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TRANSFORMATION OF THE AMERICAN

MANUFACTURING PARADIGM

VOLUME I

By

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A DISSERTATION

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ABSTRACT**TRANSFORMATION OF THE AMERICAN
MANUFACTURING PARADIGM****By****Paul Timothy Bushnell**

In response to the recession of the early 1980's and the loss of American competitiveness, American managers attempted to learn Japanese approaches to the organization of production. This study explores the meaning of this unprecedented learning from abroad by placing it in the context of American manufacturing tradition as well as preexisting domestic programs of reform that had developed in the 1960's and 1970's. As chapter one explains, manufacturing management has been guided throughout this century by the core Tayloristic principles of (1) the separation of planning from execution and (2) the compartmentalization of both planning functions and shop floor tasks. These principles were challenged by the success of Japanese innovations in worker participation, quality control, and production and delivery scheduling. An examination of American developments in these three fields prior to 1980 reveals both struggles to break free of the Tayloristic tradition and frustrated efforts to further extend the application of its principles. The number of experiments with worker participation increased continuously during the 1970's representing a clear

challenge to the tradition. Meanwhile, preeminent leaders of the quality control profession were articulating a need to reject the traditional Tayloristic assignment of the responsibility for quality control to a single quality control department and advocating development of quality control skills and a focus on quality problems throughout the firm that would bring quality control to the sources of problems. In scheduling, decade-long efforts to transfer all decisions about work priorities to a central computer using a technique known as materials requirements planning (MRP) were frequently acknowledged by the end of the 1970's to have failed. Japanese approaches to quality control and scheduling employing a high degree of worker participation are shown to have presented American managers with a coherent alternative to the Taylor paradigm for the management of complex production systems. The essence of the paradigm is development of grass roots problem solving ability and the structuring of incentives within all niches of the production organization to promote the continual improvement of systemic coordination rather than a series of discretely conceived local productivities.

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I have been fortunate in being able to write this dissertation under the guidance of a man I consider one of the most vigorous, passionate and encompassing intellects at work in the field of economics. Embodying more than anyone I have known the ideals of Emerson's "Self Reliance," he instinctively and insightfully draws out that which is most original in all of those around him. He was often able to express my own thoughts better than I could myself, stripping away, both in conversation and as editor, all that is pedantic, digressionary or merely according to form in order to preserve and build up directly and coherently the really important ideas. Robert Solo is responsible for providing me with the intellectual nourishment that allowed me to survive and at times to flourish during my time in graduate school. I recall with great fondness the first couple of years in which it was my habit to stop in at his office every couple of weeks to express with confidence of a comprehending ear any thoughts I had about economics or anything else and to have the pleasure of literally watching him think, the degree and orientation of his engagement in what he was saying always registering minutely in his eyes and the tilt of his head.

Out of these conversations and many like ones subsequently I was given the confidence in the value of my work without which I may well have never completed a dissertation.

Despite the reputation of the university, I have learned not to take for granted the opportunity for freely searching conversation, the heart and soul of the intellectual life. I have also been blessed with such conversation with several other faculty including the members of my committee, Harold Wein, Mary Cookingham, and Paul Strassman. Harold Wein provided me with sustaining employment while I wrote my dissertation, in the course of which we very happily could not resist indulging our mutual interests in dissecting the shortcomings of microeconomic theory and antitrust law as well as a host of other topics in political and social economy and in life generally. I am grateful to have been able to absorb what little I could from his wealth of knowledge in industry and economics. Mary Cookingham has always been a congenial link within this department with the values and vocation of the historian and has shown a refreshing undogmatic integrity in her classes and in her critiques of my work. Paul Strassman I would like to thank for injecting a judicious amount of expediency to bring this dissertation to a conclusion and for conveyance of his insights into the methodology of economics and his own work.

Writing this dissertation brought me to a greater awareness of the distinctiveness of the intellectual

heritage I owe to my parents. There are few boundaries in their intellectual universe, nothing that is repelled as being alien or inherently uninteresting. They take and expect great pleasure in the variety of experience and personality they see around them, appreciating each in its own way. The underlying belief seems to be that to understand is to love. I feel that growing up in such an environment leads one away from simple generalizations about the world. At the same time, there has always been a strong sense of political and spiritual caring about the world, that leads one to search for the right side of history, or perhaps a kind of moral order. Being emotionally situated between the psychological and spiritual poles of wanting to understand each part of the world for itself and wanting to find meaning within the world as a whole, has prepared me well for scholarship of a certain type and I hope and feel that this is reflected in the present study.

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INTRODUCTION

This dissertation is a study of the transformation, associated with the industrial crisis of the 1980's, of the generalized image prevailing within American enterprise of the manufacturing process and how it should be managed. It is true that the coherence of any such generalized image is problematic since different industries use very different technologies and serve very different markets. It has been commonly accepted, nevertheless, that there are several clearly salient, general features of production in a modern industrialized economy. One of these is, of course, extensive division of labor, the starting point of Adam Smith's inquiry into the wealth of nations in 1776. Closely associated with the division of labor are the principles of "scientific management" developed and advocated by Frederick Winslow Taylor early in the twentieth century. Taylor's work helped to found the modern study of production management while generating the first significant wave of conscious management reform in American history. Our focus will be on the erosion of Taylorism, culminating in a second great wave of management reform.

To document a fundamental transformation of American managerial thought raises the question of the relationship between theory and practice. Unfortunately, what lacks, not only here but in American business scholarship generally, is a satisfying historical account of managerial practices in the twentieth century.¹ One would like to know, for example, to what extent Taylor's principles were really implemented. For they were almost nowhere adopted in their pure form despite the fact that they became dominant in the realm of organized discourse among those who attempt to formulate general principles of manufacturing organization and control.

For the most part, discourse on production management has consisted of a stream of advocacies that attempt to persuade by logical argument and a few key examples. Acceptance of the advocated goals as the ideal does not mean that they are implemented in the terms in which they are expressed. The semantics of a paradigm are extremely problematic. Yet a commonly accepted paradigm must surely be a critical variable in the formation of practice. Its

¹ Scholarly work on the history of production management is exceedingly scarce and fragmentary. There are of course many business and economic histories that emphasize the development of markets and new technologies and labor histories that emphasize union-management struggles, but little that focuses specifically on how production is organized once the basic facilities are in place and workers are on the job. Textbooks are full of descriptions of how things ought to be done, but they rarely give useful characterizations of the state of actual practice.

very coherence is a psychological and social force influencing the shape of our production organizations.

Whether it was because management followed the teachings of scientific management advocates or because independently emerging managerial strategies were persuasively rationalized, it is generally agreed that the fundamental features of Taylor's system were incorporated into American industry in the second and third decades of this century. The first chapter of this dissertation summarizes the Taylor paradigm and shows in a general way how developments in industry since Taylor's time have served, up until recently, mostly to extend, deepen and support his original vision.

The second chapter is a review of the principal facts relied upon to support the contention that fundamental reform of American management, particularly manufacturing management, was needed. The concern in this chapter is not to evaluate the need for managerial change but to summarize the facts which served (and were sufficient) in American public discourse to bring about a break with the Taylor paradigm. The transformation follows an outline somewhat analogous to the theory developed by Thomas Kuhn in his The Structure of Scientific Revolution. Burdened by accumulating discontents and anomalies, the American paradigm breaks under the failure to meet Japanese competition and is replaced by another that takes as its model the Japanese approach which exhibits all the

organizational and technological sophistication of U.S. industry while incorporating several striking innovations.

Japanese management (or the management style of several of the most successful American companies sharing certain characteristics with Japanese firms) came very rapidly to be perceived as a necessary part of the solution to the loss of American competitiveness. Most of the salient innovative features of Japanese management relative to American practice fell into three categories: (1) worker participation, (2) quality control, and (3) scheduling of operations and deliveries. Innovations in each of these three areas can be emulated independently of one another, but they are also theoretically and practically integrated by Japanese firms into what is often referred to as the just-in-time (JIT) production system. It is the interconnectedness of the whole range of Japanese innovations which allowed them to function as a new paradigm of management.

Once the new paradigm came into view, it became possible to see how certain American managerial developments before 1980 were signaling the need to break with the Taylor paradigm and how they set the stage for adoption of Japanese innovations. Before the emergence of the Japanese management paradigm, domestic managerial ideas and innovations that broke the Tayloristic mold remained largely isolated from each other in different functional sectors of management so that their larger implications

remained latent. The third, fourth, and fifth chapters of this dissertation are separate, focused examinations of domestic managerial innovation and thought in the areas of worker participation, scheduling, and quality control.

Experiments in worker participation in American industry grew steadily throughout the 1970's, cumulating into a well recognized quality-of-work-life movement by the end of the decade. Chapter three describes the magnitude and the character of this movement, along with its associated rationales, so that American management's receptivity to the high degree of worker participation as a centerpiece of Japanese practice can be put in perspective.

The fourth chapter will describe methods of computerized production and delivery scheduling that were pioneered in the 1960's and propagated in the 1970's by an American professional society's educational crusade. Out of the varied and fragmentary accounts available in the specialized literature, an attempt is made to construct a coherent explanation for the overall failure of this effort in scheduling and inventory control. The nature of the failure will be seen as a contributing factor to American receptiveness to Japanese scheduling techniques and the Japanese manufacturing management paradigm.

In the fifth chapter, we will see how the recognized leaders of the American quality control profession developed a strong critique of American quality control practice and a plan for its reform in the 1960's and

1970's. A review of some of the details of the history of quality control since the 1930's will provide needed context for the quality control experts' recommendations. These recommendations, it will be seen, pointed toward a need to modify modern manufacturing organizations in ways that conflict with the Taylor paradigm.

Scheduling and quality control are subjects that require an introduction for the general reader. They have always been important standard components of production or operations management courses in business schools. But in the 1980's, they became for the first time, prominent topics in the general business press because of a new perception of their vital importance to the overall level of industrial competitiveness. Scheduling and quality control, on closer examination, turn out to be much more than just two areas of management in which the Japanese happened to have made particularly notable contributions. They are in fact the central coordinative activities of any production organization. Scheduling and quality control take as given a set of facilities and a complement of people with certain skills as well as markets for supplies and products. Once these general tasks and resources for production are essentially in place, quality control and scheduling must be employed to time-phase all of production's interdependent activities and to determine and enforce standards for all of the physical parameters of processes and products in each stage and branch of

production. The coordinative functions of scheduling and quality control are critical to the efficiency of the overall production process and to the success with which production as a whole is harnessed to the character and timing of market demands.

They also appear in this dissertation as case studies of experience with the Taylor paradigm. To focus separately on different dimensions of production management allows us to see in greater detail how the Taylor paradigm works out in practice and to explore the paradigm's viability in a context that is relatively free of general institutional predispositions to manage according to that paradigm. As are all managers in one degree or another, those who are faced with the responsibility for scheduling or for quality are not focused exclusively and directly on productive efficiency, the ultimate value in the Taylor paradigm. They judge their success on the basis of a whole complex of qualitative measures of coordination and control and they must do so because there is in fact no definitive way of determining the relationship between their activities and overall efficiency. Absorbed by the details of their tasks and the test of practicality, they are sometimes drawn toward solutions and approaches that are at variance with the paradigm within which they normally operate. After reviewing the experiments of the 1970's in worker participation as obvious challenges to the Taylor paradigm and forerunners of participatory reforms of the

1980's, an examination of the recent history of management thought in the fields of scheduling and quality control gives us an opportunity to see how several independent developments were contributing to departure from that paradigm.

The early 1980's was a time not only of great ferment in management thought but of rapid emergence of new technologies. Advances in computerization of manufacturing equipment reinvigorated old dreams of the completely automatic factory while opening new vistas of unprecedented flexibility in the control of manufacturing processes. In particular, the beginning of the 1980's saw explosive growth in the development and production of robots and the generation of a tremendous interest in manufacturing systems that pioneered the central, computerized coordination and control of groups of machine tools linked by automatic material handling equipment. The sixth chapter deals with the capabilities of this new technology and the pattern of its diffusion and deployment. We will show that its potentials have been selectively perceived and exploited to extend such Taylorist norms as the radical separation of planning and execution. In addition, we venture a focused and skeptical look at the solutions offered by this newest of technology to cope with quality and scheduling problems, shown in earlier chapters to be largely unyielding to Taylorist approaches.

Chapter seven will describe the emergence in 1980 of a consensus that American management needed fundamental reform, and will explain the Japanese production management techniques to which American managers became so suddenly attracted. It will become apparent how Japanese innovations in worker participation, quality control, scheduling and the development of automation are closely interconnected, forming a sharp contrast to the mutual isolation of previous American developments in these fields.

American managerial practice is still essentially in the Taylorist mode. However, we will argue that the growing perception of Japanese innovations as conceptually and practically integrated has spearheaded the transformation of the established paradigm and will constitute a continuing force in the shaping of American manufacturing organizations.

There are larger implications to this study which go beyond the realm of manufacturing. The Taylor model has deeply influenced how people view the role of the individual in any large organization and how decision making within large organizations must take place. Most people are aware on one level or another that it is the Taylorist organization on which our material abundance and culture are based. The Taylorist rationalization of factory organization serves as a fundamental mode of rationalization for the exercise of authority in society, and the Taylorist factory model serves as a template for

nonindustrial organizations --- in the schools, in government and in other spheres. If the Taylorist paradigm can be dislodged, we may expect to see many of our institutions begin to recast themselves in a new image.

CHAPTER ONE

THE TAYLOR PARADIGM

This chapter will attempt to show why we are justified in giving Taylor's name to the dominant framework of thought in American manufacturing enterprise during many decades of tremendous economic expansion and change. To begin, we will discuss Taylor's seminal work which has continued to serve effectively, well into the later twentieth century, as a touchstone of efficient industrial management. After discussing early forms of implementation of Taylor's doctrines, we will consider how the development technology, the growth of management hierarchies and staff, and the rise of union power have all modified, yet in many ways reinforced and brought new ways of implementing conventional scientific management principles. Following this, academic management thought since Taylor will be reviewed to estimate its impact on the position of scientific management as the dominant model of efficiency in the management of manufacturing. Finally, the shift of focus away from manufacturing on the part of management in the post World War II period is described.

Problems of Management in the Late Nineteenth Century

The first great wave of interest in the evaluation and reform of manufacturing management grew out of the financial collapse of the late 1870's and the problems caused by the growing size and complexity of manufacturing establishments. One of the principal focuses of attention was the difficulty of getting employees of large firms to work with intensity under the traditional scheme of paying by the day. In small enterprises of a few men, the owner-entrepreneur typically had detailed knowledge of all phases of an operation and could monitor and evaluate his men by working along-side them, using reward and punishment as he saw fit. In the larger enterprises of several hundred or thousand men that were being built up in the late nineteenth century, no single man or small group of men could realistically be deeply involved in all operations on the factory floor. Foremen and, increasingly, middle managers had to be hired to enforce the will of management upon those doing the actual work.

Yet the foremen did not themselves always have a clear interest in intensifying work since their rate of pay was not directly linked to their success in this regard. Standards of productivity could be set through convention while taking advantage of the ignorance of the employer as to exactly how much could be accomplished in a given amount of time with a given amount of resources. In addition, the foremen had to take into account the ability of workers to

push back and withhold needed cooperation. The workers would compound the problem by attempting to cooperate among themselves in working at a comfortable pace which could be made to appear to the foremen as representing a reasonable level of intensity. Frequently, the foremen, many of whom were not of the caliber and experience of the owner entrepreneurs,¹ were less capable of mastering the details and potentials of production techniques, and workers had to be allowed some latitude in determining their own work habits and standards. But when foremen were pressed to step up production, they often resorted to capricious and unreasonable discipline and firings which created massive worker resentment and a rising wave of union organizing activity in the 1890's that continued into the first two decades of this century. Thus the attempt to squeeze more output out of workers on a fixed daily wage had increasingly severe consequences for the new large establishments.

Variations on piece rate pay that linked the amount of wages paid directly to the quantity of work accomplished came to be seen in the 1880's as a possible way out of this situation. The problem of workers slowing the pace of work and keeping productivity low was not, however, solved

¹ Judith Merkle, Management and Ideology: The Legacy of the International Scientific Management Movement (Berkeley: University of California Press, 1980), p.23; Robert B. Reich, The Next American Frontier (New York: Times Books, 1983; Harmondsworth, Middlesex, England; New York: Penguin Books, 1984), p.37.

simply by use of the piece rate. Wage incentives to produce more would lead to the setting of higher conventional standards for the rate of production as workers sped up. This would lead to a lowering of the piece rate when the owners were tempted to redistribute the proceeds of increased efficiency back to themselves. Once this cycle had been demonstrated to the workers they would go back to slowing the work pace to keep piece rates high.

Taylor's Management Doctrine

In the 1880's, Frederick Taylor, an engineer and manager, developed a powerful new vision of how workers could be made to work harder while preserving worker-management harmony. He perceived that workers would be willing to work with great diligence at a low piece rate if they were taught and encouraged to work with such tremendous speed and efficiency that their total daily pay could still be increased by 30% to 100%.² The meticulous research that Taylor advocated to determine optimal work methods and maximum speeds would supposedly uncover a vast and hitherto unsuspected amount of wasted motion and unlock secrets of huge increases in efficiency. Out of the cost savings from improved methods there would be more than

² Frederick W. Taylor, "Shop Management," as reprinted in Scientific Management, with a forward by Harlow S. Person, paper presented before a meeting of the American Society of Mechanical Engineers, (Saratoga, NY, 1903), (New York and London: Harper and Brothers, 1947), p.25.

enough to entice financially motivated workers into precisely following management instructions and demonstrating a new diligence. Not only would workers welcome the increase in pay but they would recognize the new piece rates and productivity standards as legitimate since they were scientifically determined rather than being the arbitrary and biased guesswork of management.

The depth of analysis of job tasks which Taylor pursued and advocated was far greater than what anyone up to his time had contemplated. His goal was to define explicitly the one best method of doing every job and to calculate the maximum speed at which it could be done. To do this, he would break a job down into its smallest definable units, timing each one individually with a stop watch, using for study only the most efficient workers during periods of peak performance. Breaking up a task into tiny units of motion served to reduce complications caused by miscellaneous delays between motions and more importantly to facilitate later calculations of minimum times for jobs which had not themselves been studied but which were composed of timed elements of other jobs which had.

Taylor claimed to be able to determine the optimum amount of rest and the amount of unavoidable delay which was to be expected for each job. The possibility of objectivity in such estimates has, however, always remained seriously in doubt. This doubt seems justified by a recent

demonstration that on at least one occasion Taylor misrepresented (as greater than it actually was) the amount of rest he allowed workers under his control.³

The greatest difficulty in carrying out a useful time study, as Taylor emphasized, is in identifying, controlling, and monitoring all of the many variables which may affect the time in which a task can be done. To find the optimum method, experiments have to be done with the states of these variables in various combinations. Investigations of complex processes such as metal-cutting can become quite time consuming raising the question of whether time and motion study is really economical in many cases. Yet Taylor demonstrated such an overwhelming intensity in his drive to reduce every last detail of work to formula that it even disturbed some of his disciples.

Once armed with "scientifically proven" time standards and methods for each job, management should then undertake, according to Taylor, to instruct, persuade, or, if necessary, force workers to adhere precisely to these methods and standards. Since productivity standards are set using the best workers it is to be expected that most ordinary workers cannot meet them and Taylor desired to construct the pay structure so that only the most capable workers would be able to earn the promised additional 30% to 100% in daily pay. Those not able to reach the

³ Merkle, p.29.

standards were expected to leave of their own accord because of low pay or be fired. Taylor rationalized that no unemployment would result overall since each worker would tend to find (or be forced to find) a job suiting his or her particular talents and that as the most effective workers were promoted to more challenging jobs workers would simply be rearranged into a hierarchy ranked by ability.

Taylor was often charged with depriving craftsmen of the opportunity to use their skill. His defense was that under scientific management there was available a path of promotions created by the effort to match individual worker ability to job requirements allowing the craftsmen to rise into the planning functions and giving unskilled laborers the chance to move into the scientifically simplified portions of skilled jobs. There was no doubt, however, that the removal of skill in the form of mental problem solving from all physical manufacturing activities was a central goal of Taylor's and indeed a prerequisite for job standardization. He emphasized that his methods enabled employees to hire a cheaper grade of labor.

As a part of his passion for imposing order on every situation, and to effectively implement time and motion study results, Taylor advocated a thorough rationalization of all aspects of shop activity. For example, it was more critical to avoid delays between successive operations when workers were being paid a piece rate based on a strict time

standard for a day's production. Adequate stocks of purchased materials and internally manufactured components had to be built up and delivered to their points of use in time. To this end, Taylor would have accurate, up to date records kept of all stocks on hand, the status of work in progress, and quantities of work waiting to be done by each class of machines and workers. Time studies would be used to estimate length of time to completion and a bulletin board showing queues for each machine would be used for spotting potential bottlenecks and rearranging order of work when necessary. Routing of work through the plant would be planned in advance and a separate group of workers dedicated to transporting materials would be activated by written orders triggered in turn by paper signals of work status so that the rest of the workers need only concern themselves with following the methods prescribed for their individual tasks. All problems of coordination were thus transferred to the planning room.

Workers and foremen were responsible in a Taylor system shop for recording all costs, times, and quantities processed in such a disciplined way that the shop could be run from the planning room with no need to establish conditions by actually walking out among the machines and workers. Extensive record-keeping would facilitate as well the establishment of performance standards and measure progress in cost reduction.

Also considered crucial to effective use of "scientifically" determined work methods was the standardization of shop conditions, particularly tooling. Taylor warned that having a number of tools of the same type possessing various degrees of quality would lead to difficulties in enforcing a high standard appropriate to the better tools. Maintenance of machines in a Taylor shop would be put on a regular, scheduled basis, not only for upholding standards but to avoid delays and increase predictability. Quality standards had to be more rigorously enforced as well since speeding up the pace of work always increased the danger of error. Taylor would therefore have a separate inspection foreman responsible for inspecting and certifying each job.

Taylor saw his ideas as the basis of a new era of worker-management cooperation. Workers would freely contribute their experience to the discovery of optimal methods confident that the implementation of those methods would be fair and lead to higher pay. Management would impose no arbitrary rules and would undertake to thoroughly instruct workers in the proper methods and to match each worker to the tasks which best fitted his or her particular abilities.

Taylor admitted there were serious obstacles to overcome in alleviating the suspicion of workers that scientific management was just another scheme to force harder work with little or no compensation (and increased

risk of unemployment.) But he liked to boast that under true scientific management worker cooperation and enthusiasm was the norm and strikes nonexistent. The key, he said, to preserving peace and building trust was to avoid rapid, wide scale implementation of time study techniques until a number of workers had been individually converted to the new system and could demonstrate the reality of just reward for increased diligence. He claimed that the many workers who were fired because of inability to meet the strict standards left with no hard feelings since they recognized the standards as objectively determined. Taylor himself also made subtle use of psychology to win workers over. He knew how to be firm and uncompromising yet personal and friendly, listening to what workers had to say and doing small things to create a perception of benevolence.⁴

Implementation and Influence of Scientific Management

The reality of scientific management was far from the ideal that Taylor described. The aversion of workers to incentive pay schemes based on time study erupted in several firms,⁵ most notably at the Watertown arsenal where

⁴ Taylor, p.184.

⁵ Richard C. Edwards, Contested Terrain: The Transformation of the Workplace in the Twentieth Century (New York: Basic Books, 1979), pp.102-3; Milton J. Nadworny, Scientific Management and the Unions, 1900-1932 (Cambridge, Mass.: Harvard University Press, 1955), pp.54,59.

the workers went out on strike in 1911. Inharmonious conditions were also suggested by a 1915 survey of 35 scientific management shops which found that efforts to introduce time study were crude and the time standards set up highly arbitrary.⁶ Problems were caused by the fact that the tools of scientific management were usually looked upon as mechanical techniques capable of being implemented without consideration of workers' values and concerns. In the opinion of the chief investigator, the autocratic mode of implementation and the tendency of Taylor's methods to break up and routinize the skilled jobs of craftsmen left the workers little hope of being dealt with fairly. Creation of a hierarchy of workers with piece work or other incentive pay also seemed a clear threat to the solidarity of craft unions.

The period of strenuous union opposition to the principles of scientific management lasted only a few years from 1911 to 1914 or so when the union position began to soften.⁷ (Prior to 1911 virtually all plants with scientific management were nonunion.⁸) During this time, most promoters of scientific management were hostile to unions, especially Taylor who saw no place for collective bargaining when it came to setting scientific standards for

⁶ Robert Franklin Hoxie, Scientific Management and Labor (New York: D. Appleton and Co., 1916), pp.39-61.

⁷ Nadworny, p.74.

⁸ Ibid., p.26

work and who believed that most organized groups had the evil effect of preventing the most productive individuals from rising in order to preserve group solidarity and power, ie. of preventing them from responding to bonus pay for higher productivity.

When the circumstances of war production brought scientific management and labor union leaders together in working relationships the whole situation began to change. The management theorists learned that union leaders could be quite reasonable and that collective bargaining could be useful in establishing cooperation. At the same time, union leaders found that many of the new management theorists could be relatively progressive in their views on working conditions and the workers' right to have a voice in decision making.

The decade of the twenties saw a steady growth in the cooperation and interchange between union officials and the exponents of scientific management. Ideologically, unions aligned themselves with the general cause of efficiency in industry and, in many cases, came to see increasing efficiency as a way of saving jobs or preserving union wage rates. Scientific management experts were sometimes hired as consultants by the unions and toward the end of the twenties there were some unions that even established consulting services for the use of employers. Most of this activity seems to have been concentrated in the textile and railroad industries. While scientific management and

unionism officially joined forces, it must be noted that time and motion study, if not implemented in open consultation with unions, was still capable of stirring deep worker resistance.⁹ This was most likely to happen when one of the many self proclaimed, unsophisticated efficiency experts capitalizing on the reputation of scientific management was successful in selling his crude scheme to management.

Ironically, scientific management, as a comprehensive approach to manufacturing was not as popular with management as it became with the unions.¹⁰ Hardly any firm had the confidence to install the complete Taylor system and Taylor complained that management often had far too little patience to wait the two or three years he thought necessary to realize the main benefits.¹¹ The increase in overhead caused by building up a planning department conflicted with the managerial habit of maximizing the proportion of employees involved in direct labor, and management always wanted to see quick results and maintain the option to reverse or change course according to financial conditions.

Scientific management was a movement created by professional engineers whose interests and values were

⁹ Ibid., p.148.

¹⁰ Ibid., p.146.

¹¹ Taylor, pp.129-30.

distinct from those of both capital and labor. The engineers wanted to create a secure economic niche for themselves within industry. But they wished to be seen also as servants of society in general, dedicated to their craft more than to the financial success of any particular firm. Though they accepted the premise of working to increase profits, the leaders of scientific management were inspired most deeply by the challenge of creating an order and harmony which they saw in their mind's eye and which they thought could not help but be profitable as well.

Though firm owners were rarely willing to go as far in implementing the ideal shop control and planning systems as the management engineers wanted, the ideas of the latter group formed an intellectual framework within which well accepted techniques were developed. By the 1920's so many versions and adaptations of Tayloristic methods were being adopted in piecemeal fashion that its influence seemed pervasive although it became difficult to point to particular firms as examples of true scientific management. As the work of management engineers evolved, it fit within the spirit of research dedicated to analysis, monitoring, recording and optimization of times, costs, and motions which Taylor had so powerfully evoked. Taylor had founded a tradition which authors of industrial management texts decades later felt entirely at home with. Indeed, time and motion study and variants of the scheduling, routing and

information gathering functions of Taylor's ideal shop are still prominent staples of those texts.

Cooperative labor-management arrangements based on the implementation of scientific management techniques, however, did not, in most cases, survive the Depression.¹² The desperate effort to stay afloat by drastically cutting the number of employees, extracting more work from workers, and cutting wages, destroyed the willingness to cooperate and the hope that cooperation would suffice to preserve both profits and worker livelihood.

Scientific Management and the Division of Labor

Taylor and scientific management are often associated with advocacy of the development of more extreme forms of the division of labor. This is mostly because time study breaks down individual jobs into small components for purposes of analysis and because there was a tendency under scientific management to segregate the most routine jobs of a craft from those requiring interpretation and improvisation. But increasing the physical division of task was not in itself an important goal of Taylor's or of scientific management's.

Rather, The focus of scientific management was on discovery of optimal work methods through research, largely taking as given some general degree of the division of

¹² Nadworny, pp.139-41.

labor warranted by the extent of the market, the dispersion of consumer tastes, and existing machine technology. While time study is most easily applied to the most repetitive tasks, scientific management was actually developed in small and medium-sized firms making a fairly large number of product variations produced on multi-purpose machines.¹³

Taylor's greatest personal research efforts were in the field of metal-cutting in which skilled craftsmen must creatively combine many considerations in devising approaches to varying jobs. Taylor attempted to reduce the interaction of at least twelve relevant variables to a formula that could be used to determine precisely the fastest way to do any machining job that might arise. Each job, though in many way unique, would be broken down into a series of cutting operations whose specific parameters could be calculated using the patterns discovered through research.

As it turned out, the machine shop has been one of the least hospitable environments for the application of time study. Machinists, being among the most skilled people in industry, have fiercely defended their independence in determining how they will accomplish their work.¹⁴ Their defense has been successful because their knowledge has

¹³ The Taylor Society, Harlow S. Person ed., Scientific Management in American Industry, (New York and London: Harper and Brothers, 1929), p.14.

¹⁴ Harley Shaiken, Work Transformed (New York: Holt, Rinehart, and Winston, 1985), pp.28-44.

not, after all, been completely reducible to explicit formulas.

Ironically, mass production was not an early focus of scientific management efforts, partly because, with extreme division of labor, the natural dexterity and speed developed through experience in repetitive tasks created an efficiency advantage in the market that could serve as a substitute for improvements in methods obtained by research. While it was true that Ford's assembly line jobs were designed with the aid of time and motion studies, they were nevertheless crudely designed by people with insufficient time and motion study training. Motions were not really simplified and induced unnecessary fatigue.¹⁵

Although there is no necessary link between scientific management and the pursuit of extreme forms of the division of labor, they have been closely allied in the ideology of American management. High volume production with increasing mechanization and narrowing of task, and the Tayloristic optimization of work motions came to be linked together in a single image of what industrial progress was all about. Division of labor flowing from the extension of the market and standardization of product had long been seen as a mainspring of the mechanization process. The simplification of human motions which it entailed facilitated the design of machines to perform those

¹⁵ Merkle, pp.96-98.

motions. Likewise, scientific management's efforts at engineering human motions and all of the inter-linked flows of the manufacturing process to operate in as predictable and controllable a way as possible could be seen as prelude to mechanization. Taylorism in its classical form seemed to be an integral link in a chain of destiny leading toward replacement of human craft with the machine. It served, therefore, as a reinforcement for the faith in the potentials of large scale production and by implication large scale enterprise as well.

Technological Advance as a Tool for Implementing Tayloristic Principles

There has long been debate about the effect of technological advance upon the character of management and industrial work. Most of it has centered on the question of the economy-wide balance between the increasing need for highly trained people to work with sophisticated technologies and the de-skilling of those relegated to tending automatic machines. It is clear, though, that on the factory floor, technological improvements have been generally conceived as a tool for decreasing reliance on skilled craftsmen and bringing workers under even more detailed control of managers and engineers. Taylor's ideal of the separation of planning from execution and the comprehensive specification of task, far from being eroded, was most often brought closer to reality by new technology.

Mechanized work transport, of which the assembly line is the best example, and various forms of automation have been developing throughout the twentieth century as a means of controlling both the details of work procedures and the speed with which they are performed. As machines have taken over tasks from human hands, the need for careful instruction of workers in optimal methods has been substantially reduced while necessary synchronization of the work of machines and people has simplified the control of work speed.

With the assembly line, the complex paper system for routing work through the plant and transferring workers between tasks is replaced by the physical linking of fixed task, work stations in a single permanent sequence. The speed of the line determines the speed with which the worker works by making highly visible for each individual both the need to keep up and the failure to keep up with the overall pace. Piece rates or other forms of incentive pay are therefore no longer needed to bring the workers up to the desired speed. As in Taylor's planning system, the optimal pace of work is supposedly determined only by "technical" considerations but with added legitimacy derived from the fact that these considerations are for the system as a whole and not for each task separately so that workers have even less basis on which to question or resist the pace.

Thus assembly lines and more automatic machines have been able to substitute to some degree for Taylor's methods of shop control and aid in realizing his goals of standardizing methods and enforcing diligence. And, as in Taylor's system, mechanization and automation enable the details of work methods to be determined off the shop floor by industrial engineers.

While the assembly line and automation in general have mostly been associated with the highest volume production, computers and electronics have, since the late fifties been introducing new possibilities of off the shop floor control of task detail into small batch production. The first use of computers on the factory floor was in the computer numerically controlled (CNC) machine tool.¹⁶ The revolutionary feature of CNC tools was their ability to be programmed, ie. they could be made to move through a long sequence of operations directed by a prerecorded set of symbols instead of requiring the continual interventions and manipulations of a human operator. Since symbolic instructions could be prepared by programmers in an office, machine operators, it was thought, would merely have to load and unload workpieces and push a few buttons. Both the pace of work and how it was accomplished would be

¹⁶ The following discussion of the management of CNC machine tool production draws heavily on Shaiken, Work Transformed, and David F. Noble, Forces of Production: A Social History of Industrial Automation (New York: Alfred E. Knopf, 1984).

determined almost entirely by the program. In effect, instructions to workers could be replaced by instructions to machines.

All of this, at any rate, was the promise of CNC according to the designers and sellers of this equipment. In actuality, CNC tools, while certainly reducing the need for highly skilled machinists in many cases, have presented unforeseen opportunities and needs for operator control of the machining process. Nevertheless, the efforts of managers to limit worker input, especially with regard to programming, demonstrated management a recurrent determination to de-skill machinists and achieve the Tayloristic values of the separation of conception from execution even where lower efficiency was the result. Although there is no technical necessity for all programming of CNC machine tools to take place away from the shop floor, managers have clearly preferred that alternative.

There are at least two important functions that a CNC machine tool operator can or must perform besides machine loading and unloading. First, the machining process must be monitored and adjusted to prevent any malfunction that could cause damage to workpiece or machine, especially since CNC machines and often the parts made on them are quite expensive. Second, much time and money can be saved if operators are able, on the spot to edit programs which are typically imperfect when first tried.

Usually, however, management has attempted with the introduction of CNC equipment to use younger, less skilled workers who do an inadequate job of monitoring machine operation since they lack the experienced eye of the skilled machinist. Skilled machinists, on the other hand, have often attempted to learn on their own how to edit and create programs. Here is where the goals of management have been starkly revealed. Instead of welcoming the spontaneous learning of new skills, usually accompanied, it would seem, by a significant rise in productivity, management has tried to lock machine controls and lay down rules restricting all programming activity to management. This reaction has reflected management's belief that the contributions of workers to the effective utilization of the new equipment are only temporarily necessary until the bugs in the programming process can be worked out and the original promise of total management control can be fulfilled.

In conclusion, the development of technology has not meant a deviation from the principles that Taylor set down at the beginning of the century but a source of powerful new ways of putting those principles into practice.

Scientific Management and the Growth of Managerial Bureaucracy

Since the height of Taylor's popularity before World War I, there has been much change in the size and structure

of management. These changes can largely be understood as extending basic principles which Taylor laid down for shop control.

Aside from the increase in firm size, the most obvious change has been the growth in the number of supervisory and managerial personnel relative to those on the factory floor directly engaged in the processes of production. This growth was most rapid in the fifties. Between 1910 and 1940, the number of foremen per one hundred workers grew only 15% to about 2-3/4 foremen per hundred workers. But between 1940 and 1960 the ratio leapt upward by 55% to 4-1/4 foremen per hundred workers, then rose by a more modest 8% during the sixties.¹⁷ Similarly, the ratio of nonproduction workers to production workers in manufacturing was fairly stable from 1919 to 1940 fluctuating between 23 and 26 per one hundred. (leaving aside the worst Depression years, 1930-32 when it went a little higher) During war production the ratio dipped precipitously to a low of 16 in 1943 but then climbed steadily, reaching pre-war levels in 1949 and a new high of 35 nonproduction workers per hundred production workers in 1963. Afterwards, relative stability was regained and the ratio fluctuated between 34 and 38 per one hundred between

¹⁷ Richard C. Edwards, Contested Terrain: The Transformation of the Workplace in the Twentieth Century (New York: Basic Books, Harper Colophon Books, 1979), p.135.

