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THE ARCANE ART OF RESEARCH AND DEVELOPMENT MANAGEMENT

I have had the very good fortune on several occasions to be assigned the primary responsibility for developing a major system and for managing the development to the point where a useful product was adopted for use and put into production. Such a responsibility resembles difficult mountain climbing by combining moments of sheer terror with enjoyable exultation when the slippery spots are successfully negotiated. On the questionable assumption that the indisputable success of several of these efforts was attributable in part to my practice of management, I have been asked to delineate my views on the role of management in a major research and development activity.

ALL MEN ARE CREATED UNIQUE

I believe that most books and articles on management that I have read suffer from an excess of patriotism. They are too fervently dedicated to the literal interpretation of the proposition that all men are created equal. This excellent precept should be interpreted as an assertion that all men (or women) when created, i.e., as newborn babies, should be treated as potentially equal in capabilities and, in an ideal world, should be provided equal opportunities. When written by our Founding Fathers, the Declaration of Independence was specifically a plea for abandonment of the then common English custom of putting people into classes as a result of the circumstances of their birth or the status of their parents. It was not intended to deny the obvious fact that each person, at birth, immediately begins to manifest and develop substantial differences in capabilities, talents, and weaknesses. But one can read long treatises about assignment of responsibilities, maintenance of communications, upward mobility, lateral mobility, training, motivation, fringe benefits, etc. in which it is implicitly assumed that all people are similarly motivated and approximately equally capable and that one man-hour is like another man-hour. When the job is the production of an item on an assembly line of the type so beautifully pictured in Charlie Chaplin's movie "Modern Times," i.e., a line in which the work done at each station has been reduced to trivial routine (installing two bolts) which almost anyone can be trained to do in about 10 minutes, there is some excuse for considering people as interchangeable. But even in this case, there are now many modern managers who find that rearranging the production line to contain far fewer stations and far more complex accomplishments at each station pays dividends in morale and, eventually, in productivity.

But many jobs cannot be broken down into a succession of tiny jobs that "anyone" can do. (It has been noted elsewhere that, in a track team, one man who can jump over a seven-foot-high bar cannot be replaced by seven men who can jump over a one-foot-high bar.[1]) Most certainly, when the job is to develop a new item, design a new device, or develop a complex system, the capabilities of the people who are going to carry out the assignment become overriding. It is essential for management to make every effort to find out what motivates its people, what interests them, what they take pride in, what gives them a sense of satisfaction, what their capabilities are, and what weaknesses they have. The most difficult problem for a manager is to become aware of his own weaknesses and then take appropriate organizational action.

In carrying out a successful development program, the importance of recognizing individual differences in the staff cannot be overemphasized. It is precisely this recognition of differences that is least stressed in many books and articles on the theory of organization and management. Such books assert that people are primarily motivated by financial reward. It is true, of course, that most people would just as soon be reasonably well paid, but salary or other financial rewards are by no means the strongest motivation for a surprisingly large number of people. Some people are particularly responsive to the challenge of a difficult technical assignment and the sense of satisfaction that results from its successful accomplishment. Some respond best to the approval and respect of their peers or superiors. It is worth noting that a few of the key people responsible for the remarkable success of NASA's Apollo program resigned industrial jobs where the pay was vastly higher in order to share in the excitement and sense of accomplishment in that almost incredibly challenging job.

A good manager tries to find out enough about his people, at least his key people, to know what makes them tick. He then tries to offer a reward for good performance in the form of the coin most highly valued. The good manager also tries to be aware of the limitations of his people and to make an assignment compatible with the interests and capabilities of the assignee. Unfortunately, many managers feel that they have fulfilled their function when they have

broken a job down into a number of areas of responsibility and assigned someone to each area. I cannot count the number of times I have been told about something that went wrong, "Well it wasn't my fault. I assigned that to Joe and I assumed he was doing it properly." The most important rule of a manager is that if someone who reports to you fails to carry out an assignment, it *is* your fault; perhaps more supervision was needed, and quite possibly he should not have been assigned the job at all. On the other hand nothing is more counter-productive than an excess of detailed supervision over a man who knows at least as well as you do how to carry out his assigned responsibility.

