WORK WEEK" SPENT ON

VARIOUS ACTIVITIES: ACTUAL VS IDEAL

(Shown are Mean Responses)

	PERCENT OF WORK WEEK			SHOULD
ACTIVITY	ACTUAL[b]	IDEAL[c]	DIFFERENCE	DELEGATE TO[d]
UNCREATIVE PAPERWORK[a]	23.4%	10.5%	12.9%	SECRETARY
GATHERING/SEARCHING FOR FILES	3.7%	1.5%	2.2%	TECHNICIAN
TELEPHONING	15.5%	11.5%	4.0%	TECHNICIAN
SEARCHING FOR PEOPLE/WALKING IN BUILDING	7.9%	2.7%	5.2%	TECHNICIAN
SCHEDULING	4.5%	5.2%	(-0.7%)	e
ATTENDING SCHEDULED MEETINGS	12.7%	11.3%	1.4%	e
ATTENDING UNSCHEDULED MEETINGS	8.5%	5.4%	3.1%	e
WRITING LETTERS	7.0%	7.7%	(-0.7%)	e
OTHER ENGINEERING ACTIVITIES	19.2%	44.0%	(-24.8%)	
	102.4%	99.8%		

NOTE: Columns should add up to 100%, but do not because of rounding errors, different response rates for specific questions, etc.

[a] Includes mail handling, copying, blueprinting, filling out forms, and proofreading.

[b] Actual percent of time spent on these activities in a "typical" week over the last three months.

[c] Percent of time should spend on activity so that time spent on it "aided in work" and "could not be done by someone at a lower level in the organization."

[d] This is the person most often mentioned by engineers when asked to whom some of the activity could be delegated.

[e] For these activities there were no particular personnel mentioned by a large proportion of respondents.

Table 4

PERCENT OF "ENGINEERING DESIGN WORK" DEVOTED TO SPECIFIC ACTIVITIES: ACTUAL VS IDEAL

(Shown Are Mean Responses)

ENGINEERING DESIGN WORK	ACTUAL	IDEAL[a]	DIFFERENCE
NEW PRODUCT DESIGN	42.1%	70.1%	-28.0%
ENGINEERING CHANGES	32.3%	12.4%	19.9%
OTHER ENGINEERING DESIGN	23.8%	16.4%	7.4%
	98.2%	98.9%	

NOTE: Columns should add to 100%, but do not because of rounding errors, different response rates for specific questions, etc.

[a] Each engineer was asked to state not only the percent of design work devoted to each activity, but how much time should be spent on the activity under ideal circumstances.

Table 5

Attitudes Toward Job, Work, and Workplace[a]

Item (not exact wording)	Mean[a]	%Agree[b]	N=
Hassles			
1. Work is uphill battle	5.6	84%	81
2. Job is headache	5.7	84%	81
3. Job is repeated hassle	4.8	65%	80
Meaningful Work			
4. Tasks often trivial/useless	3.2	32%	81
5. Work is not meaningful[c]	2.9	14%	81
Affect Toward Job/Workplace			
6. Hard to care about doing work right	2.1	11%	81
7. Generally, not satisfied with job[c]	3.3	28%	81
8. Often think of quitting job	3.2	30%	81
9. Not satisfied with work on job[c]	2.9	17%	80
10. Overall, not excellent place to work [c]	3.8	34%	80

[a] Engineers were asked how much they agree or disagree (on a seven point Likert scale from strongly disagree=1 to strongly agree=7) with statements about their job, work, and workplace.

[b] Percent of engineers who agreed slightly, agreed, or agreed strongly with the statement.

[c] These questions were actually stated as positive statements. To compare them with responses to negative statements, they have been restated here in the negative (by inserting not in the statement) and the response categories have been reverse scored (*e.g.*, agree slightly with the positive statement is treated as disagree slightly with a negative statement).

Table 6

Correlations Between Specific System Barriers and
Three Work Attitude Indices

SYSTEM BARRIERS	ATTITUDE INDICES[a]			
	Hassles	Meaningless Work	Job Dissatisfication	N=
1) Lack of time for engineering design[b]	.35	.36	.54	(74)
2) Lack of information to do work[c]	.28	.08	.13	(67)
3) Lack of support staff[d]	.21	.11	.26	(79)
4) Bypass standard procedures for engineering changes[e]	.34	.12	.21	(59)
5) Unclear responsibility in new job[f]	.03	.21	.19	(80)

[a] Based on average of items show in Table 5, where "Hassles" is based on items 1-3, "Meaningless work" is based on items 4-5, and "Dissatisfaction" is based on items 6-10.

[b] Difference between percent of work week "actually" spends on "other engineering activities" and "ideally" should be spent on "other engineering" (see Table 3).

[c] Based on percent of time cannot successfully contact others in sufficient time so work is not impeded. This is an average correlation across all information sources (see Table 2). Since different information sources were applicable to different engineers, the "N" is based on the average number of respondents.