1961 and 1974 making the average ratio for the 1961-74 period 50% higher than it was for the inter-war period.¹⁸

Some portion of this growth in the managerial fraction of the workforce may be attributed to added nonproduction functions, but the trend has also been a contribution to the fulfillment of Taylor's wish to transfer all planning work from shop floor workers to a planning department ie. management. The principal barrier to such a shift, in Taylor's eyes, was the impossibility of a single foreman grasping and monitoring all details of the work being done under his supervision. While the foreman, in Taylor's time, had nearly total authority over his men and freedom to carry out the tasks delegated to him by upper management as he saw fit, the practical limits of his power to direct and control workers was severe, allowing workers to exercise a considerable latitude in deciding how to accomplish their jobs. Taylor therefore advocated dividing the responsibilities of work supervision among several foremen, each in charge of a facet of the process such as scheduling, quality control, or work methods. The result of this, as Taylor pointed out, would be to decrease the number of workers and to increase the number of foremen and managers supervising them. The modern proliferation and growth of management departments has, in fact, been

¹⁸ U.S. Dept. of Labor, Bureau of Labor Statistics, 1975 Handbook of Labor Statistics (Washington D.C.: GPO, 1975), figures derived from data in Table 43, p.111.

associated with greater division of supervisory duties and line authority as well as the independent growth of staff. This trend is illustrated by the relatively recent attempts at matrix management in which people report on aspects of their activity to several different managers.¹⁹

As the size of management hierarchies have grown, they have become more bureaucratic, operating according to rules and written procedure. Such codification of established practice has come to serve the same function as Taylor's rigorously detailed instructions and incentive pay structures for shop floor workers. Modern bureaucracy demonstrated that the specification of task detail and carefully calibrated reward systems could be applied to supervisory as well as to production workers, a possibility that Taylor clearly perceived the desirability of.²⁰

One of the salient features of mid and late twentieth century corporate bureaucracy is the extremely fine, formal differentiation of employee positions and finely graduated pay scales, in combination with the policy of regularly and systematically promoting people from within the firm up well defined career ladders. A Stunning example is given by Richard Edwards for production workers at Polaroid. He calculates that there are 2100 combinations of job titles and pay steps available (nine possible pay steps for each

¹⁹ Reich, p.142.

²⁰ Taylor, p.105.

job title with raises dependent on performance) to a total of 6,397 people and that a similar profusion of job statuses and compensation levels exists for salaried personnel.²¹ For each job at Polaroid, there is a quite concrete and comprehensive description of virtually everything its holder will be called upon to do. For supervisors and managers in turn, there are prescribed criteria for evaluating those under them and mechanisms are put in place for holding them accountable in detail for adhering to those criteria.

Job standards are not and often cannot be set forth with the physical precision attempted in time and motion study, but, at Polaroid, performance evaluation based on written descriptions of job duties is specific, regular, and as objective as possible. Neither are employees paid on the basis of a piece rate or given bonuses linked directly to their output. They are, however, frequently eligible at predictable intervals for promotions and pay raises. The clear rewards for individual effort supposedly allow each employee to rise to the level that suits his or her abilities discouraging the tacit group formation of productivity standards which Taylor fought so vigorously. Legitimacy of performance expectations, rewards , and punishments is enhanced by being written and applied as rule. As rule, they represent both tradition and the

²¹ Edwards, p.134.

specifics of an overall design, dependent for its success on individual obedience. Working within such a system it is difficult to resist instructions of immediate supervisors since they are subject to the same set of rules. Here is a clear example, then, of how the rules of modern corporate bureaucracy have substituted for the experimental results of Taylor's science yet served essentially the same philosophy of control.

Reinforcement of the Scientific Management Mode of Control
by the Grievance and Collective Bargaining System

Management was responsible for the establishment of elaborate codifications of job duties, pay scales, and mechanisms of promotion.²² But unions have made use of these codifications and even forced their extension in the process of defending labor interests and worker rights. Because the personnel policies and specific performance expectations of employers have been subject to extensive planning and have been put into written form, workers have been able to use them managements accountable for their actions. Agreements with unions in the United States have usually established a formal grievance process whereby the

²² This section draws heavily from Edwards, Contested Terrain, Reich, The Next American Frontier, Ira C. Magaziner and Robert B. Reich, Minding America's Business: The Decline and Rise of the American Economy (Harcourt, Brace, Jovanovich, 1982; New York: Random House, vintage Books, February 1983) and Michael J. Piore and Charles F. Sabel, The Second Industrial Divide: Possibilities for Prosperity (New York: Basic Books, 1984).

written policies of a firm with respect to job duties, pay rates, promotion and layoff become the basis for negotiated settlements and legal rulings. Thus Collective bargaining has extended beyond matters of general wage rates into such things as work rules, task assignments, and criteria for promotions.

Unions have often seen a direct connection between employment security and the way in which management distributes tasks among workers. Management perceives its interest to be in minimizing the number of skilled people in its workforce, and thus makes frequent attempts to have the unskilled perform or learn to perform the routine parts of skilled jobs. It is also common for management to transfer some of the decision-making elements involved in skilled work to planning personnel within management. Both of these erosions of skilled workers' domain of responsibility are defended against by recourse to the written job descriptions and the common law of the shop made enforceable by the grievance process.

The employment not just of the skilled, but of all workers may be threatened by the power of management to redeploy the workforce. A high degree of flexibility in assigning work allows maximum use of employee time thereby causing a reduction in the number of workers needed. Union reinforcement of the clear delineation of job duties prevents this.

In their concern for equity in the distribution of employment opportunities, unions have also fought for the rights of seniority in matters of promotion, layoff and rehiring. Management has resisted, wanting the freedom to place much more emphasis on job qualifications and performance. Battles on seniority have tended to reinforce the trend toward detailed, formal designation of job duties and mechanisms of promotion.

The unions' defense of seniority has become dependent to a large degree on having a ladder of jobs clearly defined with rates of pay and levels of skill ascending together. When promotion up the ladder is heavily influenced by seniority which, after all, corresponds with experience if not ability, seniority is made to align more closely with skill and is thereby reinforced in its legitimacy as a criterion for higher pay, better working conditions and retention in case of layoffs. A major seniority issue has been the practice of bumping whereby layoffs are concentrated at the bottom of the job ladder, the less experienced workers being bumped from their jobs by workers with more seniority moving down the ladder. Bumping has been irksome to employers because it causes reshuffling of people among jobs leading to disruption of production and added training costs, but the point here is that the system rests on a carefully worked out definition and ranking of jobs.

Second, management has had to make its means of evaluating job performance as explicit as possible in order to better defend itself when overriding seniority considerations.

Written specification of job tasks has also provided unions with a basis on which to protest and negotiate working conditions and relationships between working conditions and pay. Holding management to its job definitions enables workers to insist on higher pay for expansion of duties, increased work hazards, etc., and to put a check on arbitrariness in supervisory determination of work loads, working conditions and rates of pay.

Finally, workers have found in precise definition of job duties a defense of their conceptions of their crafts and their individual roles in production, and what these conceptions imply about their domains of autonomy on the job. No matter how much management attempts to routinize jobs, employees must still exercise judgement and skill allowing them a certain freedom to determine work methods or conditions and a measure of independence that gives them dignity. While formal codification of job duties limits and controls what workers do, it also provides a precedent for the degree of autonomy that workers retain. In Harley Shaiken's words, "skilled workers defend work rules because

they lack the power to enforce a more flexible organization of work."²³

As management attempted to control employees with ever more specific rules, it found that confrontations with unions created a need for still more rules. Codifications of work duties, and the associated fine calibration of the wage structure, and mechanisms of promotion have become foci of battles with labor and in the process have become rigidified. Management, while making the rules, always hoped to reserve the freedom to break them and change them as it saw fit, and, from its own perspective, management had a legal right freely to redeploy workers and resources. Ironically, this managerial prerogative, as it is called, has always been formally acknowledged in union contracts although the contract itself represents a substantial constraint on managerial power. For the most part, the attitude of American managers toward collective bargaining has been that it is an unfortunate though often unavoidable limit on their desire to unilaterally set the rules of work.

Management Thought Since Taylor

The scientific management view of manufacturing organization remained largely unchallenged as a management ideal until the publication in 1938 of Chester Barnard's

²³ Shaiken, p.33.

Functions of the Executive.²⁴ This book emphasized a reality of large business organizations which had been overlooked in efforts to mold organizations in the image of scientific management. Barnard described organizations as organisms of naturally cooperative structure with influence and power flowing upward from the ranks and decision-making taking place in groups. Power was not installed by the formal lines of authority and nominal position alone. It did not operate according to design. Power was something that had to be built up and legitimized, won out of respect, the ability to construct compromise, guide consensus, and make appropriate decisions.

Barnard, president of the New Jersey Bell Telephone Company, put forward a view from the top of a large, multilayered bureaucracy. His discussion of groups and cooperation was most relevant to the experience of white collar personnel far from the shop floor. A year after Barnard's book was published, his work was complemented by a report on the Hawthorne studies, a series of investigations of groups of production workers which was to serve as the foundation for much subsequent work in what was later called the human relations school. It described the natural formation of informal work groups independent

²⁴ This section draws heavily on Charles Perrow, "The Short and Glorious History of Organization Theory," as reprinted in Jay M. Shafritz and Philip H. Whitbeck, eds., Classics of Organization Theory, 1st ed. (Oak Park, Ill.: Moore Publishing Company, Inc., 1978)

of the formal organizational structure. The research demonstrated that workers could no longer be considered wholly motivated by financial reward. They were also powerfully motivated by feelings of participation and status within the group. The social environment of the firm henceforth became a variable which management was aware it should concern itself with in the interest of efficiency. Improvement in this area was seen as dependent upon management willingness to accept feedback from and demonstrate concern for those under their direction.

After World War II, scientific management fell very much out of favor with those studying and writing on the subject of management and organizations. Increasing numbers of social scientists from various disciplines studied the actual functioning of work groups and whole organizations, and, as the studies accumulated, real organizations appeared to conform less and less to the old hierarchical ideal. Organizational theorists began to see technological, market, and social change as making necessary an increasing fluidity and multilateral cooperativeness of organizational relationships. In the new view, the old style chain of command was only viable when stability in the organization's environment and patterns of responding to it allowed management to predict future requirements and reduce the specification of appropriate actions for those in the lower ranks to a set of rules.

Many of the people in the new human relations school took on the role of strong advocates for reform. They were concerned to increase the possibilities of human growth and fulfillment by allowing participation of subordinates in decision-making and opening up channels of communication. Democracy was the thing they valued most and they promoted it as the key to increased productivity and organizational adaptability.

Human relations researchers, attacking the heart of scientific management doctrine, recommended "job enlargement" and "job enrichment." Both concepts involved attenuating the division of labor by aggregating a greater number of tasks in individual jobs. Job enrichment went further by giving workers more scope for deciding exactly how tasks would be integrated and carried out. Alleviation of boredom was the immediate goal, along with the hope of giving workers more of a sense of pride and responsibility.

Job enrichment, though it represented a principle of job design diametrically opposed to traditional principles, was in fact conceived in a form that made it a far less significant departure than it might have been. It was thought of as a small compromise with the ideal division of labor and perfect definition of task as determined on an engineering basis. In other words, job enrichment was considered more of a necessary evil than a positive means of increasing productivity. Here is a typical appraisal: "In the case of job enlargement, the issue is one of giving

up extreme specialization, with a probable small loss in efficiency, for a reduction in boredom and monotony, which makes for more satisfied and effectively motivated workers."²⁵

Another factor working against successful implementation of job enlargement and enrichment was the negative attitude of unions and workers who did not usually participate in the job redesign process. The suspiciousness of unions toward job enrichment can be considered appropriate given that the job design values of management and engineers were not really altered by the new concepts, and that well defined job duties were a means of defense of worker rights. In addition, workers often did not welcome the increased uncertainty and responsibility entailed in job enrichment, particularly since it was not usually accompanied by extra pay.

The consensus that developed on the effectiveness of job enlargement and job enrichment was that its benefits were primarily in areas other than the all important one of efficiency.²⁶ The most solid benefits obtained in many successful programs were lower absenteeism and labor

²⁵ Franklin G. Moore and Thomas E. Hendrick, Production and Operations Management, 8th ed. (Homewood: Richard D. Irwin, 1980), p.265.

²⁶ Norman Gaither, Production and Operations Management: A Problem-solving Approach, (Hinsdale: The Dryden Press), 1980, p.416; Moore and Hendrick, p.265.

turnover.²⁷ Results of experiments were decidedly mixed and inconclusive, and there was a tendency, even after some degree of success, to revert to old ways when direct efficiency benefits were meager.²⁸

Effectively reinforcing the failure to substantially change the traditional orientation towards exploiting the division of labor and subjecting worker tasks to detailed rules, optimal organizational characteristics came to be seen in the sixties as heavily dependent upon the nature of the technology involved. An early landmark work demonstrating this concept was Joan Woodward's book Industrial Organization; Theory and Practice published in 1965. It showed that complexity of technology was associated with complex and multilayered bureaucratic structures and that firms that had an organizational structure conforming closely to the general pattern suggested by the study were more successful. Later studies showed that organizational structure was most clearly determined by technology in those parts of the organization most closely involved with day to day operations. The essential implication of all this was that high volume production situations still called for adherence to the old scientific management and division of labor principles, and

²⁷ Moore and Hendrick, p. 226.

²⁸ Gaither, p.416.

of course high volume production remained the dominant model of manufacturing efficiency.

That Woodward's demonstration of the significance of technology's impact on organization should be perceived in the sixties as a conceptual breakthrough can be seen as an indication of how divorced from the realities of the shop floor and the engineering laboratory the organizational theorists were. Psychologists, sociologists, and political scientists were not concerned with specifying steps to increase efficiency but were trying to understand very complex social and political group processes. The more complex things appeared, the more complex the academic models became. The systems approach to the analysis of organizations, emerging as dominant in the late sixties and early seventies, represented an advance in realism and comprehensiveness but produced less clear recommendations for American managers. It brought into view an array of societal, market and historical variables interacting with technological and psychological variables to produce the organizational phenomenon. Everything affected everything else but exactly to what degree each variable affected all the others was terribly difficult to pin down and nearly impossible to generalize upon. Within this more sophisticated and nebulous framework, there was plenty of room to maintain the belief that process technology determined to a very large degree what types and numbers of jobs there should be and how they should be coordinated and

supervised. Particularly when it came to the case of high volume production, the new complexities of organizational theory could easily be pushed into the background in favor of a technological determinism. Here is a typical statement: "...effective mass production and large batch plants tend to adhere to traditional static organizational principles. The relatively stable, routine, long-linked sequences of tasks in these organizations are well served by a clear-cut hierarchical structure and centralized decision-making."²⁹

Pursuing a path independent of the social scientists in the post World War II decades were the operations researchers, basically made up of engineers, economists, mathematicians and statisticians. They were rarely concerned with the structure of organizations and the functioning of social decision making processes. Instead, they constructed quantitative models to provide optimal choices to managers. Major areas to which their techniques were applied were investment decisions, plant location and layout, inventory control, production scheduling, quality control, line balancing, market forecasting, and work methods study, the traditional domain of scientific management.

²⁹ Webber, Ross, Management: Basic Elements of Managing Organizations (Homewood, Ill.: Richard D. Irwin, 1979), p.388.

Operations research came to be employed extensively in firms during the sixties and seventies. In an indirect way, as a result of its essential nature, it supported a still strong affinity on the part of managers for the tenets of scientific management. The idea of determining optimal solutions to problems based on numerical information lent itself to decision-making at the top of the hierarchy without the input of judgement from those below. Sometimes going under the alternate banner of management science, operations research was also explicit in its assumption that total specification of task and extensive division of labor were the foundation of efficiency. Here is how one operations management text reexpressed the traditional vision of industrial progress:

"The basic job structures in most operating systems today are dictated by the efficiencies resulting from aggregation, division of labor and economies of size and mechanization. Aggregation....permits division of labor and economies of size and provides the production volume needed if the capital expenditures required for efficient equipment are to be economical.

The productivity of manufacturers continues to increase, and jobs in the goods producing area will undoubtedly require a decreasing proportion of the labor force in the future. ...Within industry, the mix of personnel is also changing; a greater proportion of the personnel is performing design, planning and control

activities, rather than operating jobs. The operating jobs that do remain will also be changing in character. At the craft stage, before mechanization begins, and in the final stages of mechanization, when almost all physical and control functions are automatically performed, operating jobs can be of intrinsic interest. It is at the intermediate stage of mechanization, [the present stage] where man is an adjunct to the machine, that the highly constrained, low-skilled repetitive jobs exist."³⁰

The Alienation of Top Management from the Production Process

We have seen how, despite the huge growth in the study of organizations and in the body of quantitative tools of decision-making since World War II, the vision of the way to manufacturing efficiency persisted in hardly altered form. Simultaneously, there was a shift in management's focus of concern away from manufacturing. Other areas increasingly drew more of its attention and absorbed more of its resources.

Part of this is attributable to increased size and complexity of managerial bureaucracies. Longer chains of authority and greater specialization of function mean more delegation of responsibilities by those at the top and a

³⁰ Gene K. Groff and John F. Muth, Operations Management: Analysis for Decisions (Homewood, Ill.: Richard D. Irwin, 1972), pp.136-37.

greater number of people who need not concern themselves directly with manufacturing activities. Also, the mobility of the workforce increasingly constrained on-the-job acquisition of knowledge concerning the particularities of technologies and hampered the development of personal commitment to the organizations that embody them. In 1980, the average worker stayed on the job 3.6 years as opposed to 4.6 years in 1963 while turnover of white collar workers had reached the point in the early eighties where as many as one half were leaving their jobs each year.³¹

Partly, detachment from the details of manufacturing resulted from the increasing emphasis within management on quantitative tools of decision-making. Some of this emphasis can be seen as another reflection of bureaucratic size and complexity. As bureaucracies developed more layers and more complex staff structures, means of evaluating sub-operations needed to become more quantitative since judgement based on direct experience of operations became less feasible. Also, efforts to make large firms manageable by decentralizing them have resulted in the creation of multiple profit centers which has reinforced a trend toward dependence on the use of financial measures of performance.

Emphasis on managing with quantitative tools has not only been a direct outgrowth of great organizational size

³¹ Reich, p.163.

but has fed upon itself, acting as an independent influence upon the general style of management. First, implementation of quantitative tools has been promoted by a growing valuation of the methods themselves. They derive prestige from their complex abstractness and because they carry the aura of science and the progress it represents. Managerial staff have thus enjoyed added prestige and legitimacy by employing them. The result has been that distance from actual manufacturing operations in the hierarchy has been increasingly seen as a sign of career success. With the general business culture emphasizing the value of white collar independence from the shop floor milieu, it is not surprising that deep involvement in manufacturing processes has become less common.

Second, quantitative methods were promoted by the institutions necessary to implement them. People trained in quantitative methods have been turned out by rapidly expanding business schools. New professions, each associated with its technical societies have been established and installed within corporate management where they have constituted a self-perpetuating force. Those people who have been schooled in the new management techniques and whose professional loyalties often compete with loyalties to the firm formed a counterweight to those in the firm who rose through the ranks or who are intimately familiar with product and process technology.

The rise of quantitative techniques has been integral to a change in management style in the post World War II period. These techniques are most easily and effectively employed by management in evaluating the financial performance of assets and operations. They are less easily employed to describe or evaluate production processes in physical terms because these processes are multifaceted and inter-linked in complex ways. This inherent bias of quantitative approaches to managerial decision-making tended to encourage the use of financial criteria in evaluating operations or any given set of alternatives. Part of the trouble with this is that financial results are heavily dependent on market conditions and other external factors and are weak and imprecise at measuring efficiencies or identifying opportunities for improvement. When financial measures became the dominant scoreboard for operations, management lost touch with actual manufacturing performance.

The character of business strategy also reflected the growing influence of the new decision-making techniques. Focus upon simple statistical projection of costs and earnings was intensified. Strategy based on unprecedented though foreseeable technological and market developments or on the aggressive shaping of these developments came to be devalued and avoided. Possibilities of taking advantage of established market patterns and of diversifying the risks of existing investment alternatives appeared to be

sufficiently broad and rewarding as to justify management preoccupation with financial and marketing aspects of business.³²

Another factor which increased the distance between top management and the production process is the post war rise in mergers and acquisitions that link distantly and completely unrelated manufacturing enterprises. The growth of layers of upper management alienated from the details of technology has been fostered by an increasing intra-firm diversity of products and industries.

In the period from 1948 to 1967, joining firms whose products and markets were totally unrelated accounted for only 17% of the total asset value of mergers and acquisitions of large manufacturing and mining firms. But from 1967 to 1977 the corresponding figure was 42%. The effect of increasingly promiscuous financial combination of manufacturing establishments is reflected in direct measures of intra-firm diversity of products and industries. In 1960, 31% of the top 200 manufacturing firms shipped products in more than five 2 digit industry groups. By the crest of the sixties merger wave in 1968, 56% did so. 37% of the largest manufacturing firms shipped products from 20 or more 5 digit product classes in 1960,

³² Reich, p.158.

but 66% did so in 1968.³³ By 1972, 33% of all manufacturing employees worked in lines of business completely unrelated to their employer's principal business.³⁴

What were the consequences of conglomerate merger and acquisition for manufacturing management? Clear evidence on this question has been scarce, but the sources and character of mergers since the sixties suggest their probable effect.

Many reasons for the growth of conglomerate merger have been advanced, but those which help explain the timing of the phenomenon must be taken most seriously. First, following the Cellar antimerger act of 1950, the government became extremely vigorous in its prosecution against horizontal and vertical mergers which have the potential of increasing market power in particular industries. This forced merger activity into the safer conglomerate mode. Second, there was an impetus given to merger of all types from a decline, beginning in 1966, of the ratio of market value to replacement value of assets, making merger and acquisition less costly than original investment. While the reason for this price disparity is not clear, it is the best single explanation of recent merger activity offered

³³ U.S. Federal Trade Commission, Economic Report on Corporate Mergers, Staff Report to the FTC, 1969, Table 4-5, p.224.

³⁴ Reich, p.147.

in a text on financial management co-authored by J. Fred Weston, a well known defender of the merger movement.³⁵

Both the step-up in antitrust enforcement and the relative decline in the market price of firms are purely external explanations of the rise of conglomerate merger. If these are indeed the two primary causative factors, it would be largely a coincidence if internal organizational and managerial effectiveness were significantly advanced at the same time.

Yet the concept of synergy, a technical and managerial cross fertilization between businesses with no traditional or direct link to one another, was a source of mystique and legitimacy for the huge new conglomerates of the late sixties. As it turned out, much of their phenomenal success was owed to innovations in accounting rather than management and stock prices of some of them plummeted when this was discovered. One study found that in a third of mergers, tax avoidance was a major factor.³⁶ Going further, Robert Reich has seen the conglomerates as just one manifestation of what he calls paper entrepreneurialism toward which corporate managers have shifted over the past few decades as they found legal and accounting maneuvers more rewarding than improvement of product and process.

³⁵ J. Fred Weston and Eugene F. Brigham, Managerial Finance, 7th ed. (Hinsdale, Ill.: The Dryden Press, 1981), p.923.

³⁶ Ibid.

There is no question, furthermore, that during the first great surge in conglomerate mergers in the sixties there was a "merger mania" among executives and investors that fed upon itself creating merger for the sake of merging. Robert Solo identifies the stock market itself with its mass of investors and brokers hungry for each new security concoction as a primary source of the impetus to merge.³⁷

The character of conglomerate merger is also indicated by the fact that its rise was coincident with the appearance of the unfriendly takeover which was virtually unknown before 1965.³⁸ Stories about managers having to seriously alter and divert attention from important internal management decisions in order to defend against takeover became common. Fear of takeover has since become pervasive. In 1981, 49% of the largest industrial firms considered themselves vulnerable to takeover and 38% of the rest had formed contingency plans to deal with a takeover threat. Of the 249 firms that faced an unfriendly takeover bid in the early eighties only 52 were able to successfully defend themselves.³⁹

The association of conglomerate merger with accounting tricks, faddism, and unfriendly takeover all suggest that

³⁷ Robert A. Solo, The Political Authority and the Market System, (Cincinnati: Southwestern, 1974), p.270.

³⁸ Reich, p.148.

³⁹ Ibid.

the quality of manufacturing management was generally at the periphery of the concerns of the conglomerators. At the same time, the fact that many of the firms brought together in conglomerates were as different as it is possible to be must lead to the presumption that effectiveness of management at the individual enterprise level was not advanced and perhaps harmed.

Still, many reasons for the superiority of conglomerate management continued to be made: new synergies, expanded ability to provide attractive opportunities for executive talent, enhanced stability of diversified firms, reduced transaction costs, superior ability to allocate capital, and the capacity to discipline managers who previously had their way with stockholders. And though they declined considerably after 1968, conglomerate mergers continued at historically high levels in the seventies. Then another big merger wave arose in the early eighties. Its causes were similar to the causes of the sixties wave---"undervaluing" of assets by the stock market and a change in government policy on mergers (towards leniency this time.)

This wave was different however, because it was accompanied by a parallel wave of divestiture. The number of sales of divisions and subsidiaries was 40% greater in 1984 than in 1980 and their total dollar value doubled in

the same period.⁴⁰ Suddenly the synergy theories were considered debunked⁴¹ and many firms sold assets in an effort to become leaner and more focussed.

The recent move to deconglomerate is perhaps the strongest evidence that conglomeration had a negative impact on management. The rate and pattern of failure in the merger game is also evidence., Between a half and two thirds of mergers are clear failures and a third of them are later undone. Furthermore, the most risky mergers have turned out to be those involving the most distantly related firms. And while it is very tough to make conglomerate merger work, manufacturing is the business function that is acknowledged to have presented the greatest difficulties in the merger process.

Frederic Scherer has confirmed that recent sales of operations by conglomerates have placed them in better hands. All but one of his sample of 15 divested firms did better under their new management which generally employed more aggressive strategies. Scherer cited a sapping of morale under the old conglomerate owners resulting from the piling on of extra layers of management.⁴²

⁴⁰ Stewart Toy, "Splitting Up: The Other Side of Merger Mania," cover story, Business Week, July 1, 1985.

⁴¹ Daniel F. Cuff, "Business Firms Seek Returns, Not Synergy," New York Times, August 5, 1985, pp.D1,D5.

⁴² "Do Mergers Really Work? Not Very Often -- Which Raises Questions About Merger Mania," cover story, Business Week, June 3, 1985, p.51.

Though the tide has finally turned against the conglomerate, the burgeoning arena of financial and legal manipulations it represents is still with us. Along with the growth of quantitative techniques, (especially financial) the movement into new realms of general business strategy divorced from the task of making specific products for specific markets has made manufacturing something of a black box of physical transformations rather than a competitive battleground of efficiency and technological progressiveness.

Summary

To sum up, it may be said that the goal of American management in the twentieth century has been to mold manufacturing organization in the image of the machine. The key feature of the machine is its predictable response to the actions of its user. Thus the attempt has been made to assign each employee a specific, pre-designed function and direct his or her tasks in as detailed a way as possible. Where scientifically or experimentally determined methods were not available, bureaucratic rules were substituted. Incentives based on performance were designed to keep each part of the organizational machine functioning consistently.

At the same time, management has tried to retain its power to rearrange and redirect the human components of its manufacturing organizations. But the power of unions to

make work assignments and rules a subject of bargaining has had the effect of rigidifying organizational structures and work practices, although, in many cases, this has resulted in protection of worker autonomy from the encroachment of even more detailed planning and control on the part of management. This has not deflected the effort of management to increase the specificity or unilateral character of control.

Mechanization has represented progress toward the image of manufacturing as a machine, not only because people have been replaced by machines, but because people working with machines can be constrained to match the regularity and pace of machines. With the advent of programmable machines, workers could be de-skilled and machines themselves made to move, without human intermediary, according to the instructions of management.

Decreased reliance on judgement and input from those directly involved with production has consistently been pursued as a feature of successful control. Rigorous systems of data collection and reports were developed so that managerial decisions could be put on as quantitative a basis as possible, as if statistical reports were the meters and dials of a machine.

Just as a machine is not expected to evolve on its own, important improvements in manufacturing processes were not expected to originate with those directly involved in production. Major technical advances were seen as

following in the wake of higher production volumes and divisions of labor which created opportunities for engineers to devise new forms of mechanization, and from science, an unpredictable realm apart.

The alienation of business management from manufacturing has created perhaps the deepest analogy of manufacturing organization to the machine. To use a machine, one need not know anything about how it works. All that is necessary is to know its inputs and outputs and how it responds to changes in its controls. Similarly, production became a function within the firm to be monitored and exploited at a distance instead of being itself the principal domain of positive action for top management. This was precisely the vision Taylor had in mind when he suggested that the planning department should ideally be able to run the plant with virtually no input from the general manager.

Though the reality of manufacturing was always a good distance from the ideal of manufacturing organization as a machine, and several cracks had appeared in the dominant management ideology, substantial transformation and displacement of the scientific management tradition did not come until the severe economic difficulties of the eighties provided the required catalyst for change.

CHAPTER TWO

INDUSTRIAL DECLINE

Introduction

In the last chapter, we viewed the development of some core concepts and practices in American manufacturing management. Continuity with the Taylor tradition was the principle theme. Now we turn to description of a constellation of facts about America's industrial performance which served as the foundation for perceptions and demonstrations of the need to break with that tradition during the recession of the early 1980's.

No attempt is made here to present a neutral and balanced assessment of America's industrial failings or to probe their causes. Rather, we simply select those problems figuring most prominently in the discourse on the need for change and set forth the basic facts about them.

Though the recession of the early nineteen-eighties was the most severe since the Great Depression, that fact alone is not sufficient to explain why it was the occasion for a major reevaluation of American manufacturing capability and a search for ways to improve it. Business cycles have traditionally been blamed mostly on imbalances and instabilities in aggregate financial flows. They have

never been seen as rooted to any significant degree in the nation's declining ability to manufacture efficiently or business's inability to respond to technological and market opportunities. This recession was different because it helped focus public attention on a set of worsening trends in American industrial performance.

The two trends that appear to have been most responsible for generating a consensus on the need for fundamental change were 1) a decline in statistical measures of the rate of productivity improvement in the seventies culminating in actual productivity drops in 1979 and 1980¹ and 2) an increase in the seventies in the share of certain domestic markets taken by Japanese firms and other foreign competitors, which accelerated during the recession exacerbating its effects.

Without each of the three principle elements---the pressure of recession, the statistical evidence of slowed productivity advance, and the loss of market share in important industries, a general sense of need to improve manufacturing management and processes might never have emerged. In the absence of a serious recession, it would have been far easier to explain disappointing productivity statistics and loss of market share in particular industries as natural or inevitable structural adjustments in the economy. Without statistical evidence of economy-

¹ U.S. President, Economic Report of the President 1983 (Washington, D.C.: GPO, 1983), p.209.

wide productivity decline, the difficulties of particular industries would not have been as readily seen as evidence of a general need for reform in American business. Finally, with no severe losses of market share, the American economy could have been seen as the world's strongest economic performer despite its participation in the worldwide recession.

Other experiences as well contributed to the conviction that American industry had to refocus its efforts on becoming more productive. First, the quality of American products began to suffer by comparison to the quality of Japanese and other imported products. Even without that unfavorable comparison, quality concerns of the public and legal action to hold manufacturers and sellers responsible for product deficiencies had been on the rise since the sixties. Though product deficiencies were not at first perceived as reflecting on productive efficiency, their existence did come to support the suggestion that the problems of American business were not external to the manufacturing process.

Another problem concerned the pace of technological advance. It came as a shock to learn that the Japanese had taken the lead in introducing critical technological innovations like robots and numerically controlled machine tools into their factories and had technologically outpaced the United States in key industries.

The sections that follow will consider in detail 1) productivity problems, 2) loss of market share, 3) loss of quality superiority, and 4) inadequate technological advance. Our discussion in each section will focus on the steel, auto machine tool, and television set industries since these were the industries most often cited as examples of America's economic decline.

Productivity

Productivity increased more slowly in America in the sixties and seventies than in all the other major industrialized nations. However, American productivity levels were originally substantially above those of other nations and were not alone in experiencing a declining rate of increase. Productivity throughout the industrialized world advanced more slowly in the seventies than in the sixties.² Thus the productivity improvement slowdown in itself did not necessarily imply that American productivity was in danger of slipping below that of competing nations or that productivity was lower than it should have been. After all, if the United States still led the world in productivity, how could the fact that other nations were catching up be prima facie evidence of failure? The argument was often made that other nations would naturally draw closer to the United States in productivity as they

² Magaziner and Reich, p.36.

recovered from World War II and the rate of technology diffusion surpassed the rate of invention.

There began to accumulate by the 1980's, however, more disturbing evidence of productivity problems in particular industries. Not only did more specific comparisons of American and Japanese productivity show American productivity to be lower, many were based on direct estimates of physical productivity ---the ratio of physical units of output to units of labor or materials--- not just the ratios of the value of output to physical units of input that national and most industry-wide productivity figures represent.

Figures published by the American Iron and Steel Institute as well as Bureau of Labor Statistics data showed that by the mid seventies, Japanese labor productivity was slipping ahead of American labor productivity in the steel industry.³ An estimate of comparative productivity from another source which appeared in 1977 had the Japanese worker putting out an average 400 tons of steel per year while the average American worker put out 250 tons.⁴ In

³ U.S. Congress, Office of Technology Assessment, Technology and Steel Industry Competitiveness, (Washington, D.C.: GPO, June 1980, p. 137; Magaziner and Reich, p.164.

⁴ Charles Bradford, "Japanese Steel Industry: A Comparison With Its United States Counterpart," New York: Merrill Lynch, Pierce, Fenner, and Smith Inc., 1977, as cited in Michael Borrus, "The Politics of Competitive Erosion in the Steel Industry" in American Industry in International Competition, ed. John Zysman and Laura Tyson, (Ithaca, NY: Cornell University Press, 1983), p. 67.

1982, still another independent study pegged the Japanese productivity advantage at 25 to 30 percent.⁵

The productivity of material inputs was also found to be greater in Japan. As far back as 1965 and up until at least 1978, Japanese use of coke per ton of pig iron produced was far less than in American plants. (429 as opposed to 597 kilograms of coke per ton of pig iron in 1978)⁶ Yield of finished steel per ton of crude steel was probably at least seven percent greater in Japan than in the United States according to 1977 and 1978 figures.⁷

Research also turned up dramatic evidence of higher Japanese productivity in the auto industry. Though overall auto industry productivity in Japan was only 88 percent of American auto industry productivity in 1974, by 1980 it was 18 percent above the American level.⁸ Figures for specific firms made the American disadvantage more concrete. Employee hours per small car was 51 for Nissan and 83 for GM in 1981.⁹ A similar comparison for 1979 showed Ford at

⁵ Magaziner and Reich, p.159.

⁶ Ibid., p.167.

⁷ Bradford as cited in Borrus; H. Mueller and K. Kawahito, "An Examination of Recent Allegations of Japanese Steel Dumping," Journal of Economics 5: 77-81 (1979) as cited in Borrus, p.67.

⁸ William Abernathy, Kim Clark, and Alan Kantrow, "The New Industrial Competition", Harvard Business Review, September-October 1981, p.72.

⁹ William Abernathy, Kim Clark, and Alan Kantrow, Industrial Renaissance (New York: Basic Books, 1983), appendix.