MARTINETS AND PUSSYCATS

The two extremes of under-supervision and over-supervision are the Scylla and Charybdis between which careful management must steer. Under-supervision may well amount to an abdication of duty. You have assigned a responsibility but you are not bothering to find out whether it is being carried out. Even when prior experience has given you every reason to believe that the man to whom you made the assignment is perfectly capable of carrying it out well, a complete lack of attention on your part may well be interpreted by him as a lack of interest. The man is justified then in assuming that his assignment is not crucial to the overall success of the project. Some degree of "supervision" is the equivalent of simple politeness; you ask how the job is coming as you would ask a close social friend about his health or that of his family. This type of minimum management attention is essential to good morale.

Over-supervision gives the employee the impression that you do not trust him to carry out his job; it arouses resentment, stifles initiative, and can easily lead to more time being spent on reporting and documenting than on doing useful, creative work. It is extensively practiced by government agencies and industry primarily because it builds up the perceived importance of the supervisor's job. If enough detailed reporting is required, a full staff may well be required to read the reports; everybody knows that the more employees you have the more important is your position. Another common reason for requiring extensive documentation and reports is to build a paper wall behind which the supervisor can hide when the brickbats start flying. When something goes wrong (and Murphy's Law says it will[1]) it is comforting to be able to bring out a six foot stack of reports and say, "I did everything I possibly could to ensure success."

Threading the narrow course between under- and over-supervision may sound like a very difficult decision-making process. In real life it is not all that hard if you avoid trying to set absolute standards that are independent of the person involved and instead are guided by the individual reactions of your personnel. Fortunately, most people are rather poor actors and are unable to completely disguise their feelings when you bug them, so there is usually available a feedback loop that warns you as you approach the overzealous limits. Only a man who is so preoccupied with himself that he makes no attempt to observe the reactions of others has any real trouble. But in the mystique of modern management this feedback is considered so crucial that many organizations send their executives to two or three week "sensitivity training" courses run by psychologists who are supposed to teach an appropriate awareness of the feelings of others. Personally, I feel that the only requirement is that the successful supervisor be a gentleman (or lady) according to the classic definition: A gentleman is a man who never offends anyone unintentionally.

I have been talking about the immediate effects of under- and over-supervision. Actually the most serious effects are those that show up in the long run. Some years ago there were a number of "controlled experiments" in which a lax management was replaced by a strict management with the result that productivity per worker increased substantially. This may well happen in the short run, expecially for a production operation. Fortunately, some of these studies were extended and the organizations were revisited after several years. It was found that the increased productivity of the strictly managed group had disappeared and the members were worse off than when the study was started. The reason was very simple. All the good people had gotten the hell out and found more rewarding jobs. The people who were left were incapable of getting a better job elsewhere and were also incapable of doing a good job where they were. The overly strict manager should not want anybody working for him who is willing to. The situation is reminiscent of Groucho Marx's perceptive comment that he would not join a club that would be willing to have him as a member. It is less obvious, but equally true, that overly lax management in the long run drives off the good people. They feel unappreciated, they see others putting forth little effort and apparently receiving comparable rewards, and they look for better opportunities elsewhere. Excessive turnover is the strongest feedback loop. Unfortunately it comes pretty late.