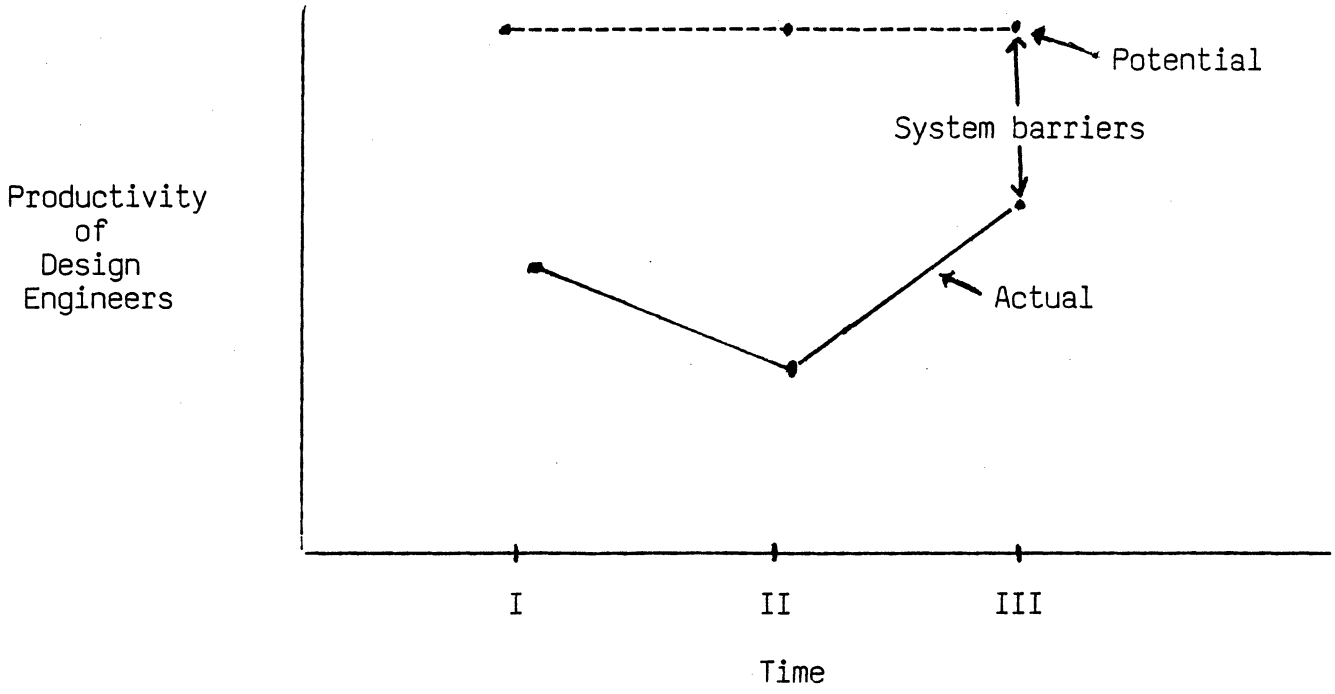
[d] The engineers were asked "to what degree" they had an "adequate number of support personnel."

[e] Based on the percentage of ECR's processed by circumventing normal procedures.

[f] The degree to which "responsibilities and requirements were not made clear upon initial placement into your current position."

Figure 1

Hypothetical Graph of Actual Versus Potential Engineering Productivity over Time*



*Assume that engineering productivity has declined between Time I and Time II and management responds with a management by Objective System. This improves productivity between Time II and Time III, yet productivity is still far below potential because of system barriers.

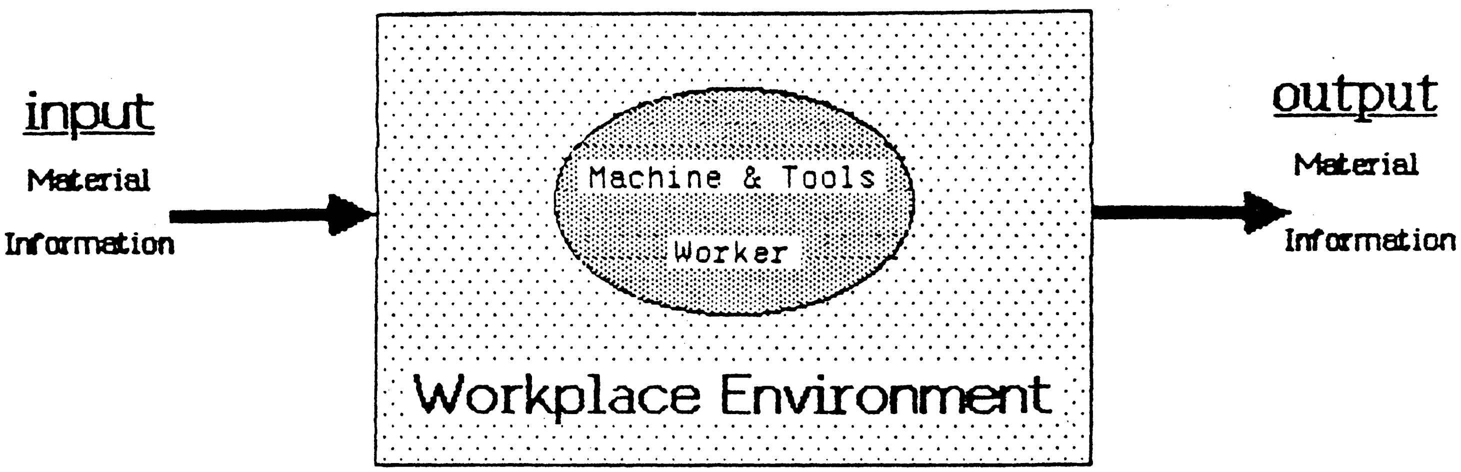


Figure 2

Generalized Workplace for Productive Work *

* See design criteria in Table 1.