87 employees per vehicle and Toyo Kogyo (Mazda) at 56 hours per vehicle.¹⁰

In one study of the color television set industry, it was discovered that wages and benefits were actually higher in two Japanese firms than in an American firm by 1979, so that low Japanese prices had to be attributed to higher productivity. In 1979, a low cost Japanese producer required .85 hours of labor per set while a high cost Japanese producer required 1.26 hours per set. In contrast, one of the five American producers required 2.68 hours per set.¹¹

Machine tool production in Japan became much more efficient than in the United States, in large part because the Japanese industry has concentrated on turning out large numbers of relatively small standardized machines while the U.S. industry concentrates on customized machines. By one analyst's account, Japanese machine tool firms had 30 percent lower labor productivity than American firms in 1976 but had reached productivity levels nearly 40 percent higher than American firms by 1984.¹² According to the International Trade Commission, Japan's productivity in

¹⁰ Abernathy, Clark, and Kantrow, "New Industrial Competition."

¹¹ Magaziner and Reich, p.173.

¹² Steven Greenhouse, "A Survival Fight in Machine Tools," New York Times, July 8, 1984, section IV, p. 24.

machine tools was twice as high as that of the United States and the other major producing nations.¹³

Report of another productivity gap in air conditioner assembly came in 1983. It was found that the median Japanese firm had a slightly higher output per direct labor man-hour than the two most efficient American plants although the difference in automation between American and Japanese plants was very slight.¹⁴

Before the end of the sixties, American manufacturing in complex product industries had rarely been seriously challenged in its home markets and in the seventies its productivity levels were generally still above Japan's. Given this situation, several pieces of hard evidence and demonstrations of foreign superiority had to accumulate before the overall decline in productivity advance was generally perceived as an indicator of inadequate progress in manufacturing. Direct productivity evidence for several industries was critical in demonstrating that Japanese success was not just due to lower wage and benefit levels.

The report of a 1976 workshop with leaders from business, government and labor sponsored by the National Academy of Sciences reported a widespread concern about the productivity improvement slowdown but no strong consensus

¹³ "U.S. Machine Tools vs. Foreign Competition," American Machinist, Nov. 1983, p. 23.

¹⁴ David Garvin, "Quality On The Line", Harvard Business Review, September-October 1983, exhibit II, p.67.

that American manufacturing firms were underperforming or that the Japanese were a particular threat to American industrial and technological leadership. At that date, the strongest evidence on productivity problems cited above had not yet arrived.¹⁵

Market Share

American firms' shares of the domestic auto, steel, television set, and machine tool markets were all seriously eroded in the early eighties recession, but in all cases this erosion built on earlier erosions of the sixties and seventies.

Japan started exporting televisions to the United States at the beginning of the sixties and had captured an eleven percent market share by 1966. At this stage, Japan's advantage was largely in cheap labor. In 1967, U.S. firms began transferring component production and black and white set final assembly to Mexico and Taiwan. By 1972, the peak year for sales of black and white sets in America, 52 percent of the imports were coming from U.S. affiliates and subsidiaries, and production of most components except picture tubes had disappeared from the

¹⁵ Technology, Trade, and the U.S. Economy, report of a workshop held at Woods Hole, Mass., Aug. 22-31, 1976, conducted by the Office of the Foreign Secretary, National Academy of Engineering and Assembly of Engineering, National Research Council, (Washington, D.C.: National Academy of Sciences, 1978), pp. 49,50.

United States. Domestic black and white set production declined from 6.7 million in 1966 to 1.7 million in 1976.¹⁶

American firms hoped to compensate for loss of black and white sales with expanded sales of color sets. The market for color sets exploded between 1963 and 1966 with domestic production going from 750 thousand to over five million. Thereafter, the Japanese quickly moved in grabbing 17 percent of the American color market by 1970. They were aided by scale economies through concentration on small sets that could be sold in high volumes and by manufacturing economies gained through a quicker adoption of solid state design.

Recession in 1974 and 1975 spurred U.S. firms to cut costs and move still more production offshore while Japanese firms moved in the opposite direction and invested further in production process improvements. With mass merchandisers Sears, Montgomery Ward, and K-Mart shifting to foreign suppliers in 1975 and 1976, imports increased dramatically. Domestic firms dropped from 85 percent of the domestic color market in 1973 to 64 percent in 1976. Industry employment dropped during these years by over a third as the effects of productivity gains and foreign sourcing of components were added to the impact of

¹⁶ This account of the rise of television set imports is drawn from James E. Millstein, "Decline in an Expanding Industry: Japanese Competition in Color Television" in American Industry in International Competition, ed. John Zysman and Laura Tyson (Ithaca, NY: Cornell University Press, 1983).

increased imports. The pressure on domestic firms continued to increase as imports of color sets leapt upwards again in 1977 leading in turn to pressure on the government to provide protection. As a result, marketing agreements were signed in 1977 with Japan and in December 1978 with Korea and Taiwan, setting quotas for imports but allowing foreign firms to increase sales provided they increase the proportion of their sets manufactured in the United States. However, the agreement did not prevent further shifts to foreign sourcing by domestic firms. It is estimated that no more than 40 percent of the value added of all sets produced domestically originates in the United States.¹⁷ Though imports declined after the marketing agreements were signed, they shot up again in 1981 by 52 percent when the agreement with Japan lapsed, hitting the American industry hard in the depths of the recession.¹⁸

Not only the television set industry but the whole field of consumer electronics has been subjected to heavy foreign competition. Japanese firms dominated the video

¹⁷ Ibid., pp.138-39.

¹⁸ National Academy of Engineering and the Committee on Engineering and Technical Systems, The National Research Council, The Competitive Status of the U.S. Electronics Industry: A Study of the Influences of Technology in Determining International Industrial Competitive Advantage, prepared by the Electronics Panel, Committee on Technology and International Economics and Trade Issues of the Office of the Foreign Secretary, (Washington D.C.: National Academy Press, 1984), p.97.

cassette recorder market from its inception in 1975 since for twenty years before that they had pushed the development of the VCR into an affordable consumer product while U.S. firms focussed only on sales of expensive units to broadcasters.¹⁹ As of 1983, there was no production of VCRs in the United States.²⁰ In 1979 over 50 percent of the overall market for consumer electronics products was taken up by imports.²¹ By 1980, the import share had risen to about 60 percent.²²

In the auto industry, losses of market share to the Japanese during the recession of the early eighties were so painful and visible that they became symbolic of a crisis in American manufacturing. But these losses were preceded by earlier waves of imports, the first of which, cresting in 1959 at 10 percent of the market, was dominated by the Volkswagon Beetle. A second wave began in the mid sixties bringing the import share up to 15 percent by 1970. In that year, German imports outnumbered Japanese imports by roughly two to one. Then, sales of Japanese cars surged in 1971 and held steady in 1972 while German imports dropped making Japan the new number one exporter to the United

¹⁹ Ibid., p.99.

²⁰ Ibid., p.94.

²¹ Magaziner and Reich, p.33.

²² National Academy of Engineering and the National Research Council, The Competitive Status of the U.S. Electronics Industry, p.94.

States.²³ When gasoline prices rose dramatically in 1974 generating more consumer interest in small, fuel-efficient cars, the Japanese again made headway against domestic automakers ratcheting the import share of the passenger car market up to about 18 percent.²⁴ The most recent import gains began with the second big gasoline price increase of 1979. By 1980, the import share had shot up to 27 percent compounding the effect of recession and shrinking total car sales.²⁵ It was feared that if the Japanese had not implemented voluntary restraint agreements beginning in 1981, imports could have soon taken a far greater proportion of the U.S. market, so great was their overall appeal by this time. In 1982, total U.S. and Canadian car and truck assemblies were lower than they had been since 1961. At the same time, expensive European makes such as Volvo, Mercedes-Benz, Jaguar, and BMW were setting new sales records. The decline of Volkswagen was reflected in the fact that the bulk of the imports, 81 percent, were now Japanese.²⁶

Significant loss of sales to foreign competitors in the domestic steel market has not been due only to the lower prices of imports; it has been associated since 1959

²³ Robert Sobel, Car Wars: The Untold Story (New York: Dutton, 1984; New York: McGraw-Hill, 1985), p.209.

²⁴ Ward's Automotive Yearbook 1983, p.106.

²⁵ Ibid., p.11.

²⁶ Ibid., p.141.

with steel buyers placing orders abroad to hedge against the possibility of a strike cutting off their supplies during years of contract negotiations with the United Steel Workers. The share of the market going to imports hit new highs in the collective bargaining years of 1959 (6.1%), 1965 (10.3%), and 1968 (16.7%). Thereafter, the import share fluctuated between 12.5 percent and 18 percent until even further import inroads were made in the early eighties.

The steel industry has considered itself distressed for many years making its first big push to win government protection from imports in 1967. Ever since 1969, the U.S. steel market has been substantially protected by one means or another. The industry has been particularly sensitive to import growth because U.S. steel consumption has risen more slowly than real GNP averaging about two percent a year over the last several decades while employment has been steadily shrinking.²⁷ Instead of slower growth, imports have meant layoffs and plant closings and, in the eighties, these became massive. By the end of 1981, a year in which imports surged taking 19 percent of the domestic market, steel plants were operating at 55 percent of capacity with about 22 percent of the production workers laid off. In 1983, total U.S. production dropped even further to about 67 million tons

²⁷ U.S. Congress, Office of Technology Assessment, Technology and Steel Industry Competitiveness, p.172.

(compared to 87 million in 1981), lower than it had been for several decades. By this time, developing countries had joined the traditional sources of imports, Japan and Western Europe, accounting for 44.1 percent of all imports.²⁸ Several of the largest domestic steel firms reacted by aggressively diversifying out of steel and even by arranging to import substantial quantities of cheaper foreign steel to feed their own finishing mills.²⁹ Not all segments of the industry have suffered equally. The minimills (13 percent of total tonnage shipped, early eighties) and the specialty steel producers (3 to 4 percent of tonnage, at least 9 percent of total value of shipments, early eighties) have been growing and are generally cost competitive with imports.³⁰

Although the share of U.S. machine tool makers in the world export market and the domestic market has been declining since at least the early sixties, real distress and (unsuccessful) calls for trade protection did not come until the early eighties. In 1964, U.S. exports of machine tools were about 23 percent of world exports while imports took less than 4 percent of the domestic market. By 1980, U.S. firms accounted for less than 7 percent of total world exports while giving up 24 percent of their own market to

²⁸ New York Times, December 18, 1983.

²⁹ Steven Greenhouse, "The Trauma of Steel Imports," New York Times, October 18, 1983, section IV, p. 9.

³⁰ Borrus, pp.65-6.

foreign competitors. 1978 was the first year in which imports exceeded exports.³¹ Then, in 1979, record order backlogs up to two years or more developed forcing many buyers to find foreign suppliers for the first time.³² This was only a more severe instance of a phenomenon which is common in extremely cyclical industries. Unfortunately, Japan was simultaneously launching a drive to increase exports of its cheaper machines manufactured in higher volumes. The effect was to increase imports' share of the market to 28 percent in 1982, 34 percent in 1983, and 40 percent in 1984.³³ Domestic shipments of machine tools dropped 26.7 percent in 1982 and 50 percent in 1983. In 1984, employment was 30 percent below its peak level in 1979 and the industry was operating at 60 percent of capacity. Japan was not the only country that participated in the import surge, accounting for only about half the

³¹ National Academy of Engineering and the Commission on Engineering and Technical Systems, National Research Council, E. Ray McClure, chairman and Paul R. Schulman, rapporteur, The Competitive Status of the U.S. Machine Tool Industry: A Study of the Influences of Technology in Determining International Industrial Competitive Advantage, prepared by the Machine Tool Panel, Committee on Technology and International Economic and Trade Issues, Office of the Foreign Secretary, (Washington D.C.: National Academy Press, 1983), p. 18.

³² Steven Greenhouse, "A Survival Fight in Machine Tools," New York Times, July 8, 1984, section IV, p.2.

³³ U.S. Dept. of Commerce, International Trade Administration, A Competitive Assessment of the Flexible Manufacturing Systems Industry, (Washington D.C.: GPO, July, 1985), p.18.

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imports as of 1984.³⁴ As in the steel and television set industries, one of the responses of many American manufacturers has been to import foreign made products either for completion in American factories, or simply for distribution through their own sales outlets.³⁵

Several other industries have lost market share over the decades of the sixties and seventies. For example, textile machinery imports rose from 6.6 percent of the market in 1960 to 45.5 percent in 1979. Food processing machinery imports rose from 3 percent to 18.7 percent and industrial organic chemicals rose from 2 percent to 19 percent in the same period.³⁶

We have not discussed here the fundamental economic forces behind the increasing share of imports in domestic markets. In most cases imported goods were priced lower and cost less to produce than American goods. Of course, this was often attributed to low wages and foreign government subsidies. There was also the rise of the dollar during the recession which made foreign goods cheaper still. Thus recession and loss of market share were the immediate problem, but they had to be seen in light of the above evidence of laggard productivity and the

³⁴ Greenhouse, "A Survival Fight in Machine Tools."

³⁵ Ralph E. Winter, "The Cutting Edge: Making Machine Tools Increasingly Requires Ties to Foreign Firms," Wall Street Journal, September 4, 1984, p.1.

³⁶ Magaziner and Reich, p.33.

indications of inadequate quality and technological advance discussed below to become an impetus for internal reform of manufacturing practices.

Quality

Problems of product quality were by far most visible in the auto industry. The seventies saw a long series of recalls that met heavy publicity inspired in part by the growing consumer right's movement. Automakers were seen as unconcerned with quality and willing to cover up known safety defects. Horror stories of sloppy assembly and dealership repair ripoffs became increasingly common. Most magazines devoted to automobiles found Japanese cars to be superior in finish and quality of assembly and in reliability.³⁷ In particular, the magazine Consumer Reports compiled frequency of repair records that consistently placed Japanese cars ahead of American ones in the body and structural category.³⁸ Other research indicated that the average number of defects one month

³⁷ Brock Yates, The Decline and Fall of the Automobile Industry, (New York: Empire Books, 1983), p. 47; Sobel, p.236.

³⁸ Consumer Reports, Annual Auto Issue, April 1979, as cited in National Academy of Engineering and the Committee on Engineering and Technical Systems, The National Research Council, The Competitive Status of the U.S. Auto Industry: A Study of the Influences of Technology in Determining International Industrial Competitive Advantage, prepared by the Automobile Panel, Committee on Technology and International Economics and Trade Issues of the Office of the Foreign Secretary, (Washington D.C.: National Academy Press, 1982), p. 98.

after delivery was running three and four times higher in small American cars than in Japanese cars.³⁹ By at least 1978, top auto executives realized that the quality issue was competitively important.⁴⁰

American cars also lacked some mechanical and performance features offered by many Japanese cars --- efficient engines that combined high gas mileage with respectable power, front wheel drive, disc brakes, radial tires, independently suspended rear wheels, and smoothly operating five speed manual transmissions.⁴¹ All of these features combined with the superior fit and finish of external parts came together for the first time in the 1976 Honda Accord which became the "target vehicle" for engineers at American companies in their efforts to create a competitive small car.⁴² When GM finally unveiled the results of their attempt to beat the Accord in 1981, they were still far short of the mark, primarily because excessive weight made acceleration poor.⁴³

Despite all of this there was no clear evidence that

³⁹ National Academy of Engineering and the National Research Council, The Competitive Status of the U.S. Auto Industry, p.97.

⁴⁰ J.M. Juran, "Japanese and Western Quality: A Contrast," Quality Progress, December 1978, p.11.

⁴¹ These features will be discussed in the next section.

⁴² Yates, pp.24,42.

⁴³ Ibid., pp.22,54,55.

the mechanical reliability of American cars was inferior.⁴⁴ In fact, American engines and transmissions were still probably more durable and their bodies less prone to rust.⁴⁵ Their larger size translated into greater safety as well. But once Japanese cars gained a superior reputation for reliability, fuel economy, and some performance features, the overall Japanese appearance and design concept became associated in consumers' minds with high quality. At the same time, the Mercedes-Benz (to which the Japanese cars were a closer approximation) displaced the Cadillac as the ultimate aspiration of car buyers.⁴⁶ Thus leadership was lost on both the inexpensive small size end of the market and the luxury end of the market.

In the mid seventies, the failure rate of American color television sets was approximately five times the failure rate of Japanese sets. Buying patterns, however, did not reflect much consumer awareness of this fact at the time. On the other hand, merchants, leasing companies, and large buyers such as hotel chains were in a position to notice Japanese reliability and their shift toward purchase of Japanese sets spurred quality improvements by American

⁴⁴ National Academy of Engineering and the National Research Council, Competitive Status of the U.S. Auto Industry, p.97.

⁴⁵ Ibid., p.98; Yates, pp.237-8.

⁴⁶ Yates, p.228.

manufacturers. In the latter half of the seventies, reliability became a much more important factor in determining consumer choice as the difference between sets in picture quality and other features became small and as awareness of the reliability gap increased. While American manufacturers were improving, so were the Japanese and in 1978 Japanese sets still had somewhere between one half to one quarter the failure rates of American sets.⁴⁷ Whereas an average Japanese factory (probably around 1979) had less than one percent of its sets removed from the assembly line for rework, in many American factories the figure was over 50 percent; and when Japanese companies extended their warranties from three months to one year, their costs rose by less than one percent of sales while a U.S. company attempting to do the same experienced cost increases of three to nine percent.⁴⁸

Japanese companies taking over American plants in the U.S. gave a direct demonstration that the quality difference was a matter of management. When a Motorola plant was purchased and run by Quasar, the cost of service calls dropped from 22 million dollars in 1974 to less than 4 million dollars in 1976. When Sanyo took over a

⁴⁷ Juran, "A Contrast," p.11.

⁴⁸ Magaziner and Reich, p.177.

Whirlpool plant, the product failure rate was lowered from about ten percent to less than two percent.⁴⁹

An even more dramatic difference between Japanese and American product quality was discovered in a case study that covered all but one of the manufacturers of room air conditioners in the United States and Japan. Since the operating features of air conditioners are more or less the same, the most important quality variable is reliability. Japanese companies had an assembly line defect rate seventy times lower than the American average and an average first year service call rate seventeen times lower than the American average. The poorest Japanese company had a failure rate of less than half that of the best U.S. plant while the service call rate of the best American manufacturer was five times better than for the worst.⁵⁰

In the machine tool market, the Japanese have concentrated on filling a demand for small machines with advanced electronic controls that U.S. firms have not been able to satisfy, at least at competitive prices.⁵¹ While there is little solid evidence of Japanese superiority in product technology, it seems that the Japanese were able to

⁴⁹ Juran, "A Contrast," p.17.

⁵⁰ David Garvin, "Quality on the Line," Harvard Business Review, September-October 1983, p.66.

⁵¹ Matsuko Murakami, "Export Surge A Mixed Blessing," American Metal Market Magazine, June 17, 1985.

better apply recent technology to produce machines with a more desirable combination of features.

If there is a weakness of Japanese machine tools, it is a lack of ruggedness in construction related to the fact that their most popular machines are mass produced with time consuming handwork kept to a minimum. American machines are better in this respect but so are the Swiss machines. In Japan, American machine tools are losing out in the small machine sector of the market to the Swiss whose machines are known for their precision.⁵²

The International Trade Commission concluded in 1983 that while American specialty machines were still considered superior to imports, standard machine tools manufactured in the United States were generally perceived by U.S. customers to be of lower overall quality.⁵³ (As noted above, only half of machine tool imports are Japanese.)

Product quality has not usually been considered one of the most important problems for the American steel industry. Nevertheless, higher quality associated with more modern production equipment has occasionally been cited as one reason for Japanese success in steel.⁵⁴

⁵² Minoru Inaba, "More Ruggedness Needed," American Metal Market Magazine, June 17, 1985.

⁵³ "U.S. Machine Tools vs. Foreign Competition," p.23.

⁵⁴ Greenhouse, "The Trauma of Steel Imports." ; U.S. Congress, Office of Technology Assessment, Technology and Steel Industry Competitiveness, p.150.

Technology

Before American managers perceived the existence of the competitive disadvantage stemming from inadequate managerial techniques, they became aware of disadvantages associated with the use of inferior equipment and with products embodying less sophisticated technology. This was to be expected since physical differences between manufacturing processes of different nations are much more easily defined and established and their meaning clearer than are the social and organizational differences.

The steel industry was the first to lag noticeably behind its foreign rivals in technology. Charges have been made that U.S. firms installed outmoded equipment during the fifties when one of the two most significant steelmaking breakthroughs of the post World War II period, the basic oxygen furnace, was first coming into widespread use.⁵⁵ Up to 1957, five years after the first basic oxygen furnace went into commercial operation in Austria, major American firms continued to build the more familiar open hearth type furnace. Thereafter, only modern furnaces were constructed.⁵⁶

⁵⁵ Ibid., p.129.

⁵⁶ Ibid., p.130.

However, during the sixties, the lead in technology was taken by the Japanese as they built several new plants that were, as a group, the largest in the world.⁵⁷ These plants set world standards in efficiency not only because of their substantially greater economies of scale, but because they were optimally laid out to take advantage of new types of equipment and to minimize transport distances between processes. In contrast, most U.S. plants were originally designed for much smaller outputs and were added to in piecemeal fashion over many decades creating bottlenecks and problems of mismatch between old and new equipment as well as necessitating ever more circuitous routings of materials.⁵⁸ U.S. firms increased their investments in the first half of the sixties in an attempt to stay competitive but did not break out of the old pattern of making marginal improvements to old plants.⁵⁹ Only one major plant was built after 1952 in the United States ---Bethlehem's Burns Harbor plant which began production in 1968.

Since U.S. capacity expanded very slowly in the sixties and seventies (10 million new tons of capacity added between 1960 and 1977 versus 46 million tons of

⁵⁷ Walter Adams and Hans Mueller, "The Steel Industry," in Walter Adams, ed. The Structure of American Industry, 6th ed., (New York: Macmillan Publishing Co., 1982), p.88.

⁵⁸ Adams and Mueller, pp.117-18.

⁵⁹ Borrus, pp.74-5.

capacity added from 1950 to 1959) and management considered it too costly to rapidly replace old furnaces with the basic oxygen furnace (BOF)⁶⁰ the proportion of steel made with the more modern type of furnace grew more slowly in America than in Japan. In 1969, 42.6 percent of American steel was made in the BOF versus 76.9 percent of Japanese steel. In 1979, Japan had no open hearth furnaces left in operation while 19.2 percent of U.S. production was still in open hearth furnaces.⁶¹ Europe had also surpassed the U.S. by this time with only 9.3 percent of production still in open hearth furnaces.⁶²

Continuous casting, the other of the two major post World War II breakthroughs in steelmaking technology, eliminates the intermediate step of pouring ingots and reheating them. It thereby increases energy, material and labor efficiencies substantially.⁶³ The lag of U.S. firms in installing continuous casters has been much more serious than for the basic oxygen furnace with nearly all foreign countries adopting it more quickly.⁶⁴ Partly, this must be due to the fact that continuous casting was not

⁶⁰ U.S. Congress, Office of Technology Assessment, Technology and Steel Industry Competitiveness, p.129.

⁶¹ Adams and Mueller, p.116.

⁶² Ibid.

⁶³ U.S. Congress, Office of Technology Assessment, Technology and Steel Industry Competitiveness, p.287.

⁶⁴ Ibid., p.288.

commercialized until the early sixties⁶⁵ while soon after this time U.S. firms seemed to have given up the idea of keeping up with Japan,⁶⁶ pushing for and receiving protection in the form of voluntary restraint agreements in 1969 and subsequently slowing the pace of investment.⁶⁷ In 1975, the percentage of steel output continuously cast was 9.1 percent in the U.S., 16.5 percent in the European Economic Community (EEC), and 31.1 percent in Japan. Adoption rates bore roughly the same relationship to each other in 1980 when the proportion continuously cast stood at 20.3 percent for the U.S., 39.2 percent for the EEC, and 59.5 percent for Japan.⁶⁸

There are several other less important technological improvements which U.S. firms have been behind in adopting. By the late sixties, both German and Japanese rolling mill technology had advanced beyond American standards.⁶⁹ The older rolling equipment of American plants operates more slowly and cannot hold tolerances as close as Japanese equipment.⁷⁰ The Japanese have also developed superior coal blending techniques that allow substitution of lower

⁶⁵ Ibid., p.286.

⁶⁶ Borrus, p.76.

⁶⁷ Ibid., p.84.

⁶⁸ Adams and Mueller, p.114.

⁶⁹ U.S.Congress, Office of Technology Assessment, Technology and Steel Industry Competitiveness, p.131.

⁷⁰ Magaziner and Reich, p.157; Adams and Mueller, p.113.

grade coals for high grade ones and blast furnace technology that lowers the amount of coke used per ton of pig iron produced. Improved Japanese methods of gathering steel scrap and the steel "fines" given off by steelmaking processes have raised the yields from raw materials.⁷¹

Corresponding to all of these examples of technological inferiority is a comparatively low level of research and development expenditures by American steel firms. In 1964, the steel industry spent 60 cents for every 100 dollars in sales on R&D compared to \$1.90 for manufacturing industry in general. In 1980, the number of R&D scientists and engineers per 1,000 employees was only 15 percent of the average for all surveyed industries, less than every other industry except apparel and textiles. International comparisons are also unfavorable: 1973 expenditures on R&D per net ton of steel products was \$1.36 in the U.S., \$1.75 in the EEC, and \$2.30 in Japan.⁷²

Though manufacturing technology in the American auto industry had a few shortcomings going into the last recession, it was not, on the whole, below the standards of the Japanese or the Europeans. A couple of exceptions were the heavier use of robots in Japanese factories⁷³ and the difficulty of bringing painting techniques up to Honda's

⁷¹ Magaziner and Reich, p.159.

⁷² Adams and Mueller, pp.110-11.

⁷³ Abernathy, Clark, and Kantrow, "New Industrial Competition," p.76.

standards.⁷⁴ Though not itself a prolific originator of process innovations, the industry has appeared to be prompt in adopting improved techniques when they became available.⁷⁵

Product technology is the area where there has been a notable record of meager engineering advance and several important instances of American industry lag. For most of the post World War II period, Detroit has focussed mainly on styling rather than mechanical improvement. Suppliers to the industry have done the bulk of initial development work on the more fundamental innovations.⁷⁶ The industry's philosophy has been that basic components and systems did not have to change to attract buyers who responded more to minor luxuries such as power door locks and plush upholstery than improvements in handling and braking. And with little mechanical change, economies of dedicated automation could be taken advantage of more fully.⁷⁷

There are several advanced engineering features that American automakers treated as unnecessarily costly refinements for many years before they were forced to add

⁷⁴ Yates, p.45.

⁷⁵ Lawrence J. White, "The Automobile Industry," in The Structure of American Industry, ed. Walter Adams, p.171.

⁷⁶ Ibid., pp.161-62.

⁷⁷ William Abernathy, The Productivity Dilemma: Roadblock to Innovation in the Automobile Industry, (Baltimore: Johns Hopkins University Press, 1978) and U.S. Congress, Office of Technology Assessment, The Competitive Status of the U.S. Auto Industry, pp. 37-8.

them in competition with the Japanese in the late seventies and early eighties. Radial tires were pioneered by Michelin in France and first appeared on the Mercedes-Benz in 1954. American automakers were still rejecting them in the seventies when they had already become standard equipment on better cars in Europe, in part because the old tiremaking equipment could not be used for radials and radials were two to three times more expensive. There were, however, clear and important advantages of radials over the old bias ply tires. They delivered better cornering and handling in both dry and wet weather, better gas mileage, and better durability. It remained for the Japanese to educate American consumers to these facts.⁷⁸

Independent rear suspension was another Japanese feature which took the Americans years to catch up to. It gave better stability over uneven surfaces than the single solid rear axles that the Americans chose to stay with because of their lower cost.⁷⁹ More difficult was the transition to front wheel drive which necessitated a major redesign of the whole automobile, but it was essential for economical use of space inside a small vehicle.⁸⁰ In transmissions, the Japanese set the standard as well since consumers responded favorably to the smoothly shifting five

⁷⁸ Yates, pp.199-201.

⁷⁹ Ibid., pp.43,207-8.

⁸⁰ Ibid., p.43.

speed manual transmissions that were standard on their models. American four speed transmissions had to be redesigned for five speeds and to shift more easily.⁸¹

American engine technology was also caught short by several years in the late seventies because U.S. automakers never created a focussed design for small cars.⁸² What was needed was a lightweight (aluminum) engine that was more efficient so as to save fuel and deliver responsive power at the same time. Instead, American firms took the shortcut to small engine design by chopping cylinders off the older, heavy V-8s.⁸³ European and Japanese cars also employed fuel injection in their engines to improve performance, reliability and maintainability. Americans had to make a lot of complicating modifications to the traditional carburetor to meet air pollution requirements while fuel injection allowed imports to meet the requirements more simply. When the move to fuel injection was finally made, Americans were behind in fuel injection technology,⁸⁴

In sum, the American automakers were not just behind in the late seventies and early eighties in achieving high gas mileage, but in a whole array of automotive

⁸¹ Ibid., pp.41,72.

⁸² Ibid., pp.208-10.

⁸³ Ibid., p.203.

⁸⁴ Ibid., pp.202-3.

developments which the Japanese and Europeans introduced to the American consumer. Though few of these technologies were very new, American automakers fell substantially behind in acquiring experience with them and learning how to adapt them to its own purposes.

One of the keys to the early success of Japanese firms in the color television market was their more rapid adoption of solid state technology. Although Motorola built the first prototype all solid state set in 1968, a Japanese firm was the first to commercialize such a set in 1969, and in 1971, 90 percent of Japanese sets were solid state. Two of the largest U.S. firms, Zenith and RCA, did not move to all solid state until 1973-74.⁸⁵ The chief advantage of solid state sets is the greater automation and manufacturing efficiency they allow. At the end of the seventies, Japanese firms were still significantly ahead in the general level of automation. Japanese plants were noted for their more automated materials handling and for more automated insertion of components into the set for which their technology was, for some time, more advanced. In 1978, 40 percent of set components were automatically inserted in the United States, whereas Japanese firms were automatically inserting 65 to 80 percent of their components.⁸⁶

⁸⁵ Millstein, pp.117-18.

⁸⁶ Magaziner and Reich, pp.172-74.

American firms had, for decades, maintained a comfortable lead over foreign producers in machine tools allowing them to charge substantially higher prices than their competitors. But in the nineteen-eighties, the lead had shrunk to a point where it had even been lost in certain areas.⁸⁷ A strong indication of the new level of technological competition was the growth of licence agreements enabling American firms to produce machines designed abroad.⁸⁸ Although a matter of some controversy, a National Academy of Engineering study concluded in 1983 that the Japanese were quite possibly ahead in control and software technology⁸⁹ and that their computer numerically controlled machines were more advanced.⁹⁰

The problem appeared to be one of applying available knowledge for the U.S. still led Japan in most areas of "high tech" machining in 1985. Some examples of such areas are ultra high speed and ultra precision machining, and laser machining. Most of the "high tech" machining

⁸⁷ Ralph E. Winter, "Machine Tool Makers Fall On Rough Times As Technological Lead Fades, Imports Soar," Wall Street Journal, January 27, 1983, p.29.

⁸⁸ Ibid., Winter, "The Cutting Edge: Making Machine Tools Increasingly Requires Ties to Foreign Firms."

⁸⁹ National Academy of Engineering and the National Research Council, The Competitive Status of the U.S. Machine Tool Industry, p. 52.

⁹⁰ Ibid., p.25.

technologies have benefited from the support of the large American military and aerospace markets.⁹¹

Where Japan's lead is not in dispute is in the technology of manufacturing machine tools.⁹² Japanese firms have adopted advanced CNC tools much more quickly than their American counterparts⁹³ and have pioneered in bringing the benefits of standardization and mass production to machine tools.⁹⁴

We have bypassed subjects such as costs, levels of investment, prices, market strategy, and profits, and focussed instead upon the more direct and physical evidence of American underperformance. A review has been made of the key examples of four basic problems in American manufacturing industry ---slowing improvement and relative decline in productivity, loss of market share, and inadequate quality and technological advance. It has been suggested that these problems, especially the first two, along with the recession of the early eighties brought

⁹¹ Minoru Inaba, "Machining Areas Lag in High Tech," American Metal Market Magazine, June 17, 1985, p.3A.

⁹² Winter, "The Cutting Edge;" National Academy of Engineering and the National Research Council, The Competitive Status of the U.S. Machine Tool Industry, p.52.

⁹³ National Academy of Engineering and the National Research Council, The Competitive Status of the U.S. Machine Tool Industry, p.52.

⁹⁴ Seymour Melman, Profits Without Production, (New York: Alfred E. Knopf, 1983), p.9.

about an impetus to change manufacturing management and methods.

To whatever sources America's economic problems might be traceable, the reality of Japanese and occasionally European superiority in productivity, quality, and technological sophistication had to be faced with the tools at hand. It is the objective of the next four chapters to describe the avenues of change in manufacturing practice which had been developing in the United States before the onset of the crisis.

CHAPTER THREE

WORKER PARTICIPATION

Introduction: Four Avenues of Change

Once economic pressure and direct evidence of underperformance had cumulated to the point where a consensus was formed on the need for fundamental change in manufacturing and manufacturing management, specific avenues of reform had to be chosen and marked out. There were at least four such avenues that could offer not only prospects of substantial improvement but a vision of total system transformation. Although each program of reform addressed a different aspect of the manufacturing process, its thoroughgoing implementation could be seen as ramifying to reorient all other aspects.

One target of reform was the structure of authority and the character of human relationships that flowed from it. Conventional organization along scientific management lines minimized the discretion of individual workers and attempted to dispense with the need for group decision making by having those at superior levels in the chain of command specify the activities of those below them on an individual basis. In the seventies, this arrangement was more and more perceived as preventing a productive use of

human resources by denying workers the opportunity of exercising their competencies both individually and as part of the group with which they worked. Not only did the structure of authority prevent this, but it deprived people of dignity by denying them the social rewards of group participation and the satisfaction of taking and meeting responsibility. The result was alienation from work and the goals of the firm which poisoned even further what were supposed to be the naturally adversarial relations of management and labor. New organizational techniques of increasing worker participation were seen as possible solutions.

A second avenue of reform was the achievement of new levels of precision in the coordination in time of input deliveries, parts manufacture, and final assembly and delivery. In conventional manufacturing, large amounts of material, work-in-process, and end product inventories have to be kept on hand to avoid shortages and late deliveries to customers which nevertheless occur with some frequency. With the use of computers to keep track of work status and calculate more exact need dates, much inventory can be eliminated while shortages are substantially reduced along with the drain on management energies caused by the need to respond to shortages.

Another focus of reform efforts was quality control. Specialists in the area contended that management typically, but wrongly, assigned responsibility for product

defects to lack of worker diligence and quality control staff incompetence or lack of manpower. Quality experts pushed for a reordering of top management priorities to favor specific quality objectives, development of new more explicit and comprehensive quality measurement systems, and a diffusion of quality control techniques to all line and staff personnel reaching down to the shop floor level and into all departments. This diffusion of techniques would require extensive training programs complemented by restructuring of responsibilities and incentives so all employees would be oriented toward taking initiative to improve quality.

Finally, new computer technologies appeared to present the opportunity to raise drastically the efficiency and control of manufacturing processes. As the eighties began, visions of a breakthrough in the comprehensiveness of computerization were in the process of being realized for the first time. In particular, individually programmable machines were now being linked together in networks and controlled and coordinated with hierarchies of computers. At the same time, rapid advances were being made in learning how to translate computer generated designs into instructions for programmable manufacturing equipment.

The rest of this chapter will specify in more detail each of these four major avenues of reform that were being opened up as American industry entered crisis.

The Growth of Worker Participation in the 1970's

The techniques the Japanese used to establish ongoing and substantive worker input into decision making on the shop floor level would capture the imagination of American managers in the eighties. But this was so partly because American experimenters in worker participation had already been developing the rationale behind such experiments and were demonstrating with increasing success how participation could work in the American environment. Throughout the seventies, both concern about the problem of worker alienation and the number of firms willing to experiment with greater worker participation was continuously on the rise.