One unlooked-for result of strict management is a kind of impoverishment of ideas. The employees of a very "strong" manager feel, usually with good reason, that the boss is not very interested in suggestions, opinions, or ideas that are at variance with his own. They generally learn to treat his suggestions as orders and spend little or no time looking for a better way to accomplish the job. Thus the organization loses the benefit of the varied training, experience, and imagination of many of its employees. A beautiful illustration of the benefits of incorporating a variety of attitudes and viewpoints is afforded by the garden walls of the University of Virginia. For these gardens, Thomas Jefferson designed serpentine walls. They are built of single courses of brick but,

instead of being perfectly straight, they wind sinously back and forth in beautiful long, sweeping, shallow curves. This gives them the effect of having broader bases and all of them have stood up for the past 160 years to anything that the weather in the Virginia Piedmont could throw at them. It is generally agreed that if each wall had been built straight with a single course of brick all of them would have blown over in the first heavy wind. The wise manager makes it clear that suggestions from any source will receive fair consideration and thus tries to find the strength that results from a variety of attitudes.

TO EACH HIS OWN.

One of the most difficult jobs facing a manager is the assignment of responsibilities. I referred earlier to the need for assigning each job to someone who can do it or at least learn to do it. It should be noticed that this requires the direct violation of the Peter Principle, which states roughly that everyone is promoted until he reaches an assignment he is totally incompetent to carry out. It is amusingly phrased but all too real and common. So the attempt to assign work to people who can do it involves a conscious and deliberate attempt to defeat the Peter Principle. It can be done but it is not easy.

The next guiding principle in making an assignment is, insofar as possible, to distinguish a carefully definable and complete piece of work with a minimum of interactions with the rest of the job. It should be an entity with distinguishable and specifiable inputs and outputs. It should be possible ultimately to write an interface document specifying everything needed to ensure this specific piece of the job will fit in with the rest to make a complete system. It should be something with which the man can identify—his piece of the system. In the case of electronics, it should be a device testable in its own right, such as an oscillator, a receiver, a modulator, a transmitter, etc.

This may seem so obvious that the reader is unable to imagine any other way in which a large job can be broken down. But in fact, complex jobs are frequently broken down in accordance with academic disciplines, specialized training, or even the components involved. To take an extreme example, it would be conceivable to train one or more resistor specialists and assign them the responsibility of selecting all resistors in all electronics packages. One need know precious little about electronics to realize how disastrous this particular assignment would be. But something like it does happen often in mechanical or hydraulic systems, where it doesn't work very well either.

Now for a much more arguable and less commonly practiced rule. Having selected a man and a piece of work with which he can identify, give him the *full* responsibility for that piece of the job, all the way from design through test to ultimate use. This piece of management philosophy is directly contrary to the tradition of many industries. It was innovative on the part of the Applied Physics Laboratory and I feel had a crucial effect on some of our successes.

When the guided missile age was young, most people designing and building guided missiles had an aircraft industry background. In the aircraft industry it was traditional to distinguish carefully between a design engineer and a test engineer. By and large a test engineer was an engineer who had flunked out as a design engineer. Design engineers provided drawings to the shop and forgot about them, going on to design something new. The shop built in accordance with the design engineers' drawings and turned the finished product over to the test engineers. If the test engineer said it didn't work, no one was in a position to determine whose failure it was and no one felt responsible for finding out except possibly the manager himself. To put the matter in modern system engineering terms, the operation was open loop.

A management system, like most systems, operates best when the loop is closed. During the Terrier 1-B program, the Laboratory had occasion to borrow a senior hydraulics design engineer from a major industry. After he had been here several weeks, a group of us were convoying him to lunch through the shop area. He suddenly stopped in front of a milling machine and pointed to the work in progress with a trembling finger, and said: "My God, they are making something I designed. As far as I know, nobody before has ever built anything I designed. If you are going actually to make these things, I'm going to be more careful." A design engineer cannot learn or even care very much if no one lets him taste the fruits of his labor.

The ultimate in open loop assignments, widely practiced today, is to select a small group of the very best, most knowledgeable, most imaginative engineers and assign them to proposal writing. If the proposal sells, it is then assigned to a totally different group of less skilled and less imaginative engineers to be carried out while the stars are writing further proposals. This usually results in the assignment being carried out far less well than anyone would have expected from reading the proposal. I firmly believe that this practice is responsible for the low repute of much industrial engineering today. It is a system that I have steadfastly refused to adopt.