In discussing these trends, our objective is to understand the blueprints for change that were available and attractive to U.S. managers by the time the recession of the early eighties provoked them into action. Thus, we are concerned with changes in ideology more than with actual trends toward worker participation which, in any case, were rather marginal during the seventies. But before we begin, a few words on the nature of ideological change itself might be in order.

Ideological changes do not occur simply because a novel set of ideas is more appealing than a set of conventional ones. Rather, ideological change is both a response to changes in experience or environmental pressures and the result of a progression of ideas which is

governed in part by requirements of logical coherence. That is, experience transforms ideas while ideas evolve in their own conceptual medium.

On one hand, there needs to be a growing number of instances of revolutionized practice. Otherwise, arguments for change become hollow and lose credibility; they cannot point at the image toward which events are tending and toward which organizations are supposed to be groping.

On the other hand, people must also usually be compelled by an argument that makes it clear why old ideas have been superceded by new ones if they are to begin to look for and recognize change. In the presence of such arguments, things which might otherwise appear without significance---as minor difficulties, as ad hoc modifications, as curious anomalies, appear instead as signs of change or the need for change toward some transformed total system.

Consider, then, the two prerequisites for change in the ideas which govern the organization of production: successful contention against the traditional logic of efficiency (as described in chapter one) and concrete examples of worker participation to emulate. If we want to understand the ideological change of the seventies and the early eighties recession, we must explore both the rationales for that change and the series of events and experiments which supported it.

To describe the emergence of worker participation as a managerial goal it is useful to begin with a rise in concern about lack of job satisfaction and inadequate productivity advance that was apparent by the early seventies.

Job dissatisfaction manifests itself most clearly to managers in the form of increased numbers of grievances, sloppy work, theft of materials and tools, drug and alcohol problems, and especially, high rates of absenteeism and tardiness, strikes, and high employee turnover. Many of these problems were perceived to be on the rise nationally in the late sixties and early seventies. A major contributor to this perception was the well publicized Work in America report issued in December 1972 which painted a bleak picture of deepening worker alienation. The famous Lordstown automobile assembly plant strike of March 1972 became symbolic of a larger trend of rebellion by younger and increasingly educated workers against unrewarding, monotonous work. Cultural changes of the sixties and early seventies seemed to bring with them less willingness to submit to authority, less belief in the values of hard work and more drug abuse.

Despite the fact that these problems significantly lowered productivity, interest in solving them did not flow from a perception of generally inadequate productivity. However, during the seventies, there was also an independently increasing interest in productivity

improvement per se. One of the first signals of concern was the setting up by the President of the National Commission on Productivity in 1970.¹ Whether the rising concern about productivity was caused by disturbing national productivity indexes, recession, inflation, or foreign competition, the search for means of improving productivity was intensified along with it.

But of course every concrete solution must be targeted at a specific problem. The structure of the situation in which solutions must be found forced previously identified specific problems into closer relationship to the general problem of productivity. In other words, worker alienation was available as a likely prime contributor to productivity problems.

The perceived relationship between job dissatisfaction and inadequate productivity changed over the decade. At first, problems with the human resource were perceived as a disease which had crept up on an otherwise healthy industrial system. It was thought that if some adjustment (such as job enlargement) could be made, then perhaps things could be set right again. There was another worry, though, that advances in technology necessarily created more monotonous, dehumanizing work. (The Lordstown plant

¹ Charlotte Gold, Employer-Employee Committees and Worker Participation, Key Issues Series, No. 20, (Ithaca, New York: Publications Division, New York State School of Industrial and Labor Relations, Cornell University, 1976), p. 19.

was noted for its advanced, highly automated equipment.) Thus the question was asked: can we increase productivity and job satisfaction at the same time?²

Many academics said yes, that in fact, higher productivity would flow from greater job satisfaction. The attempt was made to demonstrate and document this, but the relationship was found to be very tenuous indeed, perhaps nonexistent.³ The academic arguments for workplace reform were thereby deprived of some of their force. But the question had been put too broadly. Job satisfaction derives from a host of things, many of which are external to the actual process of work, such as wages, safety, various amenities, and schedule flexibility.

Still, however, there were notable successful experiments in which academics were involved causing them to advocate further attempts, though with much cautioning that failure was quite likely without the proper commitment and sensitivity to the psychological dynamics of organizational change. Common sense too suggested that workers who identified with their work and who felt a sense

² Raymond Katzell and Daniel Yankelovitch with others, Productivity, Participation, and Job Satisfaction: An Evaluation of Policy-Related Research (New York: Psychological Corporation, January 1975), p.5. See page 23 on the lack of literature focussing on both job satisfaction and productivity.

³ Clark, Susan G., Kathleen D. Warren, and George Greisinger, Assessment of Quality-of-Work-Life Programs For The Transit Industry Research Report (Washington D.C.: Transportation Research Board, National Academy of Sciences, December 1983), p. 11.

of pride and responsibility would turn out more and better quality work than workers who were just going through the motions. Added to this was the fact that failures were often unpublicized while testimonials to some of the resounding successes were broadcast far and wide. A handful of examples was enough to satisfy the requirements of journalists and those managers who only needed confirmation of their own sense of potential for progress.

The establishment in the mid seventies of independent organizations dedicated to research, education and consulting in the field also played a critical role in increasing interest in participatory work reform.⁴ Regardless of the overall success of worker participation programs, these organizations were dedicated to collecting and disseminating information on successful programs. The gathering together of information on isolated and varied experiments made their similar general thrust more apparent marking their significance as part of a movement or trend. The trend toward worker participation was probably accelerated by being thus defined and documented.

The role of academics in the spread of worker participation experiments was critical both inside and outside the firm, especially in the earlier years. They

⁴ The Work in America Institute in Scarsdale New York was established in mid 1975 (Louis E. Davis, "Enhancing the Quality of Working Life: Developments in the United States," International Labor Review, vol.116, no.1 (July-August 1977), p. 63) and the National Center for Quality of Work in Washington D.C. was set up in 1973-74.

were the ones who organized conferences, analyzed and monitored the progress of experimenters in print, formed information clearinghouses, and set up university courses centering on the problems of the quality of working life. Most important of all, academics were the points of contact between companies and outside institutions. Nearly all of the early projects and most of the later ones were carried out with the help of academic consultants.⁵ This consulting work is the source of most of the available published information. There was also a substantial number of social psychologists on the staffs of most of the companies that pioneered in worker participation.⁶ They would have acted as the working interface with the consultants.

Undoubtedly, another critical factor promoting the growing willingness to attempt new forms of worker participation was the ability to use plant visits to gather information on what other firms were doing in the field. Some of the centers and institutes arranged large numbers of plant visits⁷ and probably many others were arranged privately. First hand experience of other firms' successes

⁵ Ibid., p.60; Clark et al., p.25.

⁶ For example, in a three year period to 1975, General Motors increased the number of social psychologists (most trained in organizational development) in its field offices from six to 110. See Ted Mills, "Human Resources---Why the New Concern," Harvard Business Review, (March-April, 1975), p. 125.

⁷ Davis, p.63.

was likely an important factor in the decision to undertake risky changes toward wider participation in complex organizations.

Regardless of the actual rate of success, then, participatory organization of work was promoted and propagated as a tool for increasing productivity. With the 1974-75 recession, pressure to find ways of raising productivity increased, and worker participation was at hand as one possible focal point for action. The heightened perception of need for productivity improvement had the effect of recasting efforts to democratize the workplace and improve the quality of work life as productivity improvement programs. Recession had a similar effect in the eighties. This was in spite of the fact that many advocates of reform tried to further the chances for long term commitment to change by emphasizing human relations benefits over direct productivity benefits.

Some survey results suggest the extent of change in attitudes toward participatory concepts of organization among American managers. A survey of 563 members of the American Management Association, probably carried out in 1974 before the worst of the 1974-75 recession had hit, showed that participation was little valued for its contribution to productivity. Following are the percentage of respondents that rated each factor to be a "very important influence" on an organization's productivity: improving the quality of work life, 16%; job redesign and

enlargement, 12%; greater participation by workers in decision making, 10%; more democracy in the organization, 6%.⁸ A 1982 survey of corporations with over 500 employees (only a little over half the companies in the 1974 survey had more than 500 employees) found that 82% thought participative management concepts were a promising new approach while only 3% thought they were a "fad destined to disappear."⁹

Firms trying new approaches involving employee participation were still in the minority in 1982,¹⁰ but a clear perception of an economy-wide need for breakthroughs in productivity combined with a widespread belief that many respected companies were already achieving these breakthroughs with increases in employee participation made greater participation appear to be the wave of the future.

The Scanlon Plan

A clearer picture of experiments in worker participation will emerge if we review separately each of the three general categories into which these experiments

⁸ Katzell et al., pp.109-10.

⁹ New York Stock Exchange, Office of Economic Research, People and Productivity: A Challenge to Corporate America, (New York: New York Stock Exchange, 1982), p.27.

¹⁰ 14% of all companies with more than 100 employees and 32% of their employees were involved in human resource initiatives to boost productivity although only about 70% of human resource programs had any impact at all on the degree of employee participation in decision making. (Ibid., p.26).

seem to fall. Each group of experiments played a somewhat different role in building the momentum behind the movement toward participation, partly because each was prevalent in a different time period. It is best to start out by noting the marginality of participatory innovations in the mid sixties. Milton Derber, summarizing developments in unionized industry from 1945 to 1965, said that "the problem of containing or even reducing union participation in management decision making was a central concern to unionized employers as a whole" and that "by and large the employers were successful in their containment movement..."¹¹

During this period, probably the most significant example of workplace reform was the Scanlon Plan¹² which was implemented in about 100 plants (both union and nonunion) by the early seventies.¹³ This was a relatively radical design for participation whereby workers were

¹¹ Milton Derber, The American Idea of Industrial Democracy (1865 - 1965), (Urbana: University of Illinois Press, 1969), pp. 495-6.

¹² Speaking of the 1945-65 period, Milton Derber said "Worker participation in decision making, as distinct from the role of their organizational representatives, was given some stimulus by the adoption of the Scanlon and Rucker Plans. But the joint production committees of WW II did not survive and, apart from the extension of suggestion systems and the establishment of some joint safety and health committees, the worker participation movement did not make much headway." (Ibid., p. 497.

¹³ In about 1968, about 125 Scanlon Plans were in effect, mostly in plants with less than 1,000 employees. (Gold, p.25).

represented on departmental committees dedicated to eliciting worker suggestions. When the suggestions cost substantial amounts of money to implement or involved more than one department they would be referred to a higher screening committee which also contained elected worker representatives. The Scanlon Plan differs from an ordinary suggestion system in that there is much emphasis placed on developing cooperative work habits and philosophy, giving workers a role in deciding whether suggestions should be used, and providing regular, prompt (typically monthly) feedback on the status of all suggestions. The other major component of the plan is the establishment of a plant-wide standard for the ratio of labor costs to value of output and the use of that standard to determine the size of a monthly bonus to which all employees are entitled. Thus the cost saving effects of suggestions are passed through to employees in a very direct and immediate fashion.

Scanlon Plan companies have been a kind of foundation of participatory work reform in the United States. Their successes were well publicized from the beginning (the first well known Scanlon Plan success was at the Lapointe Machine Tool Company which started the plan in 1947) and there was a unity among its practitioners manifested in associations and annual conferences; yet the Scanlon Plan never spawned a fad. This appears to be because it was never presented as a neat gimmick or formula and never perceived widely as such. Newcomers to the plan were urged

by consultants to approach adoption with caution, in a democratic manner (after a trial period, employees were allowed to vote to determine whether to adopt the plan) and finally, with commitment.¹⁴ Also, the Scanlon Plan was apparently most successful in small plants leading larger organizations to take a cautious or skeptical attitude toward it. One of the firms that uses a version of the Scanlon Plan, Donnelly Mirrors, has been using it since the fifties and served as one of the key examples of a stable participatory work system in the seventies. Douglass McGregor, one of the two or three best known psychological theorists of worker participation in the post World War II period regularly called attention to the Scanlon Plan as the best example of participatory ideas in action.¹⁵

Estimates of the number of Scanlon Plans in effect during the seventies do not evidence much diffusion¹⁶ but many more firms probably tried the plan at the end of the seventies and the early eighties since by 1981 or so,

¹⁴ John Simmons and William Mares, Working Together: Employee Participation in Action, (New York: Alfred E. Knopf; New York and London: New York University Press, 1985), p.36.

¹⁵ Derber, p.479.

¹⁶ The number of Scanlon Plan companies was placed at 100 by a 1977 report cited in George Lodge and Karen Henderson, "United States of America," in Toward Industrial Democracy: Europe, Japan, and the United States, ed. Benjamin C. Roberts, (Montclair, New Jersey: Allanheld, Osmun, and Co., 1979), p.256. Another source claims that there were at least 500 Scanlon firms by 1980. (Simmons and Mares, p.35).

Scanlon Plan firms numbered around 400 or 500.¹⁷ (up from around 100 in the early seventies) In addition, between 1974 and 1982, more than 100 companies, some of them quite large, adopted Improshare which is similar to the Scanlon Plan but uses a more accurate method of calculating productivity improvements.¹⁸

Worker Participation in Nonunion Plants

Another group of examples of participatory work reform appearing mainly in small (less than 500 employees), nonunion plants came into prominence in the early and mid seventies. Even top consultants in the field however, have had difficulty in summarizing the nature and estimating the magnitude of this varied crop of experiments.

Whereas most of the companies that pioneered early in worker participation such as the Scanlon Plan firms had been small, the notable experiments in the early seventies were carried out mostly by the best known, largest corporations although only in a few of their smaller plants. A roster of the most prominent includes Monsanto, Cummins Engine, First National City Bank, Traveler's

¹⁷ A March 1981 study reported about 400 Scanlon Plan firms in existence: "Productivity Sharing Programs: Can They contribute to Productivity Improvement?," (Washington D.C.: U.S. General Accounting Office), p. 9 as cited in Irving H. Siegel and Edgar Weinberg, Labor-Management Cooperation: The American Experience, (Kalamazoo, Michigan: W. E. Upjohn Institute for Employment Research, 1982), p. 186.

¹⁸ New York Stock Exchange, p.33.

Insurance, General Motors, Weyerhaeuser, Ralston Purina, Burlington Mills, AT&T, Corning Glass, Bankers Trust, Union Carbide, General Foods, Ford Motor, and Proctor and Gamble. While not yet undergoing any deep or widespread transformation of managerial ideology, these firms considered themselves to be engineering significant tools of productivity improvement and they kept the details of their activities secret as if they were protecting a mechanical or chemical invention.¹⁹

Estimates of the number of these early corporate experiments are hard to interpret since the type of experiment being counted cannot be clearly specified. A low estimate of 75 to 90 experiments undertaken between the years 1970 and 1976 probably corresponds roughly with the type of major innovation under discussion here.²⁰ Another estimate of 2,000 firms involved in substantial, planned changes in definition of task and structures of decision-making in 1975 serves to show that receptivity to participatory alternatives was spreading beyond the principle innovators and that it is very difficult to know just how much activity there actually was. In any case,

¹⁹ Many of these programs were considered prototypes to be replicated elsewhere in the corporation in case of success. See Ted Mills, "Human Resources---Why the New Concern?" Harvard Business Review, March-April 1975, p.125.

²⁰ P. S. Goodman and E. E. Lawler III, "'United States," in New Forms of Work Organization, 1, (Geneva: International Labor Office, 1979), p. 1, as cited in Siegel and Weinberg, p.143.

human resource initiatives of the early to mid seventies seemed to be "mushrooming", making the "human relations movement" of the sixties appear "superficial and fleeting."²¹

The essence of the most influential experiments²² consisted in the formation of work groups who manage their affairs with some degree of autonomy. This entailed a lessening of the hierarchical character of workers' relationships to their supervisors who had to take on a more advisory and less disciplinary role. Whereas job enrichment meant a widening of the scope of worker tasks and decision-making responsibilities, the newer projects tended to go beyond this to stress the development of group processes of decision-making, and growth in employee capabilities over time. Instead of simply carving out a wider space in the organization for the individual, they emphasized the dynamic qualities of organizational relationships. In a sense, the advanced forms of worker participation of the early seventies could be interpreted as an extension of management approaches and ideas that were concerned strictly with the character of human relationships to take account of the growing recognition that the quality of human relationships and overall job satisfaction depended critically upon the technical

²¹ Mills, pp.124,121.

²² The single most prominent experiment was at a Topeka dog food plant owned by General Foods.

requirements of the job and the structure of the division of labor.

While most of the organizational innovations were focused on the restructuring of jobs at the shop floor level, impetus for them did not come from workers or lower management. They were rarely undertaken in cooperation with unions or other worker representatives and seldom were they the response of plant managers to local problems. Thus, ironically, participation was decreed, designed and installed from above. As a result, it was circumscribed by traditional forms of authority from the outset and was relatively easily terminated when growing participation threatened management control.²³

Early seventies experimentation with increased worker participation tended to be associated with technological sophistication. Companies in industries of rapid technological change such as TRW and Texas Instruments fostered a kind of democratic teamwork and individual initiative in order to draw from their more educated employees the creativity and flexibility they needed to compete.

²³ A high rate of program termination even for those programs which were initially successes was noted by P. S. Goodman, "Quality of Worklife Projects in the 1980's," Proceedings of the 1980 Spring Meeting of the Industrial Relations Research Association, (1980), p. 490 as cited in Siegel and Weinberg, p.150. See also the description of unilateral termination of worker participation by management in the last chapter of Noble, Forces of Production.

Companies with less sophisticated products, on the other hand, often saw the installation of new process technology or new plant construction as an opportunity to implement the most advanced social technologies as well. They took advantage of the fact that plant layout and equipment controls could be designed to allow more employee interaction and individual control over work quality and work flow.

The formal conceptualization behind this integrated approach is known as sociotechnical systems theory. In the first chapter, it was noted that the all inclusiveness and complexity of interactions between variables in this model did not do much to tear down the traditional concept of technological determinism in the organization of high volume manufacturing. Yet, sociotechnical systems was a notion that made the logic of drawing on the expertise of social scientists clear. As corporations increasingly drew recruits from the universities in the natural sciences, engineering and the business specialties, using the contributions of psychologists and sociologists came more as a matter of course. To some extent, innovations in the structure of authority during the late sixties and the first half of the seventies could be seen as linked to a general trend toward thinking in terms of systems and as part of the systems planning response to problems of all kinds that was continually on the rise in American business.

Worker Participation in Union Plants

Worker participation in American industry did not really begin to progress beyond the "research and development" stage until unions came into the picture in the mid and late seventies. Up to this time, unions were quite suspicious of any management initiatives with the ostensible goal of making workers happier since such initiatives, if successful, could be seen as decreasing support for unions in their role of bargaining with management. In addition, participatory experiments were aimed at least in part at increasing productivity which, as in Taylor's day, was a goal associated in labor's mind with speed ups and layoffs. But when unions began at last to play an active role in implementing worker participation experiments, (other than in Scanlon Plan firms) management commitment to achieving the participatory values sought could not as easily be abandoned.

In America, industrial democracy traditionally meant collective bargaining and establishment of fair rules through a system of union representation. Since at least the nineteen twenties, this concept was occasionally broadened when labor and management representatives met in alternative forums called labor-management committees. These bodies were unorthodox because they dispensed with the adversarial framework and were premised on the idea that problems of various sorts could be solved through

mutual consultation and cooperation. These labor-management committees became the vehicle of introducing participatory reforms into unionized plants.

The steel industry's productivity committees of the early seventies were the most important precursors to the quality of work life committees of the later seventies and eighties. In 1973, of 509,000 workers covered by major collective bargaining agreements with provisions for labor-management committees, 72 percent were in primary metal industries.²⁴ The committees were formed, following a United Steelworkers contract provision of 1971, in response to severe import competition.²⁵ As with most committees, it was explicitly agreed in advance that they would in no way substitute for the collective bargaining and grievance machinery or modify the rights of any of the parties specified in the basic labor agreement. About 230 plant level committees were established by 1973.²⁶ The range of issues open to discussion was quite wide: virtually anything relating to productivity including worker morale,²⁷ but the level of participation was extremely varied: some committees really only existed on

²⁴ H. M. Douty, "Labor-Management Productivity Committees in American Industry," Unpublished report prepared for the National Commission on Productivity and Work Quality as cited in Gold, p.37.

²⁵ Gold, p.28.

²⁶ Siegel and Weinberg, p.127.

²⁷ Gold, p.30.

paper.²⁸ Still, some of the subsequent gains in industry productivity and a 1974 contract provision barring strikes until 1977 have been attributed to the committees²⁹ and they were continued and further developed in a participatory direction into the eighties.³⁰

Joint union-management quality of work life (QWL) programs have usually begun as plant level committees composed of top management and union officials. Their initial emphasis has usually been on establishment of trust and communication and the finding of mutual areas of interest to help break down habits of constant conflict, antagonism and suspicion. Often, the goal of productivity increase is even disavowed in order to increase the possibility of real discussion and a frank exchange of views. The whole idea is to change the work culture and to establish the principle that work does not have to be a zero sum game between workers and managers.

In a later phase as, for example, in the steel industry, departmental and shop floor committees have often been added.³¹ This creates what is known as a parallel

²⁸ Siegel and Weinberg, p.127.

²⁹ Gold, p.30.

³⁰ Siegel and Weinberg, pp.128-29.

³¹ This path of development is suggested in Clark, Warren, and Greisinger, p.23; A review of the committee-based structures of quality of work life programs in United States Dept. of Labor, Division of Cooperative Labor-Management Programs, Resource Guide to Labor-Management Cooperation, (September 1982) also suggests such a pattern.

organization. The drawback of this structure as far as worker participation is concerned is that the original authority structure remains intact and the participative committees only involve a small percentage of the workforce since committee members are elected representatives.

Although worker suggestions may be listened to and implemented by committees, the average worker does not get a feeling of participation, especially when the committees are not terribly active or do not attempt to tackle major issues.³²

1977 is perhaps the year that marked the gelling of a real interindustry movement among union members to promote the quality of work life concept. In that year, the American Center for the Quality of Work Life arranged the first informal conference of workers, union officials, foremen and supervisors from a group of seventeen diverse organizations for exchange of experiences with their QWL programs. The discovery of the commonalities of their experiences and aspirations inspired the participants to step up commitment to overcoming the serious attitudinal obstacles most were facing in making the work environment

³² This problem is discussed in Toward a More Human Way of Working in America, A Report on the First National Conference of the American Quality of Work Life Association Convoked by the American Center for the Quality of Work Life, May 20-22, 1977, U.S. Department of Health, Education, and Welfare, Public Health Service Alcohol, Drug Abuse, and Mental Health Administration, National Institute of Mental Health, (Washington D.C., 1979) pp. 25-30.

more humane and participatory and they decided to repeat such conferences annually.³³

Quality of Work Life at General Motors

The largest QWL program and probably the best known, notable for its success and important by virtue of the industry involved was one at GM's Tarrytown, New York assembly plant.³⁴ A few details of its evolution may help to illustrate what the QWL movement is all about. One writer has seen in it the microcosm of industrial workplace developments of the future.³⁵

Tarrytown was not the first GM experiment. Three years earlier, in 1968, the first pilot project including four plants was begun with the assistance of the Social Research Institute in Ann Arbor. The project was a response to a set of disturbing trends at GM in the late sixties: Employee attitude surveys showed increased work dissatisfaction; absenteeism increased 50% between 1965 and 1969; in the same period, turnover rates increased 70%, grievances 38%, and disciplinary layoff more than 40%. Profit rates had also slipped substantially. The potential

³³ Ibid.

³⁴ The following account is drawn mainly from Simmons and Mares, chapter four, and Rosabeth Moss-Kanter, The Change Masters: Innovations for Productivity in the American Corporation, (New York: Simon and Schuster, 1983) chapter 11.

³⁵ Robert Guest, "Learning From Tarrytown," Harvard Business Review, July-August 1975.

to change the situation was clearly identified by corporate executive Edward Cole when he visited 130 plants and found surprising differences in the character and effectiveness of working environments.

The first project produced a success at the Lakewood plant in Georgia, which went from being one of the worst GM plants to being one of the best. The financial payoffs were significant and apparent and the word was spread by a GM vice president that plant managers should be working on what he called new "people initiatives."

That same year the plant manager at Tarrytown faced an increasingly tense situation in which the air was charged with animosity and mutual suspicions, and union and management were continuously geared for conflict. Productivity was so low that GM headquarters had threatened to shut the plant down permanently. So Tarrytown's manager approached some union officials and expressed a desire to change the whole philosophy of management and keep the plant open.³⁶

Changes began informally. Aware of the manager's desires, a lower level supervisor came up with the idea of getting workers in on the work of laying out and installing a new assembly line. The few workers who got involved generated so many useful suggestions that the principle of worker participation gained a solid beachhead.

³⁶ Simmons and Mares, p.63.

In 1973, the concept of quality of work life gained substantial legitimacy and publicity within GM through a clause in the UAW contract committing management and the union to set up joint plant committees for exploring ways to improve the quality of work life. This was principally the initiative of union official Irving Bluestone who was sympathetic to the goals of recent GM experiments and saw the opportunity for the union to influence the direction of developments by getting involved. The contract clause was the first official union agreement to participate in QWL programs in the United States.

The following year, the Tarrytown plant began a formal QWL project which included 34 volunteer workers and two supervisors. A consultant was brought in on Saturdays to teach this group problem solving techniques and to help workers and supervisors break through communications barriers. Workers again came up with many useful contributions. Subsequently, word spread throughout the plant about the pilot group and other participative groups sprang up. The QWL program was then expanded to two entire departments with a combined personnel of about 600.

95% of these workers volunteered for the program and were given 27 hours of instruction. On the basis of the GM Assembly Division performance index, the Tarrytown plant had, by 1977, moved from sixteenth out of eighteen plants to first. In that year, the decision was made to expand

QWL to the rest of management and the 3,500 hourly workers, and training at the rate of fifty workers per week began.

Training for each group was conducted over a three day period, on company time, by both workers and supervisors who had themselves been trained as trainers. The content of the training included the philosophy of the QWL program, problem solving techniques, basic methods of measuring productivity and quality, and detailed information about how the plant was organized and managed. It was made clear that workers were assumed to be experts at their own jobs. They were therefore shown how to get any information concerning the plant that they wanted. In addition, workers were involved in experiential exercises designed to get them to reflect on their own behavior and modes of interpersonal communication.

Documented results of the Tarrytown program are few, but it has been indicated that the financial savings were far greater than the 1.6 million dollars spent on training. It is also known that absenteeism went down from seven percent to between two and three percent, and that in 1978 there were only 38 grievances filed compared to 2,000 seven years earlier. In general, workers seem to have responded more rapidly and eagerly than their supervisors expected (and sometimes could accept) to the opportunity of getting information on costs and operations and having influence in the determination of work method details. Once exposed to

a successful QWL program, workers were willing to fight to keep it going even if the union had decided to pull out.

Some important features of the QWL program at Tarrytown should be emphasized. First, individual participation is completely voluntary. Second, it does not replace or alter the formal structure of management. Third, it has not been targeted at the vast ranks of middle management and staff who have sometimes wished it were.

GM later experimented with more far reaching participative reforms, particularly at new plants built since 1972. In these programs, the structure of authority was formally altered with managers acting more as resource people than as bosses. Employees were members of teams who elect their own team leaders. One type of program creates new organizational structures and slots alongside the old ones to absorb the energies of supervisors whose responsibilities in the traditional hierarchy have been attenuated by increasing participation in decision making from those below.

By 1979, there were 40 joint, plant-level QWL committees in GM. This left more than two thirds of the plants without QWL committees and many of the plants that had them did not have the QWL training and philosophy spread throughout the plant as at Tarrytown. After all, Tarrytown was a pioneer and did not extend the QWL program to all of its employees until 1978.

As the auto industry faced another, more serious crisis in 1980, QWL efforts were growing and spreading across GM. Both union leaders and top management had grown more and more committed to the concept and had seen a renaissance of mutual trust and cooperative working relationships develop in several plants.

The GM efforts were also being heavily used as models for firms in other industries interested in alleviating the bitterness of relations with their unions and in motivating their employees to contribute more of their knowledge and energies to their jobs. The phrase "quality of work life" had, in fact, become a recognized symbol of a broad range of American management programs that placed new emphasis on respect for worker dignity and talents. In 1980, two other major unions joined the UAW under the QWL banner. The United Steelworkers signed a contract fully endorsing the QWL concept while the Communications Workers of America signed a contract with AT&T establishing a commitment to jointly explore ways of improving work life and worker input.

The single proposition that has been most useful in justifying QWL programs in American business has been that the worker is the one who knows his or her job best. More explicitly, the person who spends years doing a particular job knows that job better than a manager who oversees many jobs. Thus expressed, it sounds like plain common sense. Yet for decades, managers under the sway of scientific

management concepts operated on the opposite assumption. In fact, QWL programs have often been a revelation to managers of worker capacity to improve work organization and methods.

The foregoing discussion described a small but growing and genuine movement toward greater worker participation in the seventies. With the recession of the early eighties, worker participation concepts as practiced by the Japanese were to capture the attention of American managers and the business press. Indeed, the rush to implement Japanese management techniques nearly swamped the earlier interest in worker participation and itself became symbolic of the American QWL movement. It seems certain that a very large part of the attraction of Japanese practices and ideas was that they appeared to represent the more humane and productive system American managers had been searching for, yet were still not sure they had found. The infusion of Japanese ideas to be discussed in chapter seven was thus a catalyst for a development already underway.

CHAPTER FOUR

PRODUCTION AND DELIVERY SCHEDULING

The Scheduling Problem and its Conventional Solutions

Americans would rush to learn new Japanese techniques of production and delivery scheduling in the eighties, but the seventies was a time of rapid American development in this field. As the eighties began, an innovative form of scheduling called Materials Requirements Planning (MRP) which had been under development in the United States since around 1960, was still evolving and stood out as one of the most promising tools of progressive management. To understand why MRP was a big improvement over former practice, it is necessary to understand some of the basic principles of conventional production scheduling and inventory control.

To begin, one must grasp the complexities of the typical situation in manufacturing where there are many different products and product variations being produced which together incorporate hundreds or even thousands of different parts, subassemblies and materials, some of which are unique to a single product and some of which are common to multiple products. Furthermore, the various phases and branches of

production are ordinarily conducted at numerous separate work centers, each with a given amount of equipment and its particular complement of trained personnel, thus introducing its own capacity constraint on production. Each work center is usually capable of performing operations on a variety of components or final products, and the determination of the order in which each work center will take up the jobs allotted to it is critical for efficient, coordinated production.

The first task of scheduling is to establish overall rates of production. Then, each operation or job is assigned to a particular work center so that job characteristics match up well with work center capabilities and so that all work centers will be kept functioning as close to capacity as possible. The sequence of operations at work centers must also be arranged so as to 1) prevent shortages of inputs at any stage of production and 2) avoid delays in meeting the demands of customers. It is easier for work centers to be kept busy and for shortages to be avoided if supplies and final products are stockpiled so that they will always be available for subsequent operations or shipment to customers even if their production or procurement is improperly timed. Unfortunately, stockpiling entails certain costs and must be limited as will be explained below.

The task of scheduling the various phases of production and the ordering of parts and materials must

cope not only with the great complexity of the factory's numerous work centers, parts, and products, but with many uncertainties as well. On one hand, (if the plant is making typical consumer goods, for example), it is hard to predict accurately the magnitude and mix of demands for final products. On the other hand, it is difficult to estimate the exact time it will take to have various components produced or delivered from suppliers because production processes are almost always something less than perfectly routine. Inevitably, there are problems such as equipment breakdowns, defective materials, or communication failures that cause delays.

While unpredictable product demands and production times make it hard to avoid at least occasional shortages, it is also hard to know what the real costs of experiencing shortages will be. The waste caused by the waiting and disorder that results from a parts shortage is nearly impossible to quantify and the loss of business due to late deliveries of final product can often only be guessed at.

In this environment of uncertainty about the timing and magnitude of requirements and the penalties of shortages, production and delivery scheduling has to be done tentatively at first, and in terms of broad categories of supplies and products. Then, as the precise character of needs comes more sharply into focus, schedules are made more specific. People on the plant floor must make the final adjustments to the schedule when they determine

precisely what to do next. If a plant is producing only to fill specific customer orders, the rate of final product output and the quantities of supplies needed are essentially predetermined, but the coordination and timing of work center activities and purchases remains difficult to plan out in detail as they must still adjust to unpredictable elements in the production process.

As was noted before, high levels of inventory increase the ability to accomplish scheduling goals. This is because final product inventories absorb unpredictable increases in customer demand, while parts and materials inventories absorb unpredicted increases in the rate of use of supplies. This allows production schedules to adjust to increased requirements with a lag. Inventories also prevent shortages by serving as a buffer against production delays and late supplier deliveries.

Target inventory levels for items at each stage of production are therefore set according to the degree of variability of their rate of use and of the length of time needed for their manufacture or delivery from outside suppliers. The greater the uncertainties for a particular item, the higher the level of inventory that would be called for. Even in a situation where production quantities and rates are fixed by customer orders, uncertainties of production and procurement would call for the prior stocking up of supplies to ensure an

uninterrupted flow of production, raising average inventory levels as a result.

The most important implication of the discussion so far is that inventory levels are not determined by the rates and times of production established in the schedule. For example, large inventories of a given item are not necessarily needed when its scheduled production rate is high: A stable demand and thoroughly reliable production processes would make it safe to have small inventories of a high volume item. Thus, inventory levels are linked primarily to the degree of uncertainty of the schedule rather than the rates of production it specifies. This makes the function of inventory control separable from production scheduling and, in fact, the two management functions have traditionally been essentially independent.

The control of inventories often takes the form of rules for each item specifying when to replenish stocks and to what level they should be replenished. These rules may specify frequent replenishment of inventories up to very modest levels or infrequent replenishment up to high levels. (or anything in between) The more infrequent is replenishment and the higher the level to which stocks therefore have to be replenished, the higher average inventory levels will be. There are many numerical formulas which are used for setting replenishment rules in such a way as to optimize inventory levels. These formulas take account not only of the uncertainties of production,

procurement and demand associated with each item, but of at least two other major factors as well.

One is the amount of the fixed costs associated with each replenishment of supplies. In the case of internally produced items, there are costs of set up. Whether a lot is large or small, set up requires a certain amount of labor time and machine downtime, and often some waste of material. For example, machine tooling may need to be changed and settings adjusted as initial test pieces are run off. Each production lot also has a certain amount of paperwork and accounting associated with it. In the case of purchased items, there are transaction costs of ordering from suppliers including transportation and inspection of each shipment. Set up costs may also be transferred from the supplier to the manufacturing customer in the form of higher per unit prices for smaller orders. The higher all of these fixed costs of procurement and job lot production are, the more advantageous it is to produce and order supplies relatively infrequently in large quantities. The result is a higher average inventory level.

Another major factor taken into account in the control of inventory levels is the cost of holding inventories. A part of this is storage cost which includes such things as storage facilities, record-keeping, handling, security, insurance, and the risk of deterioration. However, the greatest single cost of holding inventory is usually the cost of capital invested in inventory which varies as a

function of the interest rate. Total costs of holding inventory are often as much as 20 percent of inventory value.¹ The higher these costs are, the more advantageous it is to order or produce supplies relatively frequently in small quantities to keep inventory levels down.

Summing up, conventional inventory control attempts to balance 1) the risks and costs of shortages and 2) the costs of ordering and set up, both of which are minimized by high levels of inventory, against the costs of holding inventory.

Still another consideration in inventory control may lead either to increased or decreased average inventory levels. This is the desirability of smoothing production rates relative to sales, so as to bring about higher average utilization of plant capacity and avoid the inefficiency of frequent adjustments to changes in production rates. There are two options: customers can be made to wait when demand is strong (lower average inventories) or inventories can be built up during slack periods to meet later peak demands. (higher average inventories)

In taking either of these options, a decision about inventory levels is linked directly to a decision about production rates. The control of inventories is governed largely, however, by the other factors discussed above

¹ Jack R. Meredith and Thomas E. Gibbs, The Management of Operations, (New York: John Wiley, 1980), p.407.

which are independent of the rates and times of production established in the schedule.

Yet, if the timing of all activities were specified in detail in the schedule, the schedule itself would thereby implicitly determine inventory levels. After all, inventories are only the result of inequalities in the rates of output and input associated with sequentially linked activities. In reality, however, schedules are typically too rough gaged and provisional to be depended upon to produce desirable inventory levels. Inventory control must step in and look at the timing of operations from another point of view --- that of the quantities of various stocks that accumulate between operations and between operations and shipments. Inventory control must determine whether the schedule is actually working out in detail and creating inventory levels that are neither dangerously low nor excessively high. Thus, even though they operate largely independently of one another, the functions of inventory control and scheduling are both essentially concerned with the timing of production operations and purchases.

Unfortunately, the lack of close coordination of production scheduling and the management of inventories is a reflection of limits on the ability to control the timing of manufacturing activities which cause shortages and near shortages to occur periodically despite the best efforts to prevent them. Often, record-keeping is not sufficiently

prevent them. Often, record-keeping is not sufficiently accurate to indicate shortages before supplies are physically pulled from inventories and staged immediately prior to an operation. There is usually a need, therefore, for a special class of employees called expeditors who move from work center to work center rearranging job priorities on an emergency basis in order to maintain the flow of production. Such emergency rearrangements often create substantial disruption and confusion. Hence, managers easily become preoccupied with "fire-fighting" activities at the expense of planning and systematic oversight. Fire-fighting typically absorbs 60% to 70% of first line supervisor time and about 50% of purchasing personnel time.³²

Materials Requirements Planning

The creators of MRP pioneered the integration of production scheduling and inventory control. Under MRP, inventories of each item are created in direct response to the specific demands of the production schedule. If the schedule calls for production of a certain number of units of a final product by a certain date, a detailed schedule for the production and purchase of the precise quantities of supplies necessary to produce those units is drawn up.

³² Vinnie Chopra, "Productivity Improvement Through Closed Loop MRP," (Part Two) Production and Inventory Management Review and APICS News, April 1982, p.50.

hand) Projecting backwards from the due date set for delivery to customers, a computer calculates the time at which supplies must be ready at each stage of production and the time at which each item's production should begin or when it should be ordered. Thus, the creation of inventories of each item can be scheduled to occur very shortly before the need for them arises. The result is that average inventory levels are substantially lower (25 percent to 40 percent for successful users)³ and that shortages are less frequent since needs are far more precisely specified and planned for.

The real key to MRP's ability to achieve a new level of precision in scheduling is its use of the computer to store and manipulate data concerning inventory levels, which parts are used in which products, and for each, the lead times required for purchase or production. Even if a comprehensively detailed schedule is constructed by conventional means, it cannot be redone from top to bottom each time the schedule needs to be adjusted. Consequently, in conventional practice, the original schedule is usually continually overridden by special rush orders and management directives as unforeseen needs arise. Inventory control must then come into play as a separate function and expeditors must be used to transmit priority changes to the

³ David A. Latham Jr., "Are You Among MRP's Walking Wounded?," Production and Inventory Control, Third Quarter, 1981, p.33.

shop floor. In short, the schedule cannot be relied upon as a guide to current production priorities as it can under MRP where the schedule is continuously updated.

Not only are changes in production priorities reflected promptly in schedule revisions under MRP, they also take a more precise and comprehensive form. While MRP accomplishes complete reorderings of production priorities for the various work centers on a routine basis, conventional practice simply piles rush orders on top of the previously existing production plans which remain unrevised. Because jobs are not systematically moved to later dates to compensate for urgent jobs being moved forward, conventional scheduling systems continually create backlogs of behind schedule jobs. Essentially what happens is that currently experienced special needs are added to projected average needs as dictated by the schedule or inventory replenishment rules and there is no easy way to identify which of the projected needs have turned out to be smaller or less urgent than expected. MRP, on the other hand, "de-expedites" jobs as readily and effectively as it expedites them. It does this in two basic kinds of situation. First, when the mix of final products being demanded changes, the production and purchase of components and materials used in the making of products now in lower demand is adjusted downward. Second, when a shortage of a supply item delays production of a given product, the MRP system delays production of other supplies necessary for

that product so that jobs for which supplies are available can be done instead.

The use of up to date schedules that everyone can see, follow, and trust puts shop floor control and communication on a much more formal basis and decreases reliance on more personal and ad hoc forms of communication. Much confusion and wasted energy is eliminated because actual needs and quantities on hand are reflected accurately in the schedule and need not be continually rechecked and reconfirmed. Such schedule integrity requires complete reliability of the data which is fed into the computer. As a consequence, one of the biggest challenges of MRP installation has been the establishment of a more disciplined system of shop floor record keeping.

One of the most important benefits of MRP is that lead times for customers are significantly diminished and easier to predict. It is possible to shorten lead times under a conventional system by producing and ordering supplies further ahead of time. But this strategy increases inventories and the associated costs. MRP can shorten lead times without increasing inventories by keeping priorities straight so that unneeded items never get produced ahead of needed ones. An accurate, up to date schedule can also be used to give customers accurate information on work status and delivery dates.

Still another benefit of MRP is that engineering changes can be phased in much more efficiently. It keeps

Still another benefit of MRP is that engineering changes can be phased in much more efficiently. It keeps track of the exact number of items belonging to a superseded design that are already on order or in process so that the system can switch to production and purchase of items needed for the new design without leaving any of the old parts and materials "orphaned", forcing them to be scrapped. At the same time, MRP can avoid the production of some of the new parts far ahead of the time when the rest of the new parts with which they must be used can be made available.

The Spread of Materials Requirements Planning

There are references to MRP systems being used as early as 1957,³⁴ but two writers say that the conceptual, managerial, and computing tools necessary for MRP were not available until 1960.³⁵ The decade of the sixties was mainly one of experimentation and development by pioneers while the seventies were a period of diffusion of an innovation whose success was, by then, recognized by authorities in the field.

³⁴ John C. Anderson et al., "Material Requirements Planning Systems: The State of the Art," Production and Inventory Management, Fourth Quarter, 1982, p. 57.

³⁵ James P. Gilbert and Richard J. Schonberger, "Inventory-Based Production Control Systems: A Historical Analysis," Production and Inventory Management, Second Quarter, 1983, p.9.

by two of the three most prominent developers of MRP.⁷ The first articles on MRP to appear in professional journals and magazines came out in 1968⁸ which seems to have also been the year of a large increase in the rate at which firms adopted MRP.⁹

According to a survey of MRP users published in the eighties, the adoption rate for MRP continued to accelerate through the early and mid seventies.¹⁰ Partly, this is attributable to the educational "crusade" launched by the American Production and Inventory Control Society in 1972¹¹ after it published a landmark special report on MRP in 1971.¹² It is also attributable, according to a 1975 article in the Harvard Business Review, to the continuing fall in the cost of computing and increasing economic instabilities which caused both materials shortages and

⁷ George W. Plossl and Oliver W. Wight. The third developer is Joseph A. Orlicky.

⁸ Ibid. p.11.

⁹ Anderson et al., p.57.

¹⁰ Anderson et al., p.57. Joseph Orlicky also reported that there were about 150 MRP using firms in 1971 and about 700 firms that had implemented MRP or were in the process of implementing MRP in late 1974. J. Orlicky, Materials Requirements Planning: The New Way of Life in Production and Inventory Management, (New York: McGraw Hill, 1975), p. ix.

¹¹ Orlicky, p.ix.

¹² George Plossl and Oliver Wight, Material Requirements Planning By Computer: A Special Report, (Washington D.C.: American Production and Inventory Control Society, 1971).

excessive inventories and a need to coordinate and control production more closely.

The first book on MRP came out in 1975.¹³ Its author, Joseph Orlicky, noted that there were only 26 items on MRP (including short articles and trade testimonials) published prior to his work, but explained the paucity of written materials by pointing out the grass roots nature of MRP development which had been led by practitioners rather than by theoreticians and academics.¹⁴ The latter half of the seventies saw a real outpouring of articles on MRP and the inclusion by most textbooks in the field of some significant discussion of MRP. In 1978 there were almost ten times as many references to MRP in the program of the annual international conference of APICS than there were in 1977.¹⁵

How far had MRP spread as of the early eighties? The best indication available is a 1982 mail survey of American Production and Inventory Control Society (APICS) members which found that 64 percent of the 679 respondents were using some form of MRP. Because the survey results were biased upwards, one would have to guess that something less

¹³ Joseph Orlicky, Material Requirements Planning: The New Way of Life in Production and Inventory Management, (New York: McGraw-Hill, 1975).

¹⁴ Orlicky, p. x.

¹⁵ George Plossl, "What We've Had and What's Ahead: 1978 Conference Review and Forecast," 21st Annual Conference Proceedings, 1978, (APICS, 1978), p.910.

which found that 64 percent of the 679 respondents were using some form of MRP. Because the survey results were biased upwards, one would have to guess that something less than half but at least a quarter of major manufacturing firms had adopted MRP by that time. Estimates of the number of firms adopting MRP between 1972 and the end of the decade range from 1,000 to around 8,000. These firms are in a wide variety of industries, but MRP use is particularly high in the electrical and electronic and transportation equipment sectors.⁴⁶

The Failure of Materials Requirements Planning

Despite individual cases of spectacular success, MRP did not make the impact on American industry that had been hoped for. The general consensus within the materials management profession was that MRP, despite the soundness of its principles, had failed in practice.⁴⁷ One report concluded that the overall performance of most U.S. materials management systems had been disappointing and that, in the majority of cases, investment in new materials

⁴⁶ Anderson et al., p. 55.

⁴⁷ By one estimate, only 10% to 15% of attempts to establish MRP could be called successful. James T. Butts, "Another Reason For MRP Failure," Production and Inventory Management Review and APICS News, Jan. 1981, p.28. A 1981 APICS conference paper began with the statement that "it is well known that 3 out of 4 MRP projects fail to achieve their stated objectives." Robert A. Stohl and Frederick L. Thorne, "MRP Re-implementation: You Too Can Be Successful," 1981 Conference Proceedings, (Falls Church, VA: APICS, 1981).

management systems had not even met the minimum goals for return on capital that firms had set for themselves.¹⁸

Many materials managers and consultants have identified what they believe to be the principal reasons for the failure of MRP. Most of the many reasons are interconnected and together constitute a fairly coherent anatomy of failure.

If there is a single underlying cause of failure to which most of the other causes suggested can be related, it is a misunderstanding of the role which a computerized scheduling technique can play in the decision-making processes of a complex business organization. There was a widespread belief, especially in the early years of MRP, that computerized scheduling techniques would provide objectively optimal schedules thus eliminating the need for human judgement and the organizational dynamics surrounding it. This belief was clearly at the root of a much criticized overemphasis on MRP's technical aspects --- the computer and its software --- and of the widely noted, corresponding lack of consideration given to the question

¹⁸ report by Booz, Allen and Hamilton described in Robert E. Fox, "Keys to Successful Materials Management Systems: A Contrast Between Japan, Europe, and the U.S.," Proceedings of the 23rd Annual Conference, (Falls Church, VA: APICS, 1981) as cited in David A. Latham, "Are You Among MRP's Walking Wounded?," Production and Inventory Management, Third Quarter, 1981, p. 33. Said MRP leader George Plossl in 1980, "based on simple statistics, no sound management would authorize significant expenditures to develop MRP programs; the success ratio is still far to low." "MRP Yesterday, Today, and Tomorrow," Production and Inventory Management, Third Quarter, 1980, p.4.

of how computer outputs could be designed to serve the needs of decision-makers as part of a larger decision-making process.¹⁹ The problem is two-fold. First, a computer program cannot predict the future states of a complex manufacturing environment which is full of uncertainties. Second, a program cannot incorporate all of the logic of a complex organizational decision-making process and provide ideal, situation-specific compromises between competing goals.

One of the most difficult and recurring decision-making situations in manufacturing is that of having to adjust priorities and redeploy resources to overcome or adapt to bottlenecks in production. A frequently cited problem with MRP is that its schedules often created bottlenecks by violating capacity constraints.²⁰ Partly,

¹⁹ George Plossl, "What We've Had and What's Ahead: 1978 Conference Review and Forecast," 21st Annual Conference Proceedings, (Falls Church, VA: APICS, 1978), p.911; David R. Schuchts, " 'Give MRP a KISS': Keep It Smooth and Simple," Production and Inventory Management, third quarter, 1979, pp.69,71; Norman L. Heilweil, "The Emperor's New Clothes - MRP," Readings in Material and Capacity Requirements Planning, (Falls Church, VA: APICS, 1984), pp.34,35.

²⁰ Joseph Orlicky is cited as identifying unrealistic schedules as one of the four main problems of MRP users in David A. Latham, "Are You Among MRP's Walking Wounded?," p.34; See also Robert W. Porter, "RX for 'Sick' MRP Systems," 1980 Conference Proceedings, (APICS, 1980), p.184, and A.W. (Gus) Berger, "101 Ways to Defeat MRP," Nineteenth Annual conference Proceedings, (APICS, 1976), p.509. "Lying to" the schedule is listed as one of the three "killer pitfalls" in MRP implementation by Edward J. Hay in "Pitfalls To Avoid In Implementing MRP," 21st Annual Conference Proceedings, (APICS, 1978), p.198.

this is a result of the fact that projected final product production rates are often determined more by sales objectives and market conditions than by production possibilities.²¹ It is also a result of the fact that capacity is difficult to estimate accurately. For one thing, it is multifaceted. With many different products, processes, and work centers, the overall capacity will vary depending on the mix of final products and the degree to which the requirements for equipment and personnel associated with various products conflict with or complement each other.²² Capacity also varies depending on the condition of equipment and the motivation and availability of personnel.²³

Compounding the bottleneck problems caused by unknown and unheeded capacity constraints are the delays resulting from the inability to control and predict lead times, estimates of which must be used as input to the MRP program for the time-phasing of operations.²⁴ The length of time necessary for an operation can vary for many reasons

²¹ Berger, p.509.

²² Kerry O'Gorman, "Capacity Planning in the 1960's, 1970's, and 1980's," Nineteenth Annual conference Proceedings, (APICS, 1976), p.290.

²³ Ibid., p.289.

²⁴ Inaccurate lead times was identified as the single greatest data problem with MRP by Rick Parham, materials manager, S R Engineering, Garden Grove, CA, (personal communication on Feb. 22, 1987).

including variations in capacity,²⁵ variable grades of material, differences in skill level and motivation, unpredictable set-up times, etc. in short, all of those factors which frustrate calculation of standard times in Tayloristic time study.

Of course, MRP's greatest feature is its capacity to reschedule in response to changed circumstances including, presumably, the unforeseen bottlenecks its schedules help create. In practice, however, firms using MRP were often unable to improve delivery performance or reduce inventories to a significant extent without increasing costs because the benefits of rescheduling were counteracted by the necessity of having to reschedule so often. The problem is that, in a manufacturing operation of any complexity, so many unexpected delays occur that to respond to all of them through rescheduling causes disruption on the shop floor due to the continual rearrangement of priorities.²⁶ In other words, the "up-to-dateness" that the MRP system is aimed at achieving cannot not be pursued without a cost in terms of stability. Ability to reschedule does not help much unless the revised schedule can actually be executed.²⁷ One fairly typical

²⁵ Ray Lankford and Stephen Smith, "The Beginning of the Post-MRP Era," Readings in Material and Capacity Requirements Planning, (APICS, 1984), p.51.

²⁶ Berger, p.509.

²⁷ Lankford and Smith, p.51.

characterization of the situation was that "MRP allows people to make mistakes a lot faster"²⁸

"Closed loop MRP" was developed to help overcome these problems by adjusting the schedule to capacity constraints before these constraints are encountered. In this advanced form of MRP, detailed workload implications of the original schedule are compared to detailed estimates of work center capacities. The discrepancies are used by the computer program to revise the schedule before any attempt is made to execute it.

New problems were created, however, by this added sophistication because revision of the schedule is not a simple computational process. When original goals cannot be met, tough choices between competing values must be made and the computer cannot be programmed to make all of them. There are, in a real manufacturing environment, a host of factors to consider in setting priorities at the various work centers.²⁹ By way of example, George Plossl lists seventeen of them including due dates, the customer for which the work is being done, amount of work remaining, workload downstream, shipping quotas (often associated

²⁸ George Plossl quoting Art Ratz who was president of APICS in 1971, "MRP Yesterday, Today and Tomorrow," Production and Inventory Management, third quarter, 1980, p.6; Plossl talked of finding in the future a method to make marginal, local adjustments to the schedule in order to avoid having to redo the whole thing from top to bottom (p.7).

²⁹ O'Gorman, p.291.

with financial goals), tooling considerations (for example, the possibility of using common tooling for different jobs), profit margins associated with an order, the possibility of outside processing, personal and shift preferences, and others.³⁰ To balance all of these considerations for each situation requires experienced judgement of a kind which is not, at least presently, possible to incorporate into a computer program.³¹

When attempts were made to do so, the program became so complex that MRP users should no longer clearly understand the logic of the system or be sure that the right weight was given to the various factors involved. It became difficult to supplement computerized schedule revisions with human judgement because the location and extent of gaps in the computerized logic was obscure.³² Because the MRP schedules could not be accepted on faith, they tended to be disregarded. What this meant was a reversion to the more comfortable and traditional "informal system" in which people make individual judgments about priorities without much guidance from a formal schedule.

³⁰ Plossl, "MRP Yesterday, Today, and Tomorrow," p.8; Another list of potential criteria for determining work priority is given by Jeffrey Miller in "Fit Production Systems to the Task," Harvard Business Review, Jan.-Feb. 1981, p.149.

³¹ Ibid.; Oliver Wight, "People --- A Stunning Comeback," Production and Inventory Management Review and APICS News, September 1981, pp.29,32.

³² O'Gorman, pp.291,292; Schuchts, p.69,71.

In doing so, they balance the urgency of needs as reflected in "hot lists" and the directives of expeditors against the need for stability in the production process.

It appears that inadequate appreciation of the difficulties just described led to another of the most frequently cited problems with MRP --- lack of top management involvement in MRP implementation. Critics complained that top management did not elicit broad enough participation in the design and operation of MRP,³³ and did not recognize the need to tailor MRP to the particular market and production conditions of their firms.³⁴ An often missing but crucial organizational vehicle for the introduction of MRP was the interdepartmental task force or steering committee staffed with high level managers devoted full time to the project.³⁵ Managerial initiative

³³ Duane Lakin, "Human Requirements Planning," Production and Inventory Management Review and APICS News, March 1982, pp.22,24,26; The following two writers point to multi-departmental participation and organizational design as the most critical factor in MRP implementation: Cash Powell, Jr., "MRP System - MRP Organization," 1981 Conference Proceedings, (APICS 1981), pp.339,343; R. Dave Garwood, "Management Communications: Implementing MRP II: The Real Challenge Is Not Technical," Production and Inventory Management Review and APICS News, pp.88,89.

³⁴ Miller, pp.145-154; Lankford and Smith, p.50; G. M. Carnahan and John B. Kanuff, "MBO, MIS, MBA: Is MRP Next?," 1980 Conference Proceedings, (APICS, 1980), pp.236-37.

³⁵ Robert I. Millard, "MRP Implementation: Futile Exercise or?," Production and Inventory Management Review and APICS News, Aug. 1983, p.33; Thomas Belot, "Closing the Loop: A Guide to the Management-MRP Marriage," Production and Inventory Management Review and APICS News, Jan. 1982, pp.18-20; Jerry D. Rose, "Craters Along the MRP Road," 21st Annual Conference Proceedings, (APICS, 1978),

was missing at the lower levels as well. Old organizational incentives were left in place and worked against adherence to MRP schedules. Often, foremen would be rewarded on the basis of dollar value of output³⁶ or success in minimizing downtime.³⁷ The work priorities suggested by these goals bear no necessary relationship to the MRP schedule. Also lacking was adequate education of employees in the philosophy, aims, and methods of MRP.³⁸ This education is critical in overcoming resistance to the loss of the informal system's scope for individual discretion in determining work priorities and to eliciting cooperation in following the schedule and keeping the data in the computer accurate and up-to-date. The source of the failure to bring broad-based organizational focus to bear on MRP seemed to be top management's conception that MRP is a specialized technology which would be most efficiently and competently installed by a small group of production control and data processing experts and whose objectively

p.214; Heilweil, p.33.

³⁶ An example of this is given in Miller, p.146.

³⁷ John Wacker and Frederick S. Hills, "The Key to Success or Failure of MRP: Overcoming Human Resistance," Production and Inventory Management, fourth quarter, 1977, p.12.

³⁸ Joseph Orlicky was cited as identifying lack of education as one of the four most common reasons for failure of MRP in Latham, p.34; Inadequate education was one of the principal unexpected difficulties encountered in MRP implementation in a survey of firms using MRP conducted by Arthur D. Little according to Heilweil, pp.34-5; Belot.

optimal outputs could be employed without question by the rest of the organization.³⁹

A key managerial issue inadequately dealt with in the design and operation of many MRP systems is what kind of tradeoff to make between prompt customer service and low production costs. Superior service requires higher inventory levels and/or schedule flexibility which shortens the planning horizon for manufacturing, leading to smaller, less economical lot sizes and more shop floor disruptions. Frequently, this situation causes conflict between the sales and manufacturing departments. It is top management's responsibility to work toward a consensus that balances the concerns of these two groups and to arrive at a broad strategic business decision regarding cost and service goals. The MRP system needs to be designed to support this decision. Where customer service is highly valued, rescheduling should take place frequently, altering priorities up to the last moment, and should probably be relatively routinized in the interests of speed. Where low cost is paramount, final product shipment schedules should be frozen several months in advance allowing time for greater refinement of sub-operation schedules and shop routings to smooth workloads, minimize set-up times and

³⁹ This attitude is described by Oliver Wight in "People --- A Stunning Comeback," Production and Inventory Management and APICS News, Sept. 1981.

maximize use of capacity.⁴⁰ Management was criticized for letting standardized MRP systems be installed without confronting critical design alternatives such as these.

Once basic decisions have been made on how much schedule flexibility will be allowed, continuing managerial leadership of sales and manufacturing is needed to reconcile customer demands and manufacturing capabilities in a detailed way so that schedules are stabilized and more readily accepted by all as legitimate.⁴¹ The input of financial managers into the scheduling process also frequently needs to be secured since financial goals can potentially conflict with sales and manufacturing plans.⁴²

Top management's lack of attention to the wide organizational scope of participation required by MRP was also the source of the much discussed failure to construct and maintain an accurate data base upon which the integrity of MRP depends. Each department supplies important inputs

⁴⁰ This set of alternatives is described in detail in Jeffrey G. Miller, "Fit Production Systems to the Task," Harvard Business Review, Jan.-Feb, 1981. See also James T. Butts, "Another Reason For MRP Failure," Production and Inventory Management Review and APICS News, Jan. 1981, p.26, and Robert W. Hall and Thomas E. Vollman, Planning Your Material Requirements," Harvard Business Review, Sept.-Oct. 1978, p.106.

⁴¹ This reconciliation process is described in Vinnie Chopra, "Productivity Improvement Through Closed Loop MRP: Part Two," Production and Inventory Management Review and APICS News, April 1982, p.49.

⁴² The problem of overloading schedules to meet financial goals is described in Berger. An example of exemplary practice in this regard is given in Hall and Vollman, p.112.

to the system. Engineering must provide accurate bills of material, the documents which list all the components of every product and subassembly. Marketing must supply good sales forecasts. Manufacturing must provide accurate lead time and capacity estimates. Stores control must keep an accurate count of removals from and additions to stocks. Shop personnel must give up-to date reports on work in progress and prompt feedback on any problems encountered. Inaccurate data has been perhaps the most readily identified obstacle and the major preoccupation for firms struggling to establish MRP.⁴³ Only later on did it become widely recognized that lack of understanding of MRP's benefits and trust in its schedules was behind the lack of scrupulousness in providing the needed data.⁴⁴

The failure of MRP can be summed up as follows: The mistaken belief that computer scheduling could fully replace human judgement in determining work priorities led to an oversimplified view of how MRP would affect the manufacturing organization. This, in turn, led to neglect of the necessary strategic and multi-departmental inputs into its design and operation, as well as incentives at odds with its operation, and insufficient support of the data needs of the system. All of these latter problems

⁴³ Parham. The problem of data integrity is described in Hall and Vollman, pp.106-110.

⁴⁴ Wight, "People --- A Stunning Comeback," p.32.

exacerbated the inherent shortcomings of computerized scheduling.

Despite pervasive disappointment with MRP, MRP using firms have reported substantial if undramatic improvements. A group of them were asked, in 1982, to compare performance of their MRP systems to what their performance would have been without MRP. The ratio of total output to average inventory level under MRP averaged 4.3 compared to a probable 3.2 without it, while the percent of deliveries to customers that were made on time averaged 77 percent compared to an estimated 61 percent had MRP not been used. The number of expeditors employed by the MRP using group was estimated to be 36 percent less than it would have been without MRP.⁴⁵

The ability to incorporate capacity planning into MRP was claimed by only 39 percent of MRP using firms surveyed in 1982 while only 9.5 percent claimed to have schedules truly in conformance with capacity, with scheduling accurate enough to maintain low inventories, make most deliveries on time, and eliminate the need for expediting.⁴⁶

⁴⁵ Anderson et al., p.64.

⁴⁶ Anderson et al., pp.58-60.

Rising Ambitions for Material Requirements Planning

Though success with MRP was quite modest, the sights of production and inventory control managers were raised to new heights in the eighties by new, more comprehensive versions of MRP including closed loop MRP and MRP II. Reflecting this, the letters MRP were now understood to stand for Manufacturing Resource Planning rather than the former Material Requirements Planning .

MRP II, the most advanced form of MRP, incorporates the function of financial planning. Because the MRP system can provide a complete picture of the timing of purchases, operations, and projected customer deliveries, it can be used to project the associated financial flows as well. Thus, financial figures and physical production figures are integrated into a single analytical model of the firm which can be used as a general framework for planning and control. Since the computer can easily generate MRP plans based on any set of assumptions, simulations of factory operations and financial flows under alternative market conditions or marketing plans can be produced. Although a relative handful of firms had realized the potential of MRP II for capacity and financial planning by 1980,⁴⁷ MRP was still being increasingly represented by authorities in the field as a goal of reform which could

⁴⁷ Ray Lankford and Stephen Smith, "The Beginning of the Post-MRP Era," Readings in Material and Capacity Requirements Planning, (APICS, 1984), p.50.

change the whole character of manufacturing management. Its leading exponents saw in it a way of integrating the functions of the firm: inventory control with production scheduling, and accounting, purchasing, and sales with production. All communication would revolve around a single integrated business and production plan and data base. Interdepartmental politics and second guessing would be replaced by adherence to explicit plans based on comprehensive information and negotiated priorities. In sum, a vision of a new, higher level of coordination, control, and discipline in manufacturing continued to evolve in the early eighties under the banner of MRP.⁴⁸

But once again, as in the case of worker participation, American developments were suddenly upstaged, beginning in 1980, by reports of Japanese successes in production scheduling and inventory control. While it was true that MRP techniques were sometimes seen as more sophisticated in some respects and better suited to certain production environments than were those of the Japanese, Japanese practices were perceived as a more complete realization of the goals of MRP.

⁴⁸ The most powerful vision of the transforming potential of MRP is perhaps painted by Oliver Wight in Manufacturing Resource Planning: Unlocking America's Productivity Potential, Rev. ed. (Essex Junction, VT: Oliver Wight; New York: Van Nostrand Reinhold, 1984).

CHAPTER FIVE

QUALITY CONTROL

In the field of quality control in the 1970's, there was no mass movement around a new technique as there had been in the field of production and delivery scheduling. There was available, however, a fairly coherent program of fundamental reform marked out by some of the most respected quality control experts. This program was based on their critiques of American quality control practice which had been undergoing a rapid evolution in the forties, fifties, and sixties. It was during this earlier period that the key innovations in quality control were generated and popularized. The conceptual limitations of these innovations and the difficulties encountered in their implementation are the context and motivation for the reform proposals. We will therefore review several historical developments in quality control beginning early in the twentieth century when quality control as a differentiated manufacturing function first began clearly to emerge. To begin, though, some general observations on quality control should be made.

Quality control is an inherent aspect of all forms of work in the sense that criteria of adequacy, usually in the

form of a preconceived image or blueprint, must always be present to guide and give form to it. This is another way of saying that work is an activity for which means and ends can be at least partially distinguished and in which the means are evaluated to some degree on the basis of degree of realization of ends. The criteria used in judging quality naturally divide into two types---those relating to the fitness for use of the product and those relating to the more proximate goal of adherence to design specifications. It is mostly the latter type of criterion that is the subject of this discussion since in modern industry, engineering and marketing departments take most of the responsibility for determining the product specifications that will best achieve fitness for use and the manufacturing department is concerned almost exclusively with meeting these specifications.

The Central Inspection Department

In the nineteenth and early twentieth century, workers' immediate supervisors, owner-entrepreneurs at first and later foremen, assumed the responsibility for enforcing quality standards which were based primarily on their personal experience. Experience, however, proved to be inadequate when the massive shift to production of a different set of products during World War I brought with it a number of quality scandals. Uniform standards had to be imposed from above, and this was done by placing

inspectors (formerly handpicked by the foremen from among the workers under them) in a separate inspection department headed by a chief inspector.¹

This first form of separate organization of the quality function brought standardization of and focus upon measurement techniques and more attention to the training of inspectors.² The necessity of having an inspection department stemmed not only from the inability to communicate quality standards effectively and direct their enforcement by generally unschooled and independent production foremen,³ but by the overemphasis both workers and foremen placed on maximizing the quantity of output. Foremen were focussed mainly on fulfilling the production quotas imposed on them by management while the piece rate system gave workers an incentive to pay minimal attention to quality.⁴

It is true that incentives for quality were theoretically capable of being incorporated into the piece rate system widely used at the time: Defective work could be paid for at a lower rate or workers could receive credit for nondefective work only. Alternatively, workers could

¹ J. M. Juran, "Management Interface: Inspection Returns To Its Origins," Quality Progress, July 1973, p.34.

² Joseph Juran, "The Two Worlds of Quality Control," Industrial Quality Control, November, 1964.

³ Juran, "The Two Worlds Of Quality Control," pp.240-41.

⁴ Juran, "Management Interface: Inspection Returns To Its Origins," p.34.

be forced to rework the defectives they produced without pay. In practice, however, quality incentives were weak. Rules on defectives were difficult to impose and created serious tensions in the workplace because many defectives were caused by factors beyond worker control such as poor materials or malfunctioning machinery.⁵

The only solution appeared to be to create an organizational hierarchy parallel to that for production which could allow the production department to devote all of its efforts to maximizing output while taking upon itself the responsibility for weeding out the defects that were produced in the process. Defects were treated as a natural by-product or even perhaps a sign of the effort to maximize efficiency. By the early forties, the use of central inspection departments spread to the majority of major industrial firms.⁶ This trend was supported by the advocates of the Taylor system as a part of their drive to divide and rationalize the various planning functions and separate them from the execution of task. The independent planning and execution of the inspection function meant

⁵ J. M. Juran, "Management Interface: The Motivation to Meet Quality Standards," Quality Progress, Aug. 1973, p.41.

⁶ J. M. Juran, ed. in chief, Frank M. Gryna, Jr. and R.S. Bingham, Jr., Associate eds., Quality Control Handbook, (New York: McGraw-Hill, 1974), chapter 7, p.6.

that workers and foremen were less frequently called upon to exercise their judgement in meeting quality standards.⁷

Other factors contributed to reinforce the separation of production and quality functions during the twenties and thirties. One was the shift from the piece rate system to the hourly wage which made penalties for defective work even more difficult to calculate and impose. In any case, worker resentment over the inequities associated with penalties for defective work led unions to press for and win the abolition of these penalties in the thirties.⁸ Still another factor was the increasing role of machines in production which took a substantial amount of control over the quality and pace of work out of the hands of workers and made worker and foreman responsibility for quality less necessary and more problematic.

Statistical Quality Control (SOC)

Statistical theory was first applied to the control of quality in manufacturing at the Hawthorne works of Western Electric where most of the Bell system equipment was manufactured. This plant was a huge one employing 40,000 people including 5,000 inspection personnel and facing a combination of quality demands that was unprecedented at

⁷ J. M. Juran, "Management Interface: The Future of the Inspection Department," Quality Progress, Oct. 1973, p.26.

⁸ J. M. Juran, "Management Interface: The Motivation to Meet Quality Standards," Quality Progress, Aug. 1973, p.41.

the time: extremely complex systems, extremely close tolerances, severe reliability requirements, and an unprecedented degree of interchangeability of machined and electrical parts.⁹ A group of men from Bell Laboratories was assigned to devise measures of quality performance and worked out as a result, several fundamental statistical tools of quality control.¹⁰ The first paper on the subject was authored by Walter Shewhart and was published in 1924. Subsequent adoption of statistical techniques was slow --- by 1937, probably not more than 12 firms had introduced them into their ordinary operations.¹¹

The first substantial diffusion of statistical techniques for the control of quality began as a result of the rush into production for World War II. Initially, a bottleneck was caused by a lack of trained government inspectors which the Ordnance Department remedied by training 600 to 700 men in the use of inspection tables

⁹ Joseph Juran, "Pioneering in Quality Control," Industrial Quality Control September, 1962.

¹⁰ Ibid.

¹¹ Acheson Duncan, Industrial Quality Control and Statistics, (Homewood IL: Richard C. Irwin, 1959), p.3; Paul Robert in "What ASQC Has Done for Quality Control" Industrial Quality Control August 1955, p.8 reports that in 1936 "you could still count on the fingers of one hand the companies that were using these techniques at all." Another estimate: "By 1940 there were probably not more than a score of the larger companies which had personnel interested in these ideas." John Henry, "A Survey and Evaluation of Types of Quality Control Education," Industrial Quality Control, September 1953. British industry adopted statistical techniques much more rapidly in this period. (Duncan, p.2)

designed with the help of statistics experts from Bell Laboratories.¹² The immediate result was massive rejections of supplier shipments that made clear the critical need to improve the performance of suppliers. In 1942, two experimental courses were given to industrial engineers at Stanford University at the suggestion of W. Edwards Deming, then an Advisor in Sampling to the Chief of Army Ordnance. Out of about sixty people who attended, only one succeeded in applying the techniques he learned but did so impressively enough that the chief of the Division of Industrial Processes of the Office of Production Research and Development (OPRD) (himself a professor acquainted with SQC) was encouraged enough to institute an SQC training program.¹³ This program lasted from 1943 to 1945 and reached 1885 people representing 810 mostly industrial and government institutions with an eight day course.¹⁴ Most of the graduates made no immediate applications of statistical techniques but others made spectacular improvements with them and these experiences were shared in periodic follow-up meetings that the graduates of each quality control course were encouraged to

¹² Martin Brumbaugh, "Highlights in the History of ASQC," Industrial Quality Control, Feb. 1956, p.7.

¹³ Eugene Grant, "Industrialists and Professors in Quality Control; A Look Back and a Look Ahead," Industrial Quality Control, July, 1953, p. 33.

¹⁴ John Henry, "A Survey and Evaluation of Types of Quality Control Education," Industrial Quality Control, September, 1953, p.20.

organize. When the national American Society for Quality Control (ASQC) was formed in February 1946, it was constituted entirely of local quality control societies which had grown out of the meetings of wartime course graduates.¹⁵

World War II experiences highlighted the complementary roles of two basic classes of statistical quality control techniques. The most readily implemented type is that which is used to increase the efficiency and accuracy of the conventional inspection function. It involves planning for the drawing of samples from finished production lots and the making of inferences from the sample characteristics about the number and seriousness of defects in an entire lot. The object is to economize on inspection effort and still make correct acceptance and rejection decisions. It is this type of statistical quality control which the Ordnance Department first turned to. Suppliers whose products were rejected as a result were forced to use the same techniques in their final inspection.