A manager should never forget that he may implicitly be making a major technical decision simply by the choice of the person to whom he assigns a particular job. Suppose, for example, that a timer (i.e., a device that throws a switch some seconds after an initiating signal) is required. The manager may ensure the development of a mechanical timer, an electronic timer, an acoustic timer, a thermal timer, a hydraulic timer, a pneumatic timer, or a chemical timer simply by assigning the development of the timer to an individual of known background and predilection. This is not necessarily bad if the manager has good reason to know which type of timer is best for the

job. What would be bad would be to make this decision unwittingly. Many years ago the production contractor for Terrier designed a mechanical timer that activated various internal systems at appropriate times. The device proved highly unreliable and I requested a feasibility study of an electronic timer to replace it. In due course I received a brief statement that a study had been made which showed that it was not feasible to develop an electronic timer for the purpose. Shortly thereafter, while visiting the contractor, I decided to track down the details of that study. My investigation finally led to a junior engineer fresh out of college who had been assigned the study. I asked him how he had determined that an electronic timer was unfeasible. His answer was unarguable. "I couldn't design an electronic timer. I know from nothing about electronics."

MODERN MANAGEMENT TOOLS

The capabilities of the modern high speed digital computer are truly awesome. But it must never be forgotten that a computer is only a tool and in no sense a substitute for the human mind. Like any tool, it can be either used or misused. If programmed to do so, it will produce irrelevant nonsense with the same equanimity with which it produces valid answers to meaningful problems. It is like a hammer and a chisel that in the hands of Michelangelo can turn a rock into a miracle of beauty and in the hands of the average duffer produce rubble.

People have been unable to resist the attempt to improve the management process by the application of any of a number of techniques, such as PERT (Program Evaluation Review Technique), that enable the computer to assist in the preparation of regular reports that are intended to advise top management of the status of the program. PERT became very popular mainly because it was used in the Polaris program, which was a notable success among DoD development programs. However, it is noteworthy that Vice Admiral Levering Smith, who was the technical director and is generally given the major share of the credit for the success of Polaris, has said that the role played by PERT in the success of the program has been generally exaggerated. The reason is very simple: PERT simply monitors the rate of accomplishment of your objectives in accordance with the plans as they were initially laid out. To the extent that PERT requires program planning in considerable detail, it is useful. Good careful planning is the *sine qua non* of program management; if the plans are faulty, however, PERT has no way to tell you that. In short, PERT cannot protect you against the unforeseen. Foresight is the exclusive prerogative of the human mind. If a development program is ill-planned, PERT can only help ensure that the bad planning is not departed from.

I myself incline to go somewhat further than Admiral Smith. I believe there is increasing evidence that the use of modern management tools, of which PERT is typical, not only may do little good but may sometimes be responsible for considerable harm. It allows interim progress reports to be made that are more or less unconsidered by the human brain. When a human was required to sift through the various facts to arrive at a status report there was always the possibility that he would notice a piece of bad planning, an overlooked item, a missing test, and the like.

Because computer capabilities make it possible, it is customary to break down the work required on even a very large system into rather fine detail, perhaps as small as one or two man-months. Now we come to a basic human characteristic. If you as manager assign a job to an individual engineer and tell him he has eight weeks to do it, he will take at least eight weeks. Even if he himself thinks he can do the job completely in an afternoon, indeed even if he does the job in an afternoon, he will spend the remainder of the weeks checking and rechecking because of the fear that he must have misunderstood something to account for the huge discrepancy in time.

There is little evidence that modern management controls prevent overrunning in time and cost, since they cannot cope with unforeseen problems. However, there is every reason to believe that they can be very effective in preventing completion of the job faster and cheaper than planned. There are other factors reinforcing this situation. The engineer given an eight week assignment knows that the manager has planned his charges against the contract so that eight weeks of salary for that engineer are chargeable against the contract. If he does the job in an afternoon, he presents the manager with the very difficult problem of finding some alternate source of funding to pay his salary for the rest of the time. The money saved does not enrich him, his manager, his company, or even his sponsor—if it is a government sponsor. Any money left over at the end of a government contract goes back to the U.S. Treasury and nobody is particularly happy about that.