But screening out defective products proved, by itself, to be inadequate, causing serious delays in delivery schedules. As a result, there was increasing research and interest in the use of statistical techniques

¹⁵ Brumbaugh, p.7.

to monitor and control production processes to prevent the production of defectives.¹⁶

Statistical Process Control (SPC) uses "control charts" to record and analyze the pattern of variation in the results of ongoing processes. The most critical part of the analysis distinguishes the inescapable random variation inherent in all processes from variations assignable to individually identifiable and potentially removable causes. Often, the comparatively small variation due to random causes is so great that it alone will cause occasional production of items that do not meet specification tolerances. If this is found to be the case, the the process equipment, work methods, and/or materials have to be fundamentally improved to achieve greater consistency. If, on the other hand, the degree of random variation is small enough so that it allows tolerances to be consistently and comfortably met, then any defectives which appear must be due to irregular changes in controllable process conditions.

The control chart is not only a format for statistical analysis but a means of visualizing process behavior. It consists of a graph for which the vertical dimension

¹⁶ Duncan, p.3; "...statistical methods provided the only way for manufacturers to meet the increasingly severe goals of output and precision that ordnance required, in the face of shortages of critical materials" W. Edwards Deming, "Management's Responsibility For the Use of Statistical Techniques in Industry," Advanced Management, Nov. 1953, pp.8-9.

represents the measured value of a variable relevant to quality (for example, the length of a machined part) and the horizontal dimension usually represents time so that measurements of work samples are arranged in the order of production. Typically, there are three horizontal lines drawn on the control chart for purposes of interpreting the plotted points. (see figure below) The middle line is drawn at the level of the target value of the the variable being studied. This should be the average outcome of the process. Above and below the middle line are the upper control limit line and the lower control limit line. These are drawn on the basis of study of past process behavior so that almost all measurements (eg. 99.9%) will fall between these limits in the absense of any unusual intervening disturbances to change the characteristics of the process. When any measurement falls beyond the upper or lower control limits, this signals the need for an investigation of a possibly emerging cause of defects. The control limits may be adjusted to trigger an investigation either more or less frequently depending on the expense involved in investigation versus the costs of allowing production of defects.

Even if there are no "out of bounds" measurements, the pattern of measurements over time may reveal the presence of non-random systematic causes of variation that could be removed. For example, there might be a clear upward or downward trend or an unusual number of measurements below

or above the process average.

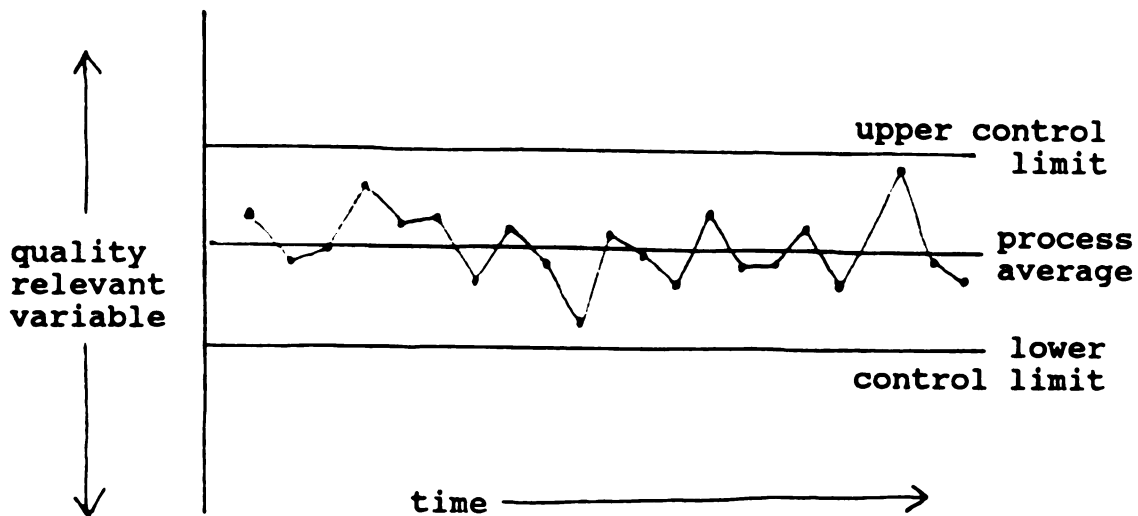


FIGURE 1. Statistical Process Control Chart

Note: Each point on the control chart normally represents not the measurement of a single workpiece but the average of a sample of several workpieces. This makes the pattern of variation more stable and decreases the chances of mistaking random behavior for a change in the process or vice versa.

Sometimes, the upper and lower control limits are confused with specification tolerances. Actually, there is no necessary relationship between the two. The control limits only describe the capabilities of the process. The specification tolerances indicate the degree of process variation which is acceptable for product function. One implication of this is that it is desirable, where economical, to have the band of variation between the control limits be considerably narrower than the band of variation between specification tolerances so that defectives are virtually never produced.

Control charts can be used as a tool to help discover the sources of extraordinary sources of variation. They document changes in the pattern of process outcomes over time which can then be correlated with changes in materials, environment, equipment settings, work methods and other factors suspected of causing problems. Particular causes of nonrandom variation will often show up on the control chart as a distinctive type of deviation from the normal random pattern. Control charts can thus be used to trouble shoot problems and then to monitor the recurrence of already identified problems such as tool wear, overheating, etc.

The use of control charts changes substantially the way processes are monitored and adjusted. When control charts are not being used, measurements are often taken only for the purpose of determining whether or not a workpiece meets or does not meet a specification tolerance. In contrast, plotting of a control chart requires measurement with a degree of precision that is capable of displaying the patterns of variation within the narrow band of the specification tolerances. The monitoring of process variations inside the range of acceptable performance enables problems to be detected and corrected before they become great enough to produce defectives. Thus, the use of control charts may lead to more frequent adjustments of the process. Statistical process control may also increase process consistency by demonstrating the futility of

frequent process adjustments where these are responses to variations in process outcomes that are random in nature. When workers attempt to compensate for random variations, they only end in needlessly introducing a source of nonrandom variation and exacerbating the problem.

Statistical inspection of finished lots and statistical process control are in some degree both substitutes and complements for each other. Where statistical process control is successful in increasing consistency, less final inspection is needed. Conversely, if final inspection can screen out defectives efficiently, statistical process control is less critical. Yet neither process control nor final inspection is usually sufficient by itself. Since final inspection is never totally effective at screening the output, prevention of defectives by statistical process control is often the only efficient way to improve overall conformance of shipped output to specifications. For example, in World War II, when improved inspection caused massive rejections of supply shipments and inspectors were in short supply, statistical process control was seen as the solution. On the other hand, since production processes are usually less than totally consistent, final inspection will be needed to weed out defectives and prevent them from being shipped.

Statistical quality control techniques of all types were widely popularized in the years following the establishment in February 1946 of the American Society for

Quality Control (ASQC). This society has been credited as "the instrument, the rallying point, the wellspring that has made possible the exceedingly rapid development of this new technology."¹⁷ In the late forties and early fifties, the inspection function was recast and more broadly construed as the quality control function. This was the period in which a great many firms created their first quality control departments.¹⁸ Often, these were barely more than glorified inspection departments with a new statistically trained staff component¹⁹---that is, inspection departments which applied statistical principles to the design of their inspection routines. (especially final inspection) The most progressive firms took the concept of quality control much further and we will discuss their innovations later. But the decade after World War II was dominated by the enthusiasm for the application of statistics.²⁰ So great was the focus on statistics, that to many it seemed that the appearance of statistical

¹⁷ Paul Robert, "What ASQC Has Done For Quality Control" Industrial Quality Control, August 1955, p.9.

¹⁸ Juran, Quality Control Handbook, pp.7-20.

¹⁹ Harry G. Romig, "The Role of Quality Control in Industry," Industrial Quality Control, July, 1954, p.22; Armand V. Feigenbaum, Total Quality Control, (New York: McGraw-Hill Book Co., 1983) p.16.

²⁰ David A. Simmons in Practical Quality Control, (Reading MA / Menlo Park, CA: Addison-Wesley, 1970) p.9, says that "the main difference between the present quality thinking and that of the statistical era [World War II to 1954] is that statistics is now a tool of the system and not the system itself."

inspection and process control represented the birth of quality control into the industrial world.²¹

That statistical quality control did not live up to its promise in the first decade of its substantial diffusion was due in part, at least, to an overenthusiasm for the new techniques was responsible.²² Quality control leader Joseph Juran saw the general situation as being one in which solutions for quality problems were adopted before the problems themselves were closely examined.²³

This occurred on two levels. One, top managers, aware of quality problems, saw statistics as the only fundamentally new remedy available and were quite ready to devote resources to it before verifying and evaluating its impact.²⁴ Two, quality control professionals themselves were interested far more in the application of statistical

²¹ J. M. Juran, "Goals For Management in the Next Decade," Industrial Quality Control, May, 1962, p.9; Dale Lobsinger, "From the President's Desk; Quality Control is People," Industrial Quality Control, June, 1957.

²² Said Bertrand Hansen, "It would be difficult to conceive of a function which started out with more potential possibility for success and which was more mishandled---principally because of the emphasis on statistical methods." Quality Control; Theory and Applications (Englewood Cliffs, NJ: Prentice-Hall, 1963) p.373.

²³ J. M. Juran, "Management's Corner: A Note on the Mortality of QC Departments," IQC, Feb. 1961, p.23.

²⁴ Ibid., p.23.

techniques than in the study of quality control needs.²⁵ As a result, the level and form of application was generally inappropriate to the magnitude and nature of particular quality problems.²⁶ Although professional commitment to statistical techniques never flagged, disappointing results helped open the way for subsequent innovation in the fifties and sixties.²⁷

While management was commonly sufficiently attracted to the new techniques to invest substantial resources in

²⁵ J. M. Juran, "The Two Worlds of Quality Control," pp.242-44, and "Goals for Quality Management in the Next Decade," Industrial Quality Control, May, 1962, p.14.

²⁶ Harry G. Romig, "The Role of Quality Control in Industry," IQC, p.19; Juran capsulized the typical chronology of quality control in parable form: "Our first step forward came in 1938 when we created a central inspection department.[] The central inspection department greatly improved the skill of inspection. Measurement became more precise, instruments were better maintained, inspectors were well trained and so on. But the production people seemed to have lost pride, and the defects gushed out. Inspection did find most of them, but the costs were awful.[] At that time the courses in Statistical Quality Control were sweeping the country. Mr. Inns [chief inspector] sent a few young fellows to take the courses. One of them, Mr. Statt, came back and made out a persuasive case for creating a new department on Statistical Quality Control. That was in 1946. There was a surge of SQC in the company---lots of charts, sampling tables, training with dice and so on. There was also a lot of argument on how to organize for quality control. Mr. Statt argued that SQC and inspection should be coordinated under one Manager of Quality Control. This was done in 1948.[] Of course, the excesses of the SQC boys caught up with them, and Mr. Statt was living on borrowed time. The end came in about 1955.[] That was when Mr. Relly proposed creation of a reliability department." J. M. Juran, "A Visit to Complex Systems," Industrial Quality Control, January, 1962, p.38.

²⁷ Juran, "A Note on the Mortality of QC Departments," p.23.

them, the quality control function was initially given a subordinate organizational status, most often being placed under the jurisdiction of the production or plant manager. A 1961 survey of 31 companies found it rare for the quality manager to report to a president or vice president.²⁸ Later, in the sixties, this situation was changing rapidly. A 1968 study found 35% of its sample of firms had the quality manager reporting to a president or vice president with 37% of quality managers reporting at a higher level than five years previously.²⁹

Environmental Factors in the Development of Quality Control

The rapid diffusion of statistical techniques after World War II was propelled by professional and managerial enthusiasm for the techniques themselves as institutionalized and propagated by the ASQC which had been the direct outgrowth of government education efforts during the war. War production had created a sudden need for a new level of control over a vast industrial system which shifted the character of its outputs more rapidly than had ever before been attempted. It was military contracts

²⁸ Lester R. Bittel, "Manufacturing Organizations Today," Factory, June 1961, pp.86-94 as cited in Bertrand l. Hansen, Quality Control: Theory and Application, (Englewood Cliffs, NJ: Prentice-Hall, 1963) pp.372-3.

²⁹ Special Report (August 1968), "Who Cares About Quality" Quality Assurance, vol.7, no.8, pp. 26-29 as cited in Kirkpatrick, Quality Control for Managers and Engineers, (New York: John Wiley, 1970) pp.319-20.

which were most directly responsible for introducing most leading manufacturers to the new techniques,³⁰ and after the war, statistical quality control had become widely enough adopted generally that it became perceived as a competitive necessity.

Requirements for new levels of business and manufacturing control including the control of quality were, however, being created as well by more gradual trends existing before the war but accelerated by it. One was the greater complexity and precision of products and processes associated with an increasingly science-based technology, and the continuing refinements made to existing products and machinery.³¹

Another trend was the increasing size and complexity of industrial organizations. It became more and more difficult to coordinate and define the responsibilities of specialized personnel.³² Statistical specifications of design requirements and process capabilities could help by

³⁰ Inspection in Industry; Report of a visit to the U.S.A. in 1951 of a Specialist Team on Inspection Methods in Industry, (London: British Productivity Council, January, 1953) p.7.

³¹ A. V. Feigenbaum, "The Significance of Quality control to Present Day Management," IQC, May 1952, p.29; J. M. Juran, "Goals for Quality Management in the Next Decade," pp.10,14.

³² J. M. Juran, "The Two Worlds of Quality Control," p.240; Feigenbaum, "The Significance of Quality Control to Present Day Management," p.30.

bringing greater precision to the communication of these requirements and capabilities.³³

It must be noted as well that increasing needs for precision and for the coordination of specialized personnel created quality problems which, even if they were not solvable by statistical means, created nonetheless a receptivity to new quality control techniques of which statistical tools were the most visible examples.

The advance of technology not only implied the need for greater control to obtain the requisite precision; it also represented the possibility of breakthroughs in the consistency and automaticity of production processes that could reduce the need for such control. It was conceivable, therefore, that statistics and other tools of quality control might eventually be phased out as production equipment grew more sophisticated. This view of the future was undoubtedly appealing to top management because it implied that very little had to be done to improve quality other than await the next generation of technology. Most of the complexities and uncertainties involved in training people to measure and analyze quality problems statistically could be avoided if only the process engineers could make sufficient design improvements.

It was thought not only that future technology might reduce variations in process outcome to insignificant

³³ Feigenbaum, "The Significance of Quality Control to Present Day Management," pp.29-30.

levels, but that inspection itself could be automated, making 100% inspection practical and eliminating the need to economize on inspection activities through analysis of small samples using statistical methods.³⁴

It is difficult to appraise the influence of this vision of technological advance on quality control practice since it was indirect and normally not remarked upon. But the pervasiveness of technological optimism, strenthened by an unbounded pride and belief in American industrial resourcefulness and know-how during the immediate post war period, suggests it was probably very strong. Such expectations, holding out the possibility of quality improvements orders of magnitude greater than statistical control of of conventioanl technology, countervailed against the programmatic effort to develop and refine existing techniques. Because infatuation with technological progress encompassed product as well as process technology, interest in better control of conventional technology was also limited by increased focus upon the progress of quality achievable through the production of fundamentally new products with new features. Thus, despite the continuing rise of the quality control profession following World War II, the focus upon quality control was persistently subverted by faith in future technological breakthroughs.

³⁴ Edward A. Reynolds, "Modern Inspection Techniques and Automation," Industrial Quality Control, June, 1961.

Problems With the Role of the Production Department
in Quality Control

From the beginning, the role of the production department and the shop floor worker in quality control was problematic. The creation of the central inspection department had separated the responsibility for quality control from the responsibility for maximization of output, so the question arose after the war whether the new statistical techniques would modify, deepen or attenuate this separation.

Because new quality control techniques were capable of increasing the consistency of manufacturing processes thereby decreasing the need to weed out defectives with massive inspection forces, it became apparent that for this reason alone that progress in quality control could affect the relationship of the inspection department to the production department. The first major demonstration of the decreased need for inspection was seen at the Hawthorne plant before World War II where the number of inspection personnel was reduced from 5,000 to 2,000 in the space of a decade. This reduction was achieved with a combination of initiatives including design improvements in product and process, rationalization of inspection systems, and factory reorganization into departments devoted to categories of product rather than categories of process equipment. Statistical techniques were only one of several reasons why

the number of inspectors could be reduced.³⁵ But it was clear from the beginning, as we saw that it was for government war production officials, that one of the biggest potential contributions of statistical process control was reduction of the need for inspection.

We already observed that the new quality control departments of the immediate post World War II period were often essentially inspection departments that had been renamed. But discussions of the role of the new quality control department in this period evidence clear concern to define the contribution of the quality control function to the firm in positive terms that would counteract the image of the inspection department as a policing system.³⁶ Inspection departments had tended to be perceived by management as imposing unfortunate constraints on the efforts to maximize output and as incurring costs without contributing to cost reduction elsewhere in the manufacturing process. In contrast, the new quality control was promoted as a substitute for inspection and rework and therefore as a cost saving activity. Creating a new image for quality control was difficult as the following observations published in 1968 show: "A concensus

³⁵ J. M. Juran, "Pioneering in Quality Control," p.13.

³⁶ "Quality control is not a police action. I believe this is perhaps one of the greatest misconceptions to the point that it is even prevalent among many members of our organization." A. W. Wortham, "Management Development Through Quality Control," IOC, June 1961, p.5 [from address at a conference at Rutgers, probably for the ASQC].

of industry opinion today would probably show that whereas quality control contributes to profits in some degree--- primarily owing to the protection that it provides through inspection---it also detracts from profits when it becomes excessively involved in other areas and there applies its unique brand of so-called inconsequential absurdities. Although somewhat exaggerated and hence not completely true to life, this sort of thinking represents the very essence of what quality control faces in its day-to-day existence."³⁷

As the quality control department developed a more specialized and sophisticated set of techniques it became more centered on its planning functions. The production department was correspondingly called upon to take more of the responsibility for implementation of quality control. This represented the beginning of a reintegration of the quality control function into the production department which could no longer be exclusive in its focus upon maximizing gross efficiency (ignoring the potential for reduction of scrap and rework through better quality control) and meeting production quotas and schedules.

However, the relationship between the quality control and production departments was not initially conceived as an organic or interactive one but as one of command and execution along Tayloristic lines. In a 1963 text, for

³⁷ John T. Hagen, Quality Control for Management, (New York: American Management Association, 1968), p.230.

example, quality control personnel were advised, where possible, not to perform quality control activities themselves but to draw up comprehensive quality control plans and require the production department to carry them out, enforcing requirements essentially by inspection of production department output.³⁸ The quality control department was to model its relationship to the production department on the relationship of two independent companies, one buying goods from the other and demanding a certain level of quality performance. The quality control department was to be the internal representative of the customer and was implicitly to wield the same power of acceptance and rejection of output.

This model of the production department's role in achieving quality goals proved unrealistic. The directives of quality control departments were not readily accepted as legitimate by production supervisors and workers and the incentives for production personnel to follow recommended quality control practice were insufficient. The quality control department did not in fact have power comparable to the customer but was forced to compromise with the demands and goals of other departments and top management. In the sixties, the quality control department was still often placed under the jurisdiction of the plant or production managers for whom the traditional production department

³⁸ Hansen, p. 369.

values of gross efficiency and on-time shipment were paramount.

It was noted earlier that overenthusiasm for statistical techniques and their consequent misapplication was largely responsible for the early failures of post WW II quality control. While some of the problems were the result of poorly designed applications on the part of quality control specialists, the other major problem was resistance to implementation on the shop floor.

The statistical tool of quality control that was at once symbolic of statistical process control and statistical quality control as a whole and probably most directly helpful to those involved in production was the control chart. Plotting of a control chart requires close contact with manufacturing processes and is most useful for process adjustment and investigation of problems when in the hands of those with the most intimate and continuous knowledge of the process. Yet at first, the use of control charts was not even thought to be within the capability of the typical production worker to learn. Even Juran, who was later to be an early champion of worker participation in quality control activities, asserted in 1952 that the control chart was still a "laboratory tool" for specialists.³⁹

³⁹ A. C. Cohen, Review of Quality Control Handbook, ed. J. M. Juran in IOC, May 1952, p.104.

Reflecting the lack of use of control charts by ordinary workers and supervisors, a book on human factors in quality control was published in 1969 and could still devote all of its discussion to inspection as though statistical process control was unimportant.⁴⁰ The truth was that the control chart, despite its prominence within the quality control field, remained largely confined to use by specialized quality control personnel. Thus the division of labor brought about by the creation of the independent inspection department remained largely intact.

The rhetoric of the quality control profession resounded from the late forties onward with the call to impose the responsibility for quality control activities on production personnel so that the quality control department could move ahead with more advanced planning and special problem-solving activities. Hansen's textbook referred to earlier was one example of this, but even he admitted in 1963 that the production department generally lacked the tools to carry out what should ideally be its quality control responsibilities. As Juran pointed out in 1957, there was an enormous failure to get SPC accepted and understood on the shop floor, although this was not reflected in the trade literature. The absence of reports of failure was attributed by Juran to the power of corporations to allow only success stories about their

⁴⁰ Douglass H. Harris and Frederick B. Chaney, Human Factors in Quality Assurance (New York: John Wiley, 1969).

operations to be published.⁴¹ Juran's breadth of experience as an early consultant, his constructively critical perspective, and strong values of public service lend his account greater credibility than anyone else's in the field as does his sober detailing of the specific resistances to SPC met with on the shop floor.

There are two major obstacles to worker use of SPC identified by Juran.⁴² The first is the change in job duties it represents. As he points out, SPC not only added the extra work of drawing samples and recording measurements, but threatened the codification of traditional shop practice embodied in work rules. Second, the use of SPC was designed to replace worker experience in determining when processes had to be adjusted, thus creating the potential for resentment over being forced to use a technique which was not understood and trusted and taking away opportunities to exercise skill. More specifically, the requirement to use a control chart conflicted in important ways with the demand to meet specifications and was not therefore perceived as fully legitimate from the perspective of production supervisors and workers.

⁴¹ J. M. Juran, "Cultural Patterns and Quality Control," p.8.

⁴² The following two paragraphs are based on Juran, "Cultural Patterns and Quality Control."

This was so in at least two senses. For one thing, control charts are normally plotted using averages of measurements taken of several pieces belonging to a small sample whereas specifications have always implicitly applied to each workpiece individually. This produced confusion and the worry that monitoring and adjusting processes using control charts would allow defectives to be produced for which the worker could be held responsible. The adjustment of processes guided by control charts does not necessarily eliminate 100% of the defectives if specification tolerances are tight relative to the capabilities of the process. (the amount of ineradicable random variation) Furthermore, the use of control charts often causes more frequent process adjustment because they can signal the appearance of nonrandom variation before it has gotten bad enough to produce defectives. Once again, more frequent adjustments means more work and replaces the more conventional and familiar practice of correcting the process only when defectives appear.

Thus statistical process control, despite much talk of delegating implementation to the production department, met with very limited diffusion and acceptance at the shop floor level. This was a failure which quality control specialists seemed not disposed to confront or even to perceive as a major failure, partly, perhaps, because their main focus was on gaining respect for the statistical tools

themselves and their own professional abilities in using them.

In the mid sixties there emerged a movement in quality control called "zero defects" which followed in the tradition of earlier quality control initiatives dedicated to motivation of employees, but which was more ambitious, elicited more testimonials of success and offered a distinctive and attractive set of psychological and programatic concepts. Zero defects (or ZD) can be viewed as a step toward reintegration of quality control into the production department and as representing to some degree an alternative view of the most effective way to improve quality.

The vast majority of companies that tried ZD programs were aerospace and defense contractors for the government and most of these may have acted as a result of keen promotion of ZD by government officials with influence in contracting decisions.⁴³ Juran saw government promotion of ZD as far heavier and more specifically focussed than for any previous management technique.⁴⁴

The centerpiece of ZD was the introduction of a radically new work psychology meant to inspire and capture the imagination of workers in its novel assertion that all mistakes are preventable and that zero defects is a

⁴³ J. M. Juran, "Quality Problems, Remedies and Nostrums," IOC, June 1966, pp.648-49.

⁴⁴ Ibid., p.649.

reasonable standard of performance. Every worker is presented with a pledge card to sign indicating personal dedication to improvement of performance through prevention of error. This is accompanied by managerial effort to review all rules and specifications to make sure they are clear and represent attainable goals. Workers are also encouraged to submit suggestions for reform of operations to remove systemic causes of error. These are reviewed by special staff teams set for the purpose. Reductions in error rates are prominently displayed on scoreboards, but no one is disciplined for lack of improvement.⁴⁵

Juran, apparently the lone public critic of ZD in the profession during ZD's heyday, persuasively made the case that most of these programs were failures and that many of the published success stories were largely cooked up for publicity purposes by the companies involved. The failure of ZD was consistent with the "shockingly poor" performance of previous motivation programs.⁴⁶

Yet viewed from a wider perspective, the ZD movement made a contribution by focussing new attention on the role of the production department and other departments in the attainment of quality goals. The motivation of production workers was identified as critical to quality control and

⁴⁵ Philip B. Crosby, "Z is for Zero Defects," *IOC*, Oct. 1964, pp.182-185; J. M. Juran, "Quality Problems, Remedies and Nostrums."

⁴⁶ Juran, "Quality Problems, Remedies and Nostrums," pp.649-50, 652.

the elicitation of their suggestions for "error cause removal" had the potential of drawing them into quality control in a more meaningful way.⁴⁷ Managers and staff were compelled to consider worker suggestions more seriously when submitted as a part of a dramatic ZD campaign.⁴⁸ Juran also pointed out that ZD programs, because they are launched and carried out with great fanfare, involve top management and potentially give them a new understanding of the importance of quality control. This perhaps led them to give quality goals more weight in the management of the firm vis a vis narrow cost considerations or delivery schedule goals.⁴⁹

Still, it remains that most ZD programs were failures and that they were very infrequently adopted in civilian industries where they were commonly perceived as inspired by unrealistic perfectionism.⁵⁰ The key problems with ZD were rooted in its implicit premise that most quality problems are a matter of insufficient motivation and tolerance of mistakes; that defectives are generally the result of inattention and lack of care in following

⁴⁷ Juran suggested that the error cause removal provisions of motivational programs of the sixties such as ZD were a part of a movement toward operator participation in quality control. Quality Control Handbook, chapter 17, p.31.

⁴⁸ Ibid., p.653.

⁴⁹ Ibid.

⁵⁰ Juran, Quality Control Handbook, chapter 18, p.51.

prescribed procedures.⁵¹ But the ZD program played to the prejudices of American managers who typically assumed that the most important source of errors is lack of motivation or skill on the part of workers. While the ZD program included provisions for correction of systemic problems, this aspect was of decidedly secondary importance, serving conceptually as support for the motivational component. That is, systemic problems were corrected in order to create the conditions under which error free work could legitimately be called for.

Yet it was pointed out at the time by Juran and later asserted by Deming that most defectives, probably about 80%, are the result of flaws in the system for which managers are responsible --- in standards, methods, equipment, environment and communication.⁵² As long as motivation remained the central focus of special initiatives in quality control, the systemic nature of most problems would prevent success and create resentment on the part of workers who could not possibly prevent errors they did not cause. Juran made it quite clear that he thought the vast majority of firms had a long way to go to correct

⁵¹ Juran, "Quality Problems, Remedies and Nostrums," p.651.

⁵² J. M. Juran, "Operator Errors --- Time For a New Look," Quality Progress, Feb. 1968, p.9.

systemic sources of error before a motivation program could succeed.⁵³

ZD and other motivation programs had little to do with the application of statistical tools for control of quality and we saw that efforts to get the production department to use statistical process control met with little success. Despite worker and supervisor resistance to using control charts, however, statistical techniques had an inherent potential to improve worker security and worker control over their own jobs.

For example, when control charts are introduced in an operation, it is first established whether or not the normal or random variations in results are sufficiently small to hold specification tolerances. Often, the random variation inherent in the process is great enough to produce a substantial number of defectives even if all nonrandom or controllable variables such as machine settings and material grades are controlled for. If this is found to be the case, then workers cannot be held responsible for all defectives. Thus the institution of SPC can uncover the limitations of methods, equipment and processes and shift the responsibility onto managers or the system relieving workers of undeserved blame.⁵⁴

⁵³ J. M. Juran, "Quality Problems, Remedies and Nostrums," p.653f.

⁵⁴ "We are all familiar with the four M's which are ingredients of the manufacturing operation; Men, Machines, Materials, and Methods. The QC engineer recognizes this

SPC is by its nature investigative in its application. That is, it comes into play where the controls built into machine designs and managers' instructions leave off. Formerly, only the worker's judgement and skill were relied upon to realize managerial plans and only the worker to blame for insufficient results. Where SPC is introduced, it is by implication assumed that the causes of problems are not all known and need to be discovered. Further, since SPC, unlike after-the-fact inspection, must be carried out on the spot and while the process is taking place, the worker is far more likely to be engaged in it and to be able to use SPC both to identify sources of problems to supervisors who may otherwise take the option of blaming those below them for mistakes, and to gain better control over their own work. A job whose results can be kept consistent with SPC is more easily accomplished and more easily defended against the scrutiny of managers.

Unions were not apparently disturbed by the statistical quality control movement,⁵⁵ although this may be more of a reflection of the fact that production worker jobs were not much affected than of the natural congeniality of statistical quality control to the worker.

fact and, when there is trouble, endeavors to determine scientifically which one or which combination of those four factors is causing the trouble. Without SQC the blame is usually placed on the man." Edwin G. Olds, "The Place of SQC in an Industrial Organization," IOC, May 1953, p.34.

⁵⁵ "Recent Trends in Quality Control," Industrial Quality Control, vol. IX, no. 5, March 1953, p.3; Olds, p.34.

However, at least one trade unionist, William Gomberg of the International Ladies' Garment Workers Union, saw statistical quality control as making an entirely welcome contribution to the field of time study.⁵⁶ This contribution was essentially the statistical perspective itself which dictates that systematic variations in the value of a variable due to individually identifiable factors be distinguished from random variations in a variable. Gomberg saw the application of statistical theory to time study as forcing recognition of the many variations in conditions of work (especially the wage structure) which could systematically affect the length of time necessary to accomplish a task. Conventional time study had been heavily biased by the assumptions and judgements of industrial engineers who were too complacent about the difficulties of assigning standard times to jobs in a complex and changing work environment. In the case of time study, then, the statistical point of view had the potential of encouraging investigation into conditions of work and industrial processes unaccounted for by management and engineers just as it had in the context of quality control. Since all of those factors which escape the ability of managers to plan, create ambiguity and render the worker more vulnerable to unjustified blame, statistical theory, which is especially useful in

⁵⁶ William Gomberg, "A Trade Unionist Looks at Quality Control," IOC, Nov. 1954, pp.14-17.

determining the limitations of these plans and investigating sources of unforeseen variations, can be seen as a natural ally of the production worker.

In a very small number of plants during the sixties, the question of the relationship between the production and quality control functions within the firm was resolved in favor of nearly complete reintegration. In one variety of innovation, workers were trained in statistical methods of quality control and took complete responsibility for accepting and rejecting products for shipment.⁵⁷ A separate inspection function remained but was vastly reduced and assigned the role simply of auditing the acceptance and rejection decisions of workers. Juran noted that this type of work organization was viable only where managers and engineers had refined processes to the point where they were fully controllable by workers and where a high degree of trust prevailed in labor-management relations. Another variety of experiment pioneered by Sidney Rubinstein beginning in about 1960, involved the formation of problem solving groups in which production workers, foremen and quality control personnel all took part on a voluntary basis two to four times a month.⁵⁸ These groups were trained in non statistical methods of

⁵⁷ J. M. Juran, "Inspectors Headed for Extinction?" IOC, Oct. 1965, p.198 and "Management Interface: Inspection Returns To Its Origins," pp.34,48.

⁵⁸ Sidney Rubinstein, "Participative Quality Control," Quality Progress, January 1971, pp.24-26.

problem solving, methods of approaching and structuring problems such as brainstorming and model building, and group dynamics, and had the aim and effect of increasing motivation by giving workers more responsibility and recognition for doing a more varied and challenging job. Inspectors were not eliminated, but workers were rotated through the inspector positions helping to establish real teamwork between production and inspection. Problems solved were not limited to quality but extended to efficiency improvements and work conditions. Rare though such innovations were, they were important in demonstrating the possibility of an alternative way of accomplishing quality control and were forerunners of many later and better publicized experiments.

Quality Control as an Engineering Activity

In the late fifties and early sixties, another development in the quality control field --- reliability analysis --- shifted the overall focus to the quality improvement potentials of design and engineering.⁵⁹ Inspection and statistical quality control had taken product design as given, but in this period, there was increasing recognition of the fact that there was much room

⁵⁹ The suggestion was made by some that reliability analysis could actually replace quality control. "Reliability quality control" as an alternative to "inspection quality control" and "statistical quality control" is discussed in A. V. Feigenbaum, "The Challenge of Total Quality Control, IOC, May 1957, pp.103-4.

for improvement of product design when these designs were reevaluated with an eye to increasing the expected product life. There grew up along with this concern for reliability and longevity a body of statistical tools to aid in the redesign process. Essentially they had to do with analyzing the cumulative effects of malfunction probabilities of components and subassemblies. New techniques of product life testing also had to be developed.

That the new attention paid to potential contributions of engineering and design to quality control had a reorienting effect on the entire quality control field is evidenced in a movement in some quarters to subordinate the quality control department to a new reliability department in a way similar to the former subsuming of the inspection department under the newer quality control department.⁶⁰ Juran saw this as a result of a need for coordinated planning of the quality control function which the quality control department was not satisfying.

The mainstream of development of quality control was perceived as blending the new engineering perspective with statistical techniques. The most common organizational accomodation of reliability engineering was probably to give it a separate department and to place it and quality

⁶⁰ J. M. Juran, "A Note on the Mortality of Quality Control Departments," IOC, Feb. 1963, p.23.

control under a single "quality assurance" banner.⁶¹ But it remains true that for some, the engineering perspective seemed broader and more fruitful, not just to those who had a personal professional interest in reliability analysis but for those who had experienced the misguided overemphasis on and disappointment with statistical quality control. The attraction of prestige was operating here too, however, for reliability problems spawned a type of analysis which could be mathematically challenging and specialized and was more frequently encountered in fields such as aerospace and defense⁶² which had led the way in other major quality control developments and in technology generally.

Another new field of engineering of the early sixties, value engineering, should be noted as a part of the general attractions of engineering for managers concerned with quality. Value engineering, like reliability engineering, is a form of reevaluation of existing designs. It explores alternative, more economical ways in which the functions of components and subassemblies can be performed. When successful, it leads to design modifications such as specification of less expensive material, or reduction of the number of product components are made. Quite often,

⁶¹ Richard Freund, "Quality Control --- A Decade of Progress," IOC, Aug. 1965, p.70; A. V. Feigenbaum, Total Quality Control, (New York: McGraw Hill, 1983), pp.87-88.

⁶² J. M. Juran, Quality control Handbook, chapter 7, p.21.

products made according to original designs are overbuilt because specifications for components, materials or dimensional tolerances contain extra margins of safety or are simply customary. Value engineering can bring specifications more into line with functional requirements which are often better known after the initial designs have been tested. It solves quality problems by increasing the ratio of performance (or quality) to cost rather than improving quality per se (although it may also turn up ways of improving performance without cost increases).

The Systems Perspective on Quality Control

In the early days of modern quality control after WW II, both quality control specialists and top management perceived quality control as a set of specialized techniques whose application would be the responsibility of the quality control department. The first post war decade was clearly dominated by the rush to apply statistical tools. Shortly thereafter, engineering specialties such as reliability analysis competed with statistical inspection and process control for the spotlight. Then the mid sixties brought the ZD movement and focus upon the role of motivation in achieving quality.

From at least the early fifties, however, there also began to be articulated, especially by Juran and A. V. Feigenbaum, a view of quality control as a system larger than any set of statistical, engineering or motivational

techniques and extending throughout all the departments and functional components of the firm. Both Juran and Feigenbaum had a broader perspective on quality control than their colleagues in that their visions of how quality control activities should be organized were based on their view of problems and their sources rather than on how available techniques should be applied. They recognized that quality was the outcome of actions in virtually all departments and that the role of the quality control department would have to be primarily the coordination and guidance of activities outside itself.

A better picture of the complexity of the quality control problem can be gained by briefly reviewing some of the roles that each of the departments of an industrial organization typically plays in achieving quality. Product engineering establishes the original specifications. Manufacturing engineering must determine the method of manufacture so that process consistency is sufficient to meet these specifications. It must also design processes to provide for adequate means of monitoring process status and results, as well as means by which to correct conditions that cause defects. Purchasing must select suppliers who are capable of consistently meeting specifications. Marketing is responsible for establishing appropriate customer expectations concerning product performance and studying customer needs and tastes. Personnel is expected to select people who are suited to

their jobs and to train them to understand their jobs and the standards they must meet. Manufacturing needs to ensure that product and process specifications are met. Accounting is responsible for compiling reports on the costs of quality control and of the failures to control quality. Quality control itself must design inspection and test procedures, analyze process capabilities and customer complaint data and carry out final product inspection and quality audits.

All of these activities may be carried out separately and sequentially, but quality goals cannot usually be met without a good deal of cooperation, communication and feedback of information between departments. This interdepartmental cooperation does not usually take place to a sufficient degree without conscious organizational and procedural planning on the part of management. Several of the following examples represent what is needed as much as they they do actual practice. Product designers need to use the knowledge of marketing specialists who study customer tastes and needs and of manufacturing engineers and shop floor personnel in creating marketable and manufacturable designs. They may also need to draw on the reliability analysis group in the quality control department to ensure that the failure modes and rates of components and subsystems do not interact in such a way as to create an unacceptable product failure rate. Manufacturing engineering needs to understand the design specifications

of product engineering and to work with manufacturing and quality control so that the people operating the machines they design can understand and control their operation. Purchasing needs to work closely with product and process engineers to know the importance of various specifications so that they are enabled to provide advice on possible substitute components and materials available in the market. Marketing must cooperate with engineers and with manufacturing to know the kinds of field data that are needed to improve product and process performance and to adequately explain product capabilities and methods of use to customers. They also need to be in touch with engineers in order to inform customers of differences in quality between the firm's products and those of competitors. Accounting needs to work with all departments in assessing their data needs and designing quality data reporting systems.

Although, by 1951, Feigenbaum had started publishing his concept of "total quality control," and Juran was already trying to impress his readers with the number of distinct occupational specialties involved in solving quality problems,⁶³ general acknowledgement within the profession that quality control is a function extending throughout the firm probably did not occur until the early

⁶³ See Cohen, review of Quality Control Handbook, ed. Juran, p.104 and J. M. Juran, "Installing a Quality Control System," IQC, May 1953, p.21.

sixties.⁶⁴ Richard Freund, one of the most respected quality control experts, saw its acceptance as the major professional development of the decade from 1955 to 1965.⁶⁵ One indirect but concrete indication that this broader view of the quality control function began to be influential in the early sixties is that seminars on quality control management (as opposed to seminars on quality control techniques) suddenly became more popular during this period.⁶⁶

No judgement can be attempted here of the extent to which industry subsequently implemented "total quality control." But if the critique of American practice set forth up to the 1980's by Juran and Feigenbaum, the two most influential writers on quality control of the entire post war period, is any criterion, implementation must have been inadequate; for most of this critique stemmed directly from their systems view of the quality control problem.

Starting from the recognition that the actions of all departments critically affect quality, Feigenbaum and Juran saw a twofold need: 1) to increase the participation of all

⁶⁴ Two books on quality control misleadingly cite Feigenbaum's Total Quality Control of 1961 as the sources of this concept: David A. Simmons, Practical Quality Control, (Reading Mass. and Menlo Park, PA: Addison-Wesley, 1970), p.9 and Elwood G. Kirkpatrick, Quality Control for Managers and Engineers, (New York: John Wiley, 1970), p.319.

⁶⁵ Freund's judgement was seconded by Kirkpatrick.

⁶⁶ Juran, "Seminars for Quality Control Management --- At Last," IOC, July 1964.

groups in the firm in activities directed to quality and 2) to increase capacity for leadership and coordination of these diverse activities.⁶⁷ Both Feigenbaum and Juran were highly critical of the overemphasis placed on particular techniques monopolized by quality control personnel, especially statistics and reliability analysis, and pushed for a more active, firm-wide planning role for the quality control department and for top management. Speaking in the context of the disappointing results of the rush to implement statistical methods, both Feigenbaum and Juran argued that top management would appreciate not only the better results of a broader systems approach but would ultimately be more sympathetic to its orientation toward problems instead of towards specific advanced techniques.⁶⁸

As they saw it, multidepartment committees would need to be formed and/or the quality department staff and top management would need to plan for the apportionment of the various interlocking responsibilities for quality as outlined above.⁶⁹ Top management would need to review and implement this assignment of duties, backing it up with

⁶⁷ J. M. Juran, "The Two Worlds of Quality Control;" A. V. Feigenbaum, "The Challenge of Total Quality Control," and Total Quality Control 3d ed. (1983) chapter 5 and chapter 8.

⁶⁸ Feigenbaum, "The Challenge of Total Quality Control," pp.103-04; Juran, "The Two Worlds of Quality Control," pp.243-44.

⁶⁹ Juran, "The Two Worlds of Quality Control," p.244; Feigenbaum, "The Challenge of Total Quality Control," pp.106-07.

incentives for each group to perform and evaluating the total quality effort with respect to quality problems as they manifest themselves in the marketplace and the firm's cost structure. The need for this recommendation was created by the orientation of quality control engineers who were by training and experience focussed on statistical and engineering techniques rather than quality as a business problem, and the orientation of top management for whom the new field of quality control was perceived as a set of special techniques which would necessarily be implemented by a restricted and specially trained group.

After statistics and reliability engineering, employee motivation threatened to become a strong enough focus of interest to distract from the systems perspective. To place primary emphasis on motivation, whether it be for shop floor workers or for all personnel, was seen by Juran as missing the point that the sources of defects are very often not known and require investigation to uncover as well as the fact that errors in engineering and system design are very often the true source of what appear to be worker errors.⁷⁰

This point was strongly seconded by W. Edwards Deming.⁷¹ Deming remained far more narrowly focussed on

⁷⁰ Juran, "Operator Errors --- Time for a New Look," p.9.

⁷¹ W. Edwards Deming, Quality, Productivity, and Competitive Position, (Cambridge, MA: Massachusetts Institute of Technology, Center for Advanced Engineering Study, 1982), p.68.

statistical techniques than Juran or Feigenbaum, regarding himself first and foremost as a statistician; but his scathing critiques of American management were essentially inspired by a view of statistical quality control as a tool for investigation and improvement of manufacturing systems. Perhaps his favorite targets of criticism were purely motivational quality campaigns that implicitly assumed that workers already knew exactly what to do to produce quality products and how to do it and that defect prevention depended mainly on instilling the will to perform consistently.⁷² This, he said, was not the case since most defects are the result of flaws in the system for which management must be responsible and which statistical techniques can help to track down and correct whether they have to do with machine design, work methods, materials or faulty specifications. Deming wanted to see the American emphasis on management through a combination of fear, coercion and exhortation replaced by an investigative attitude toward work which would be embodied in the massive adoption of statistical techniques at all levels of the hierarchy from upper management down to the shop floor

⁷² Sam L. Jones, "30-Yr. Lag in US Quality Control: Deming," American Metal Market, Feb.14, 1983; Edwards Deming, "'Made in Japan' Is No Joke Now, Thanks To Edwards Deming: His New Problem Is Made In U.S.A.," interview by Clare Crawford-Mason, People, September 8, 1980.

worker.⁷³ Despite the widespread existence of quality control departments with statistical expertise, Deming felt that without extensive statistical training of employees at every level, meaningful application of statistical techniques would not take place. In other words, statistical competence had to be brought down to where the people most familiar with problems can use it to solve them.⁷⁴ Said Deming in 1980, "to my horror, I have discovered that most American companies think they already have statistical control of quality. What they have is a lot of printouts full of irrelevant and out of date information."⁷⁵

Thus while Feigenbaum and Juran warned against an overemphasis on statistics and emphasised the recognition and apportionment of the varied responsibilities for quality among the departments, Deming pushed for far greater emphasis on statistics but in such a way that statistical competence would be the basis for a broader systemic view of quality problems. Juran and Deming both agreed that capability for statistical monitoring of processes should be diffused downward and that attempts to

⁷³ W. Edwards Deming, "What top Management Must Do," Business Week, July 20, 1981, [part of a special advertising section sponsored by Japanese firms]; "30-Yr. Lag," American Metal Market.

⁷⁴ Ibid.

⁷⁵ Deming, "'Made in Japan' Is No Joke Now."

apply statistics by a professional staff alienated from the shop floor were wasteful and often harmful.

Linked to programs of reform advocating the analysis and planning of complete quality control systems were calls for more extensive accounting for the costs of quality control and quality control failure and for better measurement of quality itself. Although Juran did not place special emphasis on the need for better quality accounting in his writings, better data gathering and reporting were seen by him as a prerequisite of and necessary complement to systems planning and the assertion of top management control over quality policy as a business problem.⁷⁶ In an early article outlining the steps involved in implementing a quality control system,⁷⁷ Juran recommended beginning with computation of what he called the "gold in the mine" or the amount by which costs would be reduced if production were completely free of defects. The next step was to decide roughly what proportion of these defect generated costs --- principally the resources used up in rework, sorting, and production of scrap --- were reasonably avoidable, and then to determine the shares of these costs assignable to the various departments and whether errors originate with operators or with planning

⁷⁶ J. M. Juran, "Goals for Quality Management in the Next Decade," p.14, and "The Two Worlds of Quality Control," p.243.

⁷⁷ J. M. Juran, "Installing a Quality Control System,"

and supervision. With estimates of avoidable quality failure costs in hand, the budgeting and planning of quality improvement efforts for each department could be accomplished according to a clear set of priorities.

Juran later used the older and more mature finance function as a model for the quality function to follow in its path toward systems planning and top management control.⁷⁸ One of the most desirable aspects of the finance function was its ability to collect and organize data from all departments in such a way as to enable top management to monitor, plan, and control all activities in the firm from the financial point of view. Just as management reviews summary budgets, so should they, according to Juran, review standardized quality reports including costs saved and incurred and principal measures of quality performance.⁷⁹ Juran, at the beginning of the seventies, hoped that the coming decade would see widespread establishment of an annual quality program for which each department would propose its own quality goals and budgets for quality improvement activities in a fashion similar to its preparation of annual operating budgets.⁸⁰

Feigenbaum, from the mid fifties to the eighties, consistently highlighted the importance of measurement and

⁷⁸ Juran, "The Two Worlds of Quality Control," pp.241-42.

⁷⁹ Juran, "Mobilizing for the 1970's," p.16,17.

⁸⁰ Ibid.

analysis of quality costs.⁸¹ He placed most of these costs into three categories --- prevention, appraisal, and failure costs. Prevention costs include quality control engineering, maintenance of tools and equipment, studies to find the causes of defects, and employee quality training. Appraisal costs include inspection and product testing. Failure costs are classified as internal or external. Major internal costs are scrap, rework and correction of defect causing conditions. Major external costs are warranty expenses and response to customer complaints.

Feigenbaum's program of "total quality control" prominently featured the reduction of these costs by a change in the allocation of resources. In Feigenbaum's estimate, quality costs were comprised of 65 to 70 percent failure costs, 20 to 25 percent appraisal costs and 5 to 10 percent prevention costs.⁸² A progressive quality control program would raise prevention costs but would realize as a result a much greater reduction in failure costs and appraisal costs. With fewer defects, there would be less scrap and rework and less need for inspection to screen good output from bad.⁸³

⁸¹ A. V. Feigenbaum, "Total Quality Control," Harvard Business Review, vol.34, no.6, Nov.-Dec. 1956; "The Challenge of Total Quality Control," and Total Quality Control, (1983), chapter 7.

⁸² Feigenbaum, "The Challenge of Total Quality Control," p.107; Total Quality Control, 3d ed., p.112.

⁸³ Ibid.

Deming did not focus on quality cost accounting, but his emphasis on prevention of defects through statistical quality control was a vision of a far greater economy in production that complemented Feigenbaum's emphasis on quality costs. Philip Crosby, one of the leaders of the ZD movement in the sixties and author of the popular 1979 book Quality is Free, also contributed to the focus on cost accounting and reduction. In his view, American managers thought of higher quality as invariably associated with higher costs and were insufficiently aware that quality in the sense of degree of conformance to existing design specifications or product performance targets could be raised while reducing costs as Feigenbaum had explained.⁸⁴ One of the most important reasons for this lack of awareness said Crosby was the underdevelopment of quality cost accounting and reporting.⁸⁵ Identifying the costs of quality failure is not easy since rework and corrective action have long been accepted as a normal part of all productive activities and the costs they occasion are consequently imbedded in their budgets.⁸⁶ Crosby estimated that only one third of all quality costs may be identified the first time they are calculated.⁸⁷

⁸⁴ Philip Crosby, Quality Is Free: The Art of Making Quality Certain, (New York: McGraw-Hill, 1979).

⁸⁵ Ibid.

⁸⁶ Hagen, p.231.

⁸⁷ Crosby, Quality Is Free.

One of the symptoms of inadequate appreciation of the cost saving potential of quality control is arbitrariness of decisions on the funding of quality control staff departments and inspection.⁸⁸ Differences in the ratio of quality control personnel to total personnel ranging over an order of magnitude were found in a study of the aerospace industry and were suggestive of a widespread lack of ability to calculate costs and benefits.⁸⁹ Juran pointed to the need for research to discover average or typical industry practice in quality control funding as a general guide to those who could not easily establish for themselves a justifiable level of expenditure.⁹⁰

In our discussion of quality related costs, we have stayed close to the manufacturing process, covering only what Feigenbaum calls "quality operating costs." This is a reflection of the quality profession's preoccupations and of the historical development of quality control department functions. Quality control first began to extend substantially to product design with reliability engineering in the late fifties, but quality control still took most product performance and business goals as given. Recognizing this, Feigenbaum and Juran tried to expand the

⁸⁸ Ibid.

⁸⁹ Ibid., pp.232-34.

⁹⁰ J. M. Juran, "What is Par?," IOC, Oct. 1966.

horizons of quality control to the point where the quality function would no longer be restricted to "control" where "control" implies that the activities being controlled have been predetermined. Instead, the quality function would concern itself with a dimension of business as pervasive as the financial and which would be the subject of major decisions on business strategy. An analogy may be made to Materials Requirements Planning which began by being a way to schedule production operations and incoming shipments but was later raised to the level of a general business management system.

Toward the late sixties, Juran began placing his strongest emphasis not on quality in terms of conformance to design specifications but on quality in terms of responsiveness of product and process design to customer needs and the shape of marketplace demand. He argued that there was even greater potential to improve profits through study of consumer needs than there was in lowering quality failure and appraisal costs through prevention and better quality systems management. Adding to his critique of the quality control department's overly narrow focus on particular techniques, he warned that quality control staff were unduly restrictive in considering themselves responsible only for quality in terms of conformance.⁹¹

⁹¹ J. M. Juran, "Quality and Profit," IOC, July 1967.

The engineering department had always been in charge of making the final determination on product specifications. Very commonly, said Juran, they would also be in charge of determining the features, configuration, and tolerances that would best meet customer needs and manufacturability requirements.⁹² But Juran saw that closer study by marketing and quality specialists of the way consumers use products in the field and the expenses they incur for maintenance and repair over the life of the product could be used to identify differences in quality from competing products or to make design improvements that would justify higher prices and/or improve market share. He used the example of a company which had studied the value to customers of the superior reliability of its product and as a result was able to quantify it, explain it to customers, and raise its prices.⁹³

Juran was also concerned that lack of knowledge of the effect of quality levels on pricing options and market share was associated with lack of explicit decision making on quality levels. Strategic targeting of superior, competitive or merely adequate product performance could be chosen according to the manufacturing and design capabilities of the firm and the character and size of demand by different customer groups. The choice of quality

⁹² J. M. Juran, "Mobilizing for the 1970's," IQC, Aug. 1969, pp.15-16.

⁹³ Juran, "Mobilizing for the 1970's," p.11.

level would be integral to formulation of price policies and market share goals.⁹⁴

Feigenbaum who, from the beginning of his career, had emphasized the need for a broader scope for quality control also came to portray quality control as a function integrally involved in business strategy and all aspects of firm operation from product design to customer service. He argued that quality control personnel should participate in formulating the original product and process concepts and have regular input into the marketing and service plans.⁹⁵ Similar to Juran, he urged study of "life cycle" product costs and feedback of information on customer problems and needs into product and process engineering and manufacturing.⁹⁶

In the last edition of Total Quality Control, Feigenbaum brought out more clearly than ever before his vision of quality control as a company wide function devoted both to the translation of customer needs into products and services and the economical conversion of inputs into outputs, two activities which between them exhaust the functions of the firm. Thus quality control had reached the stage, at least conceptually, of becoming a fundamental approach to the production of value and one

⁹⁴ Ibid. pp.11-12.

⁹⁵ Feigenbaum, Total Quality Control, 3d ed. p.107.

⁹⁶ Ibid. pp.138-141.

which was broad enough to provide a general framework for business strategy.

Deming, the American quality control expert brought to prominence in the eighties because of his work with the Japanese, added, in his own way, to the rise of quality control to become a general and fundamental approach to business and manufacturing. Promoting statistical techniques as the key to quality control, he nevertheless derided American managers for running their businesses by the numbers. As he saw it, short term financial goals and numerical goals for defect levels distracted attention from the real problems --- devising and investing in long term strategies with respect to product and process development, building up the capabilities of the manufacturing organization through extensive training, and tracking down through statistically aided research the sources of productivity sapping defects.⁹⁷

We have reviewed the principal critiques of American quality control practice as a response to and a reflection of the shortcomings and misdirections in the development of the quality control function in American industry. In chapter seven, we will focus on the powerful attraction of Japanese quality control as a model for the transformation of American industry in the eighties. Well before the

⁹⁷ David Halberstam, "Yes We Can!" Parade, July 8, 1984, pp.4,5.

eighties, however, Japan had already begun to emerge as a standard of comparison in the writings of Juran.

Juran warned in 1969 that the Japanese were definately heading for world quality leadership.⁹⁸ By 1978, he was telling American executives to visit Japan to observe why the Japanese were superior in quality.⁹⁹ In that year, he described the Japanese quality circle movement and the broad quality training programs associated with it as a successful innovation to which the rest of the world would eventually have to respond. Though he did not advocate adoption of the quality circle concept itself, he maintained that an equivalent way should be found to increase participative problem solving in the West.¹⁰⁰ Juran also reported that the Japanese were better at bringing quality control considerations and expertise into product and process engineering. They made more use of data on customer repair and maintenance costs and put products through a more thorough debugging process before

⁹⁸ J. M. Juran, "Mobilizing for the 1970's," IOC, p.14.

⁹⁹ J. M. Juran, "Japanese and Western Quality --- A Contrast," p.17; Juran foresaw the tremendous growth of interest in Japanese quality control: "As I read the trends, I have no hesitancy in predicting that by the end of the 1980's, Japanese quality leadership will be the subject of far more discussion and action than has been the case to date. This discussion will not be limited to those industrial companies who will be on the defensive. The discussion will extend to the legislative bodies, the labor unions, the public press and still other organs of society." p.16.

¹⁰⁰ *ibid.* p.16.

going into production.¹⁰¹ They also paid more attention to details of process design that would prevent shop floor errors, a practice that was aided by including production experience in the training of designers.¹⁰² In general, Japanese quality control had evolved further towards the achievement of a true system in which all of the varied activities it comprises are integrated with each other and with other activities in the firm. The Japanese did not possess superior individual techniques, but had been more successful in educating large numbers of people in their use and closely harnessing their application to solution of problems rather than allowing the techniques themselves to be the focus of the implementation process.

When the Japanese challenge shook American industry in the eighties and their superior quality became an issue, the American quality control profession was well situated to take up the Japanese model. SQC had been the subject of an earlier professional and managerial movement which had met with very limited success because of the failure of top management to understand its potentials and evaluate its contributions and the failure of technically preoccupied quality control staff to integrate their knowledge with that of the people directly involved in production. Japan, by contrast, offered the example of a quality control

¹⁰¹ *ibid.* pp.11-13.

¹⁰² *ibid.* p.15.

function given highest priority by top management and featuring the extensive use of statistical techniques by all departments and levels of employee. Furthermore, Deming and Juran were the two people most responsible for introducing American methods of quality control to the Japanese in the fifties, and both had already held up the Japanese as examples of superior practice. But events of the eighties made it widely apparent for the first time that a fundamental reorientation towards quality was necessary and that the Japanese system as a whole needed to be understood as a guide to that reorientation.

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**TRANSFORMATION OF THE AMERICAN
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VOLUME II

By

Paul Timothy Bushnell

A DISSERTATION

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CHAPTER SIX
COMPUTER CONTROLLED MANUFACTURING

Introduction

In the early 1980's, the potentials for the computerization of manufacturing were becoming more and more clear, and were partially realized in a new kind of automation that was both flexible and more comprehensive than earlier types. Instead of the motions of machines being determined by their fixed, physical configuration, they could be controlled by computer programs which could be freely revised. Moreover, computers could be used to plan and control almost every dimension and phase of manufacturing --- product and process design, machine set-up, machine loading and unloading, the movement of workpieces between machines, and error detection and correction. In short, the new computer control made the workerless factory seem just around the bend.

This emerging automation is different from that which was installed during the 1950's and early 1960's when automation was also the subject of so much discussion and speculation. It is true that then as now, the computer was associated with a new age in which the computer would recreate, augment and replace human decision making in the

production process. Moreover, the operations of many "process" industries such as oil refining, chemicals and milk processing were beginning to come under computerized control. Computers were also extensively used in office functions such as accounting and payroll. But so far as manufacturing proper was concerned, the use of the computer was still rare. As of 1960, there were only approximately 750 machine tools in the U.S. for which the computer was employed to create programmed instructions.¹

The automation of that era also lacked the flexibility that the new computer control offered. The prototypical example of automation was the automotive engine transfer line in which transfer machines, designed to accomodate a single engine block design, moved engine blocks from one machining station to the next. Even the computerized process plants of the day had to be redesigned in the 1970's for lack of flexibility.²

Although not nearly so pervasive as had been predicted two decades earlier, by 1980, the use of the computer was well established in discrete product manufacturing industries, and computing costs were continuing a rapid decline. The use of computer controlled machine tools was spreading rapidly and programmable robots had already been

¹ John Diebold, "Congressional Testimony," in Morris Philipson, ed., Automation: Implications for the Future, (New York: Random House, 1962) pp.33-4.

² David Noble, "Toward the Automatic Factory," chapter 10 in Forces of Production.

demonstrated as highly practical in several applications, particularly in the auto industry.

In the early 80's, rapid advances were also being made in techniques of computer aided design of products and tooling. And technological advances seemed imminent that would allow manufacturing control instructions to be automatically generated from computer created designs. Finally, the early 80's saw the first widespread publicizing of systems in which computers linked individual computer controlled machines by planning and controlling the flow of materials between them. A clear and concrete image of the fully automated factory at last began to take shape. Drawings of such factories were published in the manufacturing trade press, and the operation of most of its components could be described on the basis of at least experimental experience.

A common label for the new developments was the "new" or "second" industrial revolution. The National Academy of Sciences proclaimed computer aided design and manufacturing the invention with the greatest potential to increase productivity since electricity.³ Fortune heralded the "race to the automatic factory"⁴ and Iron Age reported urgently that "the automated factory has been a buzzword

³ John Teresko, "CAD/CAM Goes to Work," Industry Week, Feb. 7, 1983, p.42.

⁴ Gene Bylinsky, "The Race to the Automatic Factory," Fortune, Feb. 21, 1983, p.54.

for the last decade. Now it's a serious business decision. And the signs are clear that any other path leads to disaster."⁵

Programmable automation is distinctive as a vision of manufacturing management because it represents the possibility of, and encourages belief in a final state of optimal control. Its image is that of the technological/managerial endpoint of development. That is, it is portrayed as a comprehensive and completed system, a total factory of the future, the design of which has taken into account every eventuality within well-defined parameters. Nothing in such a system can be left until after installation to be worked out on an ad hoc basis.

Thus, manufacturing control is collapsed into process and product engineering. This largely reverses an historical process in which the various control functions such as quality control and materials management were increasingly organizationally differentiated. Thus the engineering of automated processes implicitly represents a substitute for progress in organizational development. In fact, one of the strongest motivations for implementing the new technology is to deskill and eliminate workers and thereby to diminish the importance of the human organization.

⁵ Alice M. Greene, "Are Factory Systems the Path to Productivity?," Iron Age, Oct. 22, 1982, p.41.

In earlier chapters, we saw new forms of worker participation and quality control not as developmental endpoints but as avenues of development. They are essentially modes of communication and tools of investigation. As such, they assume an environment of continuously emerging problems.

The drive toward flexible, computer coordinated manufacturing is much more akin to ambitions to computerize scheduling decisions under MRP. In fact, MRP is often envisioned as just one subcomponent of futuristic automation. It is logical to suppose that problems stemming from overoptimism about the ability of computers to replace human judgement and communication will be encountered with computerized manufacturing as they were with MRP. We will see later that this is in fact the case. But while MRP had already undergone, by the early 80's, substantial reconceptualization as less of a governor than a tool of the human organization, the vision of the computer controlled factory of the future still postulated an engineering solution to the problems of control and represented an endpoint rather than a path of reform.

MRP, progressive quality control systems and, to a lesser extent, greater worker participation were all avenues of reform which developed into general reorienting perspectives on manufacturing management. The same was true of the new flexible automation. Furthermore, all of them opened up ways of harnessing manufacturing more

directly and specifically to market demands. This is most clear in the case of quality control as it grew to take on the responsibility of researching modes of product use in the field and translating its findings into design and manufacturing control priorities. MRP promised shorter lead times for delivery of product, better ability to predict and promise delivery dates, and easier, better coordinated adaptations to engineering changes. Worker participation, particularly in the high technology companies, was initiated, in part, to encourage more innovation and adaptability to market demand shifts. All of these developments formed a contrast to earlier practice where quality control, production scheduling and work organization were considered almost solely within the context of manufacturing which was managed largely in isolation from sales and customer service.

With its flexibility, the computerized factory of the future also promised to tie manufacturing control more closely to the market. New product designs could be brought into production more quickly without having to replace or extensively retool dedicated machines. Instead, reprogramming would largely suffice. Perhaps more significantly, it enabled a more varied product line since machines operating according to computer instructions can switch from one type of workpiece to another with little or no intervening set-up time. This means that the economies of mass production can be approached while customizing

products for a greater number of market segments.

Flexibility of manufacturing's response to the market is also theoretically enhanced by placement of control over the factory floor in the office, because managerial priorities are translated directly into production activities as, for example, in scheduling.

Thus, computerized manufacturing, as a paradigm of manufacturing management, is both complementary to and in conflict with the reform movements in other functional areas of management. We will therefore explain the goals and methods of computer controlled manufacturing and compare them, where possible, with the goals and methods of quality control, worker participation, and production and delivery scheduling.

The complete factory of the future integrates a number of computer-controllable components such as computer numerically controlled (CNC) machine tools, robots, various types of material transport, and sensing and measuring devices. All of these components can be individually deployed without being made part of a larger system. We will review the accumulated experience with these individual components in order to elucidate the problems and implications of more complete flexible manufacturing systems which are still in an early stage of development. It will also be interesting to see how the new images and approximations to the factory of the future which appeared in the early 80's were fed by the convergent development

and acceptance of these components, particularly CNC machine tools and robots.

Numerically Controlled Machine Tools

Conventional machine tools are operated by highly skilled machinists who are responsible for planning the sequence of cuts, selecting tooling, devising fixtures, adjusting machine settings including feed rates and spindle speeds, and for manipulating various cranks and levers to control the machining process. Numerically controlled (NC) machine tools, on the other hand, are controlled by numerical and symbolic codes which are recorded on paper or magnetic tape or some other medium and translated into electrical impulses to actuate electric motors and/or hydraulic and pneumatic devices on the machine. The work planning functions of the machinist are most often carried out by a separate machine tool programmer, usually with the aid of a computer and away from the shop floor. After the workpiece and tooling are loaded by the operator into the machine, the programmed instructions are "read" and followed by the machine to perform all of the operations automatically.

The original inspiration for NC machines was the need to accurately machine the very complex shape of a helicopter blade. Defining points along the curve of the blade with numerical coordinates and using those coordinates to position the cutter of a machine tool

resulted in a more consistent and faithful reproduction of the original design. An advantage of modern NC is the ability to control the motion of machine tools along several axes of motion at once to realize shapes which could not be machined at all or machined consistently using manual control. The vast majority of metalworking operations, however, don't require such an advanced capability.

From the early stages of its development, the most attractive feature of NC equipment has been its ability to extend the control and rationalization of the production process, enabling direct translation of highly detailed manufacturing plans into machine motions without the intervening uncertainties of human interpretation of instructions or the difficulties of imposing supervisory discipline over such a multifaceted activity as machining. Machine tool programs can be stored and recalled whenever needed so time is not wasted in planning work methods each time a new batch of a part is produced. The preservation by programs of optimal methods also means that time requirements for the machining of parts are standardized. Because machine operators only load and unload workpieces and tooling, and monitor operation, they don't influence the pace of work as much and are easier to supervise.

One of the most revolutionary implications of NC machining for manufacturing management and industrial structure is its flexibility, particularly its radical

reduction of set-up time and expense. With NC, set-up is only a matter of changing the program and loading the tooling, and the need for complex jigs and fixtures is greatly reduced. In addition, numerical control has made practical the building of machine tools called machining centers which perform several operations formerly performed on separate machines eg. milling, drilling and boring. Most machining centers have automatic tool changers. This reduces the number of set-ups and the time spent loading and transporting workpieces. The result of fewer and faster set-ups is that while conventional machines are commonly in operation about 20% of the time, NC equipment utilization rates of 70% are claimed to be a reasonable goal.⁶

Greatly reduced set-up time means that small batch production becomes much less costly relative to large batch production. NC machines make their biggest contribution to reduced costs at batch sizes of a few pieces, particularly where there is an irregular, but recurrent demand for a large variety of items.

The first laboratory demonstration of numerical control was in 1952. Development was funded by the Air Force, and early purchases were subsidized. The aircraft industry was the first to use NC but it was not until 1963 that it made the first large commitment of its own funds

⁶ Modern Machine Shop 1986 NC/CIM Guidebook,
(Cincinnati: Gardner Publications, January, 1986) p.22.

to NC. Diffusion was much slower in the 1960's than was expected.⁷ NC remained concentrated in the aircraft and machine tool industries during this decade.⁸ A 1968 study found that even in the aircraft industry the area of its economic applicability was "surprisingly limited"⁹ NC still accounted for less than 1% of machine tools in 1973.

The slow rate of diffusion in the 1960's was partly attributable to skepticism and fear of the new, complex, and often unreliable technology. Reinforcing this attitude were the high cost of NC machines and the the lack of programming and maintenance skills. Fears of NC were largely justified. By one 1972 estimate, 50% of NC machine

⁷ Said one researcher in 1963, "there is ample evidence to suggest that numerical control has attained a state of development which makes it economically feasible in most low-volume and medium-volume industrial machining operations." "Various industry sources have estimated that by 1965 approximately 50% of all new machine tools purchased will be equipped with numerical control and that this total may reach 75% of total machine tool sales by 1975." (Frank Lynn, Management Research Division, IIT Research Institute, Technology Center, Chicago, "Metalworking in 1980," American Machinist, vol.107, no.25, Dec. 25, 1963) Yet in the decade from 1973 to 1983, NC accounted for only about 11% of machine tools shipped. (13th American Machinist Inventory, American Machinist Nov. 1983, calculated from data on pp.120-21)

⁸ Jack Rosenberg, "A History of Numerical Control," cited in Noble, p.213.

⁹ Edward Crossman, Stephen Laner and Stanley Caplan, "The Impact of Numerical Control at Plant Level U.S.A.," (Human Factors in Technology Research Group, Dept. of Industrial Engineering and Operations Research, University of California, Berkeley, Feb. 1968) cited in Noble, p.232.

tool installations were not performing to the satisfaction of management.¹⁰

The obstacles to NC use were made much more formidable than they might have been by the dominating influence of the U.S. military upon NC machine manufacturers. Because both development and purchases were subsidized heavily in the 1950's, machine tool builders oriented themselves to military design priorities which stressed maximum capability for machining complex shapes, very high precision, and a universal language for machine programming to allow use of programs on different machines and their transference between plants and firms. As a result, the most expensive and sophisticated but difficult to program design alternatives were emphasized.¹¹

The number of NC machine tools doubled approximately every five to six years from the early sixties to the eighties (from about 5,000 in 1963 to 103,000 in 1983).¹² In the 1970's, this growth broadened participation in the new technology. Small plants, which are more likely to produce in smaller batches and which are therefore ostensibly able to make especially good use of NC machines, appear to have increased their share of NC equipment very

¹⁰ John H. Greening, "N/C, DNC, CAM: Panacea or Poison?" in M.A. DeVries, ed., The Expanding World of N/C (Numerical Control Society, 1981) cited in Noble, p.223.

¹¹ Noble, chapters 7,8 and 9.

¹² 13th American Machinist Inventory, p.113.

substantially from 1973 to 1983.¹³ At the same time, the share of NC machine tools owned by the aircraft and machine tool industry declined. From 1978 to 1983, their share dropped from 27% to 20%.¹⁴

The 1970's and early 1980's saw the spread of more advanced computer numerical control (CNC) machines which incorporate a minicomputer into the machine control. The most important advantage of CNC is the potential it offers for creating and editing programs at the machine. CNC machines are also more flexible in interpreting various types of programming inputs and languages because their logic is resident in the software rather than the permanent wiring. In addition, CNC machines can be designed to monitor and report process status on the display screen. Up to the early 1970's, all machine controls were hard wired.¹⁵ In 1976, the full CNC concept emerged at the annual machine tool show.¹⁶ With the tremendously rapid decline in the costs of computer circuitry as well as the adaptation of machine tool features to the commercial

¹³ In 1973, shops with less than 100 employees representing 83% of the metalworking industry had 22% of the NC machines. (Noble, p.213 drawing on testimony in hearings at the Small Business Administration) In 1983, shops with less than 100 employees accounting for 42% of machine tools had 37% of the NC equipment. (13th American Machinist Inventory, pp.120,123)

¹⁴ "13th American Machinist Inventory," p.119.

¹⁵ 1986 NC/CIM Guidebook, p.40.

¹⁶ 1986 NC/CIM Guidebook, p.41.

market, CNC gained rapidly in acceptance. By 1982, CNC was found on almost all machines at the annual show.¹⁷ Small Japanese machines were especially popular because of their much lower price and better designed controls and Japanese machines took a very large part of the market for the biggest selling categories of NC machines such as machining centers.¹⁸ The low costs they achieved through large batch production of standardized models should be credited with a significant share of the diffusion of CNC to smaller shops outside the military sector.

By 1983, 10.9% of machine tools less than ten years old and 4.7% of all machine tools were NC or CNC.¹⁹ These statistics understate the importance of NC equipment in metalworking since NC machines cut metal a greater percentage of the time than conventional machines due to the reduction in set-up time, and because they are used for more critical, high value work. An indication of this is that 31% of the value of metalcutting machines shipped in 1979 was assignable to NC.²⁰

¹⁷ Harley Shaiken, Work Transformed, p.107.

¹⁸ Seymour Melman, Profits Without Production, (New York: Alfred A. Knopf, 1983) p.7.

¹⁹ "13th American Machinist Inventory," Nov. 1983, calculated from data on pp.120-21.