Years ago when management controls were much less developed, it was customary to assign rather broad areas of responsibility. Under these circumstances if a particular job could be done in an afternoon instead of eight weeks, it posed no difficulty because the engineer could simply proceed to another of the pieces of his broad responsibility and he was reasonably sure to find one that would take longer than expected. So he could make up on the potato chips what he lost on the peanuts. Modern controls are indeed exceedingly effective in ensuring that anything you lose on the peanuts is a total loss and that you are legally restrained from making it up on the potato chips.

In case the reader feels that finding a way to do an eight week job in an afternoon is too extreme, I would like to give some illustrations of the kind of time that can be saved by an alternate approach. In the early Terrier days we were experimenting with a device, a roll polarimeter, that incorporated a ferrite

mechanism to rotate the plane of the polarization of a radar beam. I was very concerned about the temperature coefficient and asked an engineer to make measurements at −40°. After a day, he came back with pardonable pride to tell me that he had located a refrigerator with a −40° capability which was available with only three months delivery time. Fortunately another engineer had an alternate suggestion. He filled up a cardboard box with dry ice, put the device inside, and made the desired −40° measurements. Total elapsed time, two hours. On another occasion a Terrier test vehicle was being prepared for flight test at Inyokern. A microswitch was not operating because the surface that should have actuated it did not push the microswitch button far enough. A first (completely normal) suggestion for repair was to remount the switch in a higher position. Because this required remaking the brackets and because of access troubles, it was estimated that the process would require three weeks. An alternate suggestion (which was adopted) was to put a drop of solder on the microswitch button. That worked fine. Total time of repair, about 20 seconds. These are by no means isolated examples, simply two that leaped to my mind; however, all the good examples are from earlier times when management controls did not prevent such innovative approaches and the contract was not written to punish ingenuity. Notice that you don't have to reward ingenuity—you just have to refrain from punishing it.

MANAGEMENT VERSUS LEADERSHIP

The preceding section on management tools made frequent use of the term ''management control.'' This reflects the simple truth that the greatest attention of management today is on controlling the program to prevent something from going wrong. ''Control'' suggests restriction. Policemen control crowds, secret police control populations, Russia controls Afghanistan. Control is exerted primarily by saying, ''Thou shalt not.'' Indeed, particularly in the government, most management activity consists of saying ''no'' to almost everything. The reason is not far to seek. Anytime a manager says ''yes,'' he takes the risk that he may subsequently be proven wrong because the suggested action may prove unwise. Anytime he says ''no,'' there is no possible way of proving he was wrong since the suggested action never gets a chance. ''Yes'' is always risky and ''no'' is always safe. I frequently refer to this kind of ''safe'' managers collectively as ''the abominable no men.''

Unfortunately a development program that is free of risk is not truly a development program. ''Nothing ventured, nothing gained'' is quite literally true of R&D. What is needed for a productive R&D program is not management but something that can only be described by that old-fashioned word *leadership*. A leader does not say ''no''; he says ''follow me.'' The men who founded this country were leaders. They took risks—horrendous risks. They risked their lives, their fortunes, and their sacred honor. And wouldn't it be wonderful if we still lived in a country where it was possible for public men to pledge their sacred honor without embarrassment or fear of evoking derision. Today one cannot even say ''I am not a crook'' without arousing unfortunate memories of Watergate. I have small hope but my best wish for the world, and specifically for this country, is that it can find its way back to the position of recognizing *leadership* as something more worthy of respect than management.

REFERENCE

[1]A. Bloch, *Murphy's Law And Other Reasons Why Things Go Wrong!*, Price, Stern, Sloan, Los Angeles (1977).