²⁰ Shaiken, pp.74,75. The 5% of the machine tool stock of a tractor plant in England that was NC in 1978 was responsible for 30% of machining output. (p.58)

A look at growth in the numbers of specific types of NC machine tools also helps in judging the importance of NC in the early 80's. As of 1983, the percentage of metalworking plants with NC turning machines, machining centers and NC milling machines (the three most common types of NC machine tools representing almost three quarters of the total NC population) reached 26%, 19% and 16% respectively.²¹ To put this in perspective, one third as many plants had NC turning equipment as had conventional turning equipment, and non NC machines were still ten times as common as NC machines.²² In the early 80's then, numerical control was spreading dramatically while expanding in its capabilities. The greater size and visibility of the NC machine tool market contributed in its own right to the focus upon the promise of the flexible, automatic factory of the future. Widening experience with NC machine tools also lent a feel of reality to discussion of more comprehensive forms of computer controlled manufacturing.

Numerical Control and Worker Participation

NC machining technology can affect work organization in different ways. It can be deployed so as to take advantage of worker skills and provide avenues for their

²¹ 13th American Machinist Inventory, p.117.

²² 13th American Machinist Inventory, p.114.

development, or it can be deployed to reduce the use of skill and narrow the scope of worker judgement. But design priorities of early NC researchers and the advertisements of early manufacturers made it clear that, from the beginning, the reduction of the skill and autonomy of the worker was one of the most important goals of those involved in NC. David Noble has described in detail the several unsuccessful efforts to commercialize a programming technique called record/playback which allowed the machinist to put the machine tool through the desired motions while having those motions recorded on magnetic tape or some other medium.²³ Record/playback dispensed with the need for an esoteric programming language requiring description of every motion in numerical form, as well as for the large computers needed for sophisticated programming. Noble shows how the potentials of this type of machine tool to put more modestly priced and easily learned methods of programmable control into the hands of firms with limited resources was never fully explored, not only because of the military emphasis on maximum sophistication, but because of the general philosophy of manufacturing management which aimed specifically at eliminating reliance on machinists' skills. Simpler forms of symbolic programming were also slow to develop because the military imposed a standard machine tool control system

²³ Noble, chapter 7, "The Road Not Taken."

and programming language on its contractors and NC suppliers which served their interest in making complex parts but which was difficult for machinists to learn.²⁴

The typical approach to the organization of NC machining has been to separate the job of programming from machine operation and, at least initially, to lower the qualifications and wage level for machine operators.²⁵ In many cases, new people without machining experience were hired as NC machine operators. This reflected management expectations that NC machine tool operation should be essentially automatic and require very little skill.

These expectations were mostly disappointed. Part programs rarely arrive on the shop floor without bugs in them, and operators often must take the initiative to correct them. Other problems arising on the shop floor call for the exercise of experienced judgement as well. Materials are uneven in quality, tools break and wear down, overheating occurs, tolerances are exceeded, machines malfunction, etc. All of this has been apparent to the operators who, if they were already skilled machinists, saw NC as an excuse to lower wages while actually extending the range of skills required. Often, NC machinists have been asked to run two or three machines at once increasing resentment still further. Where worker-management friction

²⁴ Noble, pp.203-210.

²⁵ The following four paragraphs draw heavily on Shaiken, chapter 4.

became great enough to cause workers to withhold their cooperation, as well as where inexperienced workers were used, quality problems and machine downtime were excessive.²⁶ Because the higher cost of NC machines demands that their utilization rate be kept high, management was sometimes forced to go back to using skilled machinists and to paying them the pre-NC wage or even more.

The will of management to make NC machining conform to its image of automation requiring a minimum of skilled intervention and control was starkly revealed in battles fought over who would be allowed to create and edit machine programs. Machinists who were accustomed to planning their own work methods naturally perceived programming as falling within the bounds of their trade. When they saw errors in programs which they could learn to correct themselves, they did so. This, after all, was far more efficient than sending program tapes back to programmers in an office and waiting for them to make the corrections. Both novice and experienced machinists sometimes took a keen interest in learning how to do the complete programming job themselves. In most cases, however, management actually attempted to prevent machinists from writing or editing programs, often resorting to locking the machines against programming inputs by the operators and sometimes restricting access to

²⁶ David A. Buchanan and David A. Boddy, Organizations in the Computer Age: Technological Imperatives and Strategic Choice (Aldershot, Hampshire, England: Gower) pp.55-6.

instructional materials. This resulted in delays, resentment, and lower machine utilization rates. Ironically, programmers have often consulted informally with machinists to take advantage of their more intimate knowledge of the machining process. (It was discovered after some experience that it was easier to make programmers out of machinists than to train people with only a background in computers.²⁷)

Even where the NC machine operator has no input into programming, he or she performs a critical role in determining the efficiency and quality of NC machining through control of the "override switch." This switch allows the operator to vary the cutter speed specified in the program, usually to slow it down because of exceptionally hard spots in the material being machined, occasionally to speed it up when a job needs to be done quickly. But even this kind of simple worker control has been a focus of labor-management battles. Workers sometimes make a practice of regularly setting the override switch at seventy or eighty percent of the programmed speed, especially when they are at odds with management. Although it creates a serious risk of higher scrap rates and machine damage, management has locked the override switch in some cases. Management's hope is to eventually

²⁷ New Technologies and Training in Metalworking, (Washington D.C.: National Center for Productivity and Quality of Working Life, Summer 1978) p.41.

eliminate the need for an override switch through a technique called adaptive control which uses sensors to automatically adjust cutter speed. Development has been proceeding for many years but has generally produced devices which have been found too temperamental for shop conditions.²⁸ In sum, the willingness of managers to sacrifice efficiency and quality to prevent shop floor control of NC machine tools demonstrated (1) a determination to reduce dependence on worker skill in order to lower wages and increase control over production by reducing the traditional autonomy of machinists and (2) a belief that NC technology has the potential to eliminate the need for shop floor skill, at least after an initial period of adjustment and refinement.

But in one case, the difficulties of transition to NC technology spawned an experiment in expanded worker autonomy and participation. Initially, the NC machine tool installation at a GE aircraft engine plant in the mid sixties was an illustration of the widespread attempt to routinize and deskill machinists' jobs. But when worker resistance and unacceptably low machine utilization and quality levels were encountered, there was a search for new approaches.²⁹ In the experiment, 60 machinists were given

²⁸ See a discussion of difficulties in 1987 NC/CIM Guide (Cincinnati: Garder Publications, January 1987), pp.259-61.

²⁹ This case is described in Noble, chapter 11.

a high degree of control over their conditions of work. Foremen were eliminated, and leaders (selected by management) from among the machinists served as work organizers. Working under a production quota, they were given the opportunity to take responsibility for program debugging, tooling management, maintenance scheduling, and quality control, and to consult with staff departments to carry out these functions. Skeptical at first, the machinists' morale improved tremendously and neighboring machining departments pressured management to expand the program to them. In 1972, a visitor to the program from GM wrote a highly favorable report on it which may have contributed to the inspiration for the Tarrytown QWL program described in an earlier chapter.³⁰ Unfortunately, the program was eventually terminated against the wishes of the embittered workers, apparently because of management's (especially GE headquarters') desire to reassert and preserve the integrity of company work rules and pay scales to avoid the setting of a precedent that could be used to weaken managerial authority elsewhere in the corporation. Ironically, the program appeared to be a success from a financial point of view although no clear figures were ever produced.

Numerical control has, by and large, represented to management a way of extending the Tayloristic model of work

³⁰ Noble, pp.288-89.

organization, standardizing machinist jobs and removing decisions on work methods to the office. Yet NC does not inherently dictate a drastic reduction of worker participation and autonomy. As we have noted, where such a reduction has been the managerial goal, productivity and quality have often suffered. Moreover, there is a range of existing machine tool design alternatives and NC shop management practices which demonstrates that both enhanced and reduced worker participation can be associated with NC.

A range of design alternatives is presented in particular by CNC. CNC tools have made it much easier to do programming at the machine. Computer display screens can graphically depict both the part to be machined and the machining process, and allow the operator to create machine instructions using a language which is much closer to the way a machinist thinks. Some CNC programming software is interactive, systematically eliciting all the necessary inputs with questions. Another feature of some CNC tools is the ability to run one program while the operator works on the next. The trade magazine Modern Machine Shop concludes that shop floor programming "is constantly being improved upon and its rightful place in the industrial scene is yet to be fully decided."³¹ At the same time, some CNC machines are being designed to preclude operator programming, being geared instead to receiving instructions

³¹ 1987 N/C Guidebook, p.182.

from a central computer and/or in a less accessible universal machine tool language.

A comparative study of the use of CNC in 12 British and West German firms also reveals a range of work organization alternatives.³² German firms were found to make fewer formal distinctions between planning and execution and they use much more shop floor programming. In some cases, they rotated workers between the planning department and the shop floor.³³ British firms were similar to American firms in working to keep programming and machine operation separate. This difference was linked by the researchers to the character of apprenticeship programs. German engineers had had craft-worker experience and training before proceeding to more advanced engineering

³² This and the following paragraph is based on Arndt Sorge and Malcom Warner, Comparative Factory Organization: An Anglo-German Comparison of Management and Manpower in Manufacturing, (Hunts, England and Brookfield, Vermont: Gower, 1986) pp.150-163.

³³ However, a survey of works councils in 1100 West German metalworking firms found that CNC machines were usually programmed by someone other than the operator. The net impact of NC is somewhat unclear since the overall effect on skills was considered "negative" by 32% of the councils and "positive" by 42%. Still, the survey reported negative effects strongly outweighing positive ones by 60% to 5% for work pace, 40% to 8% for performance monitoring, 78% to 4% for psychological stress, and 55% to 12% for task variety. The survey was done by I G Metall, the German metalworking firm, and the results were translated and reported by Peter Unterweger in Robert U. Ayres et al., Robotics and Flexible Manufacturing Technology: Assessment, Impacts and Forecast, (Park Ridge, N.J.: Noyes Publications, 1985) pp.246-8.

work whereas British apprenticeships for "technicians" were completely distinct from those of workers.

The problems encountered with CNC in the plants studied were generally in traditional areas such as tooling and the setting of feed rates and cutter speeds. This motivated a tendency observed in both German firms and small English firms to increase the level of machining skills among operators and to further soften the distinctions between planning and operating. The German example and both the German and British experience serve to illustrate further that the decrease in worker autonomy associated with NC in the U.S. was not so much technically determined as much as it was a result of American managers' selective perception and exploitation of NC's potentials.

Robots

Like CNC machine tools, robots are programmable and therefore flexible, and can be used as components of larger, computer controlled systems. But robots make their own distinctive contribution to automation and serve in their own right as one of its symbols. Much of the increased focus on the potentials of manufacturing automation in the early eighties can be attributed to the explosive growth of the newly emerging robotics industry at that time.

The popular image of robots is of machines that mimic both the mental and physical behavior of humans.

Industrial robots, however, usually consist of a single arm mounted on a base which is stationary or which moves along a track. The arm has several joints, each allowing either rotational motion or a linear motion of extension and retraction. Combining motions at each of the joints, either simultaneously or in sequence, allows the end of the arm to move in a variety of ways to any point within a defined volume of space around the robot. At the end of the arm is attached a device for doing almost any kind of work --- for gripping and manipulating objects, for welding, for spray painting, for machining, or even for sensing and measuring. The robot, like the human arm, is a simple and elegant instrument for accomplishing complex motions. Sophisticated electronic control of the extent and direction of motion at each joint substitutes for complexity of physical configuration. Robots therefore cost less than comparably capable, dedicated automatic equipment. Most robots, however, perform work which was formerly done manually because the complexity of motion and the difficulty of precisely controlling workpiece position and dimension had heretofore made it resistant to mechanization. (The latter factor is an obstacle to robot use as well, although new robot sensor technology is beginning to overcome it.)

As of 1983, the distribution of robots by application was as follows:³⁴

TABLE 1. Distribution of Robots By Applications

welding (mostly spot welding)	35%
material handling (including, for example, packaging, stacking, and transport of parts to and from storage and other transport devices such as conveyors)	25%
machine loading	20%
painting, finishing	10%
assembly	3%
machining	2%
other	5%

The biggest change in the mix of robot uses being predicted in 1983 was an increase in the proportion devoted to assembly to 25% in 1990.³⁵ There were several problems to solve, however, before this could happen, including the simplification of complicated programming methods³⁶.

(Assembly involves motions which are relatively complex and therefore relatively complex programs.) Much improvement was also needed in internal control mechanisms and external sensors to make robot manipulations adaptive as well as gentle and dynamically accurate. When fitting parts

³⁴ Tech Tran Corporation, Industrial Robots: A Summary and Forecast, 2nd Ed. (Naperville, Illinois: Tech Tran Corporation, 1983) p.81.

³⁵ Prediction by Laura Conigliaro of Prudential-Bache Securities cited in "The Great Robot Race," Ward's Auto World, April 1982.

³⁶ "Robot Languages Developing," American Metal Market, Sept. 21, 1983, and "Comments" December 5, 1983.

together, a tiny difference in position can make a tremendous difference in the amount of resistance encountered, and small irregularities in parts need to be compensated for. To aid in assembly and other applications, much research is being devoted to vision systems which will give robots the ability to recognize and engage workpieces regardless of their orientation (as, for example, when they are jumbled together in a bin). This will allow robots to overcome the problem of irregular workpiece positioning and compensate for it somewhat as humans do.

The first commercial sale of robots occurred in 1961, but up to the early 70's, the use of robots could be characterized as mostly experimental.³⁷ Unimation, the pioneer firm in the field, still accounted for almost all robot sales from 1975 to 1977. Most of its sales were to the auto industry which was moving to robotic spot welding of auto bodies. (By 1980, 52% of body welding was done by robots.³⁸)

Publicity about robotics bloomed tremendously during the recession of the early 80's. The number of magazine articles on robots in the popular and general business

³⁷ Industrial Robots, p.90.

³⁸ Bruce T. Allen, "Microelectronics, Employment and Labour in the United States Automobile Industry," chapter IV in Susumu Watanabe, ed., Microelectronics, Automation and Employment in the Automobile Industry, (John Wiley, 1987) p.90.

press rose from only 3 in 1979 to 33 in 1982.³⁹ This coincided with a new stage of development for the robotics industry. The years 1979 to 1981 saw explosive sales growth averaging 65-70% per year.⁴⁰ A high water mark of enthusiasm was probably reached in 1982. In March of that year, the atmosphere at a major robotics conference was described as euphoric.⁴¹ Due in part to the recession, sales finally slowed in 1982, but still increased substantially to \$195 million, up from about \$150 million in 1981 and \$30 million in 1978. 1982 and 1983 projections for robot industry sales in 1990 were commonly set at about \$2 billion.

The new prospects in robotics brought a major change in industry structure. The share of the six leading companies dropped from 94-95% of robot sales in 1980 and 1981 to only 60% in 1983. During this period, many small startup companies entered the field, tripling the number of suppliers to about 50 between 1980 and 1982. Close on the heels of the small firms were several major diversified manufacturers. GE was the first of these to enter the

³⁹ These figures are the number of entries under robots in the Reader's Guide to Periodical Literature.

⁴⁰ Industrial Robots, p.8.

⁴¹ Laura Conigliaro, "Trends in the Robot Industry (Revisited): Where Are We Now?" in 13th International Symposium on Industrial Robots and Robots 7: Conference Proceedings, Applications Worldwide, vol. 1, April 17-21, 1983, Chicago, Illinois, (Dearborn, Michigan: Robotics International of SME) p.1-16.

market in 1981. By 1983, GE was joined by IBM, Westinghouse, Bendix, GM, United Technologies, Textron, and Allegheny International.⁴²

At the end of this burst of growth, however, the robot industry was still quite small --- in 1983, robot sales were equivalent to only about 5% of machine tool sales.⁴³ One relatively low set of estimates of the robot population had it growing from about 1700 at the end of 1978 to about 6,200 at the end of 1982. Other estimates placed the 1982 robot population closer to 8,000.⁴⁴ In 1983, robots were being used in 400 to 500 plants, but one third of the robots were in only 5 to 10 of these plants.⁴⁵ About 40% of robots (most of them welding robots) were being used by the automakers and their major suppliers.⁴⁶

The principal motivation for the installation of robots has been the reduction of labor costs in operations

⁴² Conigliaro, p.1-6.

⁴³ Recent Trends in Flexible Manufacturing, (United Nations, 1986) p.32.

⁴⁴ According to Industrial Robots, there were 6,200 robots at the end of 1982. Ward's Auto World in "The Great Robot Race" cites a figure of 4,500 for the beginning of 1982 which is roughly consistent with this estimate. Forbes ("Shakeout," July 16, 1984, p.70) said there were 7,000 robots in use in 1982. Harley Shaiken says there were about 8,000 robots "by 1982." Predicasts, cited in Allen, p.89, estimated the number of robots in 1980 to be 5093 which is roughly consistent with Shaiken's figure for 1982.

⁴⁵ Industrial Robots, p.79.

⁴⁶ Ibid., p.86.

formerly performed manually by unskilled and semi-skilled workers.⁴⁷ Since robots generally work at about the same pace as people⁴⁸ and are used for two shifts on average,⁴⁹ about two manual workers are replaced for each robot installed.⁵⁰ This displacement is moderated slightly by the need for technicians to maintain and program the robots. One of these skilled workers is needed for every six to ten manual workers replaced.⁵¹

Robots have apparently been quite cost effective in practice. The high initial cost of robots (about \$115,000 on average, including installation⁵²) has generally been considered a substantial barrier to their diffusion,⁵³ but investments in robots have been recovered in about two years on average.⁵⁴ Where robots have been used on at least two shifts, almost all users have been satisfied with

⁴⁷ Dorf, p.1-31; Shaiken, p.162; Industrial Robots, pp.92,93; Allen, p.87 (auto industry).

⁴⁸ Industrial Robots, p.56.

⁴⁹ Ibid., p.95.

⁵⁰ This is a commonly used rule of thumb for calculating worker displacement. Allen, pp.96,97.

⁵¹ Allen, p.97.

⁵² Industrial Robots, p.96.

⁵³ See, for example, Shaiken, p.167, and Richard C. Dorf, "Robotics and Automated Manufacturing Equipment Industry" in 13th International Symposium on Industrial Robots and Robots 7: Conference Proceedings; Applications Worldwide, vol.1, April 17-21, 1983, Chicago, Illinois, (Dearborn, Michigan: Robotics International of SME) p.1-37.

⁵⁴ Industrial Robots, p.95.

the savings realized.⁵⁵ Reliability problems have essentially been resolved for current robot uses. Downtime for repairs and maintenance has been averaging about 4%⁵⁶ and 2% is not uncommon.⁵⁷

Unlike CNC machine tools, robots have been well accepted by unions and shop floor workers.⁵⁸ Since robots were still few in number, there had been few jobs lost to them up to 1983, and the projected displacement of 100,000 to 200,000 workers by 1990 was expected to be absorbed by attrition, job reassignment, and retraining for robot technician jobs.⁵⁹ While highly skilled machinists fought the deskilling of their work by CNC machine tools, less skilled workers have generally seen in robotics new opportunities to upgrade their skills.⁶⁰ Robot programming is relatively accessible to lesser skilled workers since most of it is accomplished by recording the motions of the robot as it is put through its paces rather than by

⁵⁵ Ibid., pp.92,94.

⁵⁶ Ibid., p.56.

⁵⁷ Shaiken, p.164.

⁵⁸ Ibid., p.167.

⁵⁹ H. Allen Hunt and Timothy L. Hunt, Human Resource Implications of Robotics, (Kalamazoo: W.E. Upjohn Institute for Employment Research, 1983) p.xi.

⁶⁰ Industrial Robots, p.94; for the auto industry: Allen, p.100.

creating mathematical and symbolic instructions at a keyboard.⁶¹

With little threat of job loss, workers have also been able to appreciate the fact that a substantial proportion of robots have been used to eliminate dangerous and unpleasant jobs such as those in painting and the transporting of very hot or hazardous materials. Improving working conditions is another way that robots reduce labor costs since this reduces personnel turnover, liability for worker safety, wage premiums and concessions on work methods and pace.

While replacement of human workers by less expensive machines has been the overriding goal of robot users, other potential benefits of robot use have been attractive as well. It might be expected that chief among these would be the flexibility that robots are well known for and which makes them a part of the vision of the flexibly automated factory of the future. Robots are naturally best suited to intermediate production volumes and batch sizes.⁶² Where batch sizes are very small, manual methods may be more efficient because robot programming is too time consuming relative to processing time, and where production volumes are very large, more complex, dedicated machinery may be more cost effective because much higher production rates

⁶¹ Ibid., pp.33,34.

⁶² Ibid., p.55.

can be reached. Within a large intermediate zone, however, robots should be capable of making small batch production more economical relative to mass production and of making mass production compatible with increased product variety and responsiveness to shifts in the character of demand.

But in practice, these potentials have not by and large, been exploited.⁶³ Robots have replaced neither the dedicated machinery of mass production nor skilled workers involved in small batch production. Instead, they have been used to replace workers who "fill in the gaps" in continuous flow, line production, doing those jobs which are quite routine and largely machine paced, yet too expensive or impossible to mechanize conventionally.

The most important subsidiary purpose of using robots has been to achieve tighter control over the production process. Robots have been heavily advertised by manufacturers as controlling the pace of work. They work more steadily and predictably, eliminating much of the need for supervision and the threat of worker slowdowns. In some instances, greater steadiness has translated into a faster work pace, especially in machine loading and assembly.⁶⁴

Robots have also enhanced control over quality in some cases, primarily because of their consistency and

⁶³ Industrial Robots, pp.92,93; Dorf, p.1-31; Hunt and Hunt, p.12; Allen, pp.87,88 (auto industry).

⁶⁴ Industrial Robots, p.92.

accuracy.⁶⁵ Increased consistency in welding has allowed automakers to reduce the number of welds in autobodies because less allowance needs to be made for missed or faulty welds.⁶⁶ Robots not only allow tighter control, they demand it. They require consistency in materials and the dimensions of workpieces and this can result in improved quality. Finally, some robots with very advanced sensing systems contribute to the quality control function itself by performing automatic inspection.

Flexible Manufacturing Systems

When several CNC machine tools are linked by automatic material handling equipment and controlled and coordinated by a supervisory computer, they form systems which reach new levels of combined automation and flexibility. Such systems suddenly became more practical at the end of the 70's and beginning of the 80's due to advances in computers and were widely publicized as a new model of manufacturing efficiency.

Belief in the power and promise of computers in manufacturing was already decades old. But the new flexible machining systems of the 80's dealt a far more serious blow to the mass production paradigm of efficiency than NC machine tools or any other form of computerized

⁶⁵ Shaiken, p.163; Industrial Robots, p.94.

⁶⁶ Allen, p.91.

manufacturing ever had. The old paradigm had powered a drive to maximize the standardization of products to achieve scale efficiencies. But now the limitations to this strategy could be cheerfully confronted. Frequently, discussions of these systems called attention to the fact that 75% of all machined parts are produced in batches of 50 or less. A new sense of virtue became attached to the ideas of flexibility and small batch production and the old wisdom seemed turned on its head. Focus upon the computer intelligence that made flexible automation possible finally began to erode focus upon scale as the key to low cost production.

A precondition for the design of flexible systems is categorization of parts to be machined into families whose similarly sized and shaped members have similar machining requirements. Variables which may be important in the determination of part family parameters include fixture and tool requirements and the number, length, variety, and sequence of operations required. Flexible manufacturing systems vary widely in the degree of flexibility they provide which is determined by the boundaries of the families they are designed to accomodate. The greater the family member variety, the more versatility is demanded of the material handling equipment and machine tools and the more complex the computer control logic must be. On the other hand, the more similar are the operation sequences

required by members of a family, the easier it is to organize the movement of workpieces between machines.

It is customary to make a distinction between small and large systems, designating the former "manufacturing cells" and reserving the term "flexible manufacturing system" or "FMS" for the latter. In the most popular form of cell, a small number of machines, usually two or three, is clustered around a robot which is programmed to transfer parts from machine to machine in whatever sequence is required for each part type. In some cases, a single versatile CNC machine tool (such as a machining center) can constitute a manufacturing cell if it is equipped with an automatic loading device and an automatic tool changer and programmed to perform a series of operations on a variety of parts, essentially without human intervention.

There is a difference of opinion as to the relative flexibility of the cell and the FMS. According to two sources, the cell is suited for machining approximately 30 to 500 or 10 to 800 different parts while the FMS is suited for only 4 to 50 or 4 to 100 parts.⁶⁷ Another source,

⁶⁷ figures estimated by George Hutchinson cited in "Flexible Manufacturing Systems," Modern Material Handling, Sept. 7, 1982, p.57; figures from Kearney and Trecker Special Products Division, Manufacturing Systems Applications Workbook, (Milwaukee: Kearney and Trecker Corp., 1982) as cited in Steven M. Miller, "Industrial Robotics and Flexible Manufacturing Systems: An Overview" in Paul Kleindorfer ed., The Management of Productivity and Technology in Manufacturing, (New York and London: Plenum Press, 1985) pp.38-9.

taking the opposite position, states that one of the principal distinguishing characteristics of the cell as compared to the FMS is its restriction to a more narrowly defined family of parts.⁶⁸ The reasons for the differences in flexibility are left unexplained in all of these sources. One might suppose that a larger number of machines would provide more versatility and scheduling flexibility. On the other hand, as will be explained below, the complexity of larger systems can become enormous, limiting their theoretical potentials.⁶⁹

The average number of machine tools in an FMS is about seven, and about 65% of the machines they contain are machining centers.⁷⁰ Greater distances between machining

⁶⁸ 1987 NC/CIM Guide, p.217.

⁶⁹ Given the difference in viewpoints on the relation between system size and flexibility as well as the modest numerical differences in part variety that have been suggested, it is perhaps appropriate to question the degree to which system size determines flexibility and whether such distinctions might not be based more on a general philosophy or approach to design than on the objective shape of technical constraints. Modern Machine Shop further distinguishes cells from FMSs by saying that the objective of cell designers [note the subjective criterion] is not usually to enable long periods of unmanned operation and links this to more limited computer capacity for coordinating the flow of parts between machines and for storing a large variety of machining programs. (NC/CIM Guide, p.217) (A trend in newer FMSs toward greater part variety was linked to improved, more flexible programming. D. Kochan ed., CAM: Developments in Computer Integrated Manufacturing, Springer-Verlag, 1986, p.34, section coauthored by Merchant and Kochan) Others, however, see no important difference in sophistication of the control systems of cells and FMSs. (Miller, pp.36-7)

⁷⁰ These are the results of a survey of most of the existing FMSs in the U.S. Recent Trends, p.63.

stations and larger, heavier workpieces help make conveyors and remotely controlled carts the material handling equipment of choice for these systems.⁷¹ Workpieces in their fixtures are typically mounted on pallets which are automatically transferred from the conveyor or cart and clamped into position on the machine tools. The identity of each part is generally encoded on the pallet or the part itself. When a part enters a work station, the supervisory computer is signalled to download the correct machining program to the machine from its comprehensive store of all part programs. The tools needed for the part program are selected and installed by automatic tool changers.

In fully flexible systems, workpieces do not proceed to the various machines in a fixed sequence. There is usually more than one versatile CNC machine that can perform any given operation, and different part designs may require different routes through the system. A computer monitors the progress of operations and individually dispatches each workpiece to successive stations according to decision rules that take account of machine loads.

In-process inventories are usually accommodated by entrance and exit queues at each machine or spurs off the main transport path. Extra inventories and tools may be

⁷¹ Out of 217 FMS in the U.S., Japan, and Europe, 160 use electronically or rail guided vehicles, 50 use conveyors and 7 use both. Economic Commission for Europe, Geneva, Recent Trends in Flexible Manufacturing (New York: United Nations, 1986) p.62.

stored at a remote location and retrieved when needed by automatic transport.

Malfunctions in the FMS can be automatically corrected, either through changing of tools or rerouting of workpieces, and errors can be automatically recorded and reported. Computer terminals can be set up to give operators directions (some tasks such as loading of workpieces on pallets may still need to be performed manually) and to give both workers and managers status reports as desired.

Another managerial computer may be linked hierarchically to the computer controlling the FMS. It may be used to do material requirements planning, timing orders from suppliers and dictating scheduling priorities for the FMS according to the pattern of customer orders and inventory levels.

It is not possible to know precisely how many FMSs there are in the U.S. or how rapidly their numbers have grown. Estimates vary greatly depending on the degree of flexibility and automaticity required to qualify as an FMS. Very few systems would have all of the features just described, especially as regards flexibility. The few figures available on the growth of FMSs suggest that they first emerged out of a strictly experimental or showpiece stage at the end of the 70's. One source counts only one FMS in 1967, 7 in 1977, and then a sharp rise to 25 in

1980.⁷² However, Harley Shaiken stated in his 1984 book that there were "probably fewer than 12 of the most advanced systems in operation."⁷³ This essentially agrees with another estimate of 15 FMS in 1984 which is based on a "strict definition" of FMS. The same survey counted 46 FMSs using a looser definition.⁷⁴ Information collected by the European Economic Commission for Europe through 1985 identified approximately 87 FMSs in the U.S.⁷⁵ (and 350 FMSs worldwide)⁷⁶, but some of these may be considered manufacturing cells rather than full systems. (A rough estimate of manufacturing cells for 1985 is 525.)⁷⁷

⁷² M. E. Merchant, "The Importance of Flexible Manufacturing Systems to the Realization of Full Computer-integrated Manufacturing," (paper presented at the UN/ECE Seminar on Flexible Manufacturing Systems: Design and Applications, Sofia, Bulgaria, September 24-28, 1984) cited in Recent Trends, p.28.

⁷³ Shaiken, p.154.

⁷⁴ The survey was done by Cross and Trecker, a major machine tool firm and supplier of FMSs. The loose definition estimate agrees with an estimate of 47 FMSs at p.viii in A Competitive Assessment of the U.S. Flexible Manufacturing Systems Industry, U.S. Dept. of Commerce, Washington D.C., 1985. Both sources were cited in Recent Trends, p.28.

⁷⁵ Recent Trends, pp.231-243.

⁷⁶ Recent Trends, p.27.

⁷⁷ "FMS: The Drive Toward Cells," Manufacturing Engineering, Aug. 1985, cited in Recent Trends, p.24.

The FMS and Scheduling

Simply put, the general managerial view is that FMSs, at least potentially, solve all scheduling problems within their boundaries. They are understood to optimize the timing of machining operations and workpiece transport in an environment of multiple part types and machines, eliminating the need for human production scheduling and control on a detailed level. Even when machine breakdowns or other problems occur, the computer control system is supposed to take it in stride and simply recalculate optimal routings. The optimizing capabilities of the FMS are seen as allowing managers the freedom of posing any scheduling problem they wish for the system, either by changing the criteria by which computer scheduling decisions are made, or by feeding workpieces into the FMS in random order and in widely varying lot sizes.⁷⁸ Because set-up times are vastly reduced, parts do not have to be transported and machined as members of a batch. Instead, the FMS can schedule workpieces on a far more precise,

⁷⁸ "Once the FMS is available, neither volume requirement nor lot size should be a major factor in whether a part or part variation should or should not be run on it." NC/CIM Guide, p.225. In fact, there is some mediation between production needs and the actual pattern of inputs into the FMS. The FMS supervisory computer receives data on production needs and generates a production plan that will adjust the mix of inputs so that demands on the system's machines will be reasonably balanced. The system's computer will signal operators to load and launch parts into the system in a certain order. (Miller in Kleindorfer ed.; Mikell P. Groover and Emory W. Zimmer, Jr., Computer Aided Design and Manufacturing, Englewood Cliffs, N.J., Prentice-Hall, 1984)

individual basis, dispatching each one to successive work stations according to the machine load situation of the moment.

What has just been described is a kind of absolute scheduling efficiency. One way of summarizing such a hypothetical state of scheduling perfection is to say that no workpiece waits to be processed and no machine waits for the arrival of workpieces.⁷⁹ Where neither machine nor workpiece waits for the other, total processing time from raw material to finished product would be at a minimum (allowing quick response to demand) and machine utilization rates would be near 100%. Moreover, work-in-process inventories would also be at a minimum. This is what very large scale "flow line" production approximates and what the FMS is supposed to bring to small and medium batch production.

In order to show how far the typical batch production practice is from the ideal approachable by the FMS, it is often stated that parts typically spend 95% of the time in transport or waiting for a machine, and of the remaining time spent on the machine, 70% is devoted to set-up.⁸⁰ Thus, if waiting time and set-up time were virtually eliminated, the decrease in total processing time or "lead

⁷⁹ This proposition abstracts from the problem of sequencing work so as to minimize set-up time to meet due dates.

⁸⁰ for example, in A Competitive Assessment of the U.S. Flexible Manufacturing Systems Industry, p.9 and NC/CIM Guide, p.208 where Cincinnati Milacron is cited as the source.

time" could be tremendous. One of the most famous cases of lead time reduction by an FMS was at GE's locomotive plant where motor frames previously machined in 16 days were finished in 16 hours. Average lead time reduction in FMSs has been estimated at 40%⁸¹ (although this figure as well as similar figures cited below are almost certainly based on a small number of successful cases and do not convey either the degree of success or failure possible.) Out of 31 FMSs throughout the world for which one study was able to obtain figures, 26 had more than a 50% reduction in lead time.⁸²

The reduction by FMSs of the length of time that workpieces spend waiting between operations reduces not only lead time but work-in-progress inventories as well. Even the inventories of FMS inputs and outputs may be reduced since shortened lead times mean that less stock is needed to absorb unpredicted increases in demand. Also, the FMS's ability to produce efficiently in very small quantities because of reduced set-up time means that stocks of FMS outputs can be economically replenished to lower levels at relatively short intervals. The reduction of inventories has, in fact, been one of the principal benefits of FMSs rivalling labor savings as the chief source of reduced costs. Frequently, however, no

⁸¹ Competitive Assessment of the FMS Industry, p.10.

⁸² Recent Trends, p.125.

quantitative estimate of savings in this area enters into the investment justification process.⁸³ The current, practical potential for inventory reduction has been cited as generally around 50% or higher.⁸⁴

The third direct result of perfect scheduling efficiency (assuming sufficient market demand) is continuous machine operation.⁸⁵ Benchmark estimates of typical machine utilization rates for stand-alone machines are imprecise. Computerized manufacturing expert Thomas Gunn says that even NC machines "often" cut metal only 10% to 30% of the time.⁸⁶ Thomas Shifo, a (White Sundstrand) machine tool company executive, estimates that both NC and conventional machines "normally" operate less than 50% of the time.⁸⁷ A leading computer aided manufacturing text

⁸³ Ibid., p.118.

⁸⁴ "The Impact of New Technology," The FMS Magazine, July 1985 as cited in Recent Trends, p.125. An FMS at White Sundstrand was reported as reducing work-in-progress inventories 40%. Modern Materials Handling, Sept. 7, 1982, p.67.

⁸⁵ Decreased demand and production rates would affect the utilization rates of conventional equipment before those of CNC equipment in most shops with both types because the latter is more efficient.

⁸⁶ Thomas G. Gunn, "The Mechanization and Design of Manufacturing," Scientific American, September, 1982, p.126.

⁸⁷ Shaiken, p.143. Modern Machine Shop claims that conventional machine tool utilization rates average 20% but that NC utilization rates of 75% are "not unusual." 1986 NC/CIM Guide, p.30.

agrees, saying most NC machines "may operate at about 50% or less."⁸⁸

An FMS improves machine utilization in two ways. First, set-up is drastically reduced by having all of the necessary machining programs and tools ready for quick automatic loading and by having workpieces mounted on fixtures and pallets before they enter the FMS so that this task does not have to be performed while the workpiece is on the machine. Second, machines are rarely kept waiting for work transport because there are usually short queues at each machine which are kept stocked by the one-by-one dispatch of workpieces. Parts do not wait to be transported to the next machine as part of a batch. According to Gunn, the advantages of the FMS result in utilization rates "as high as" 50-90%.⁸⁹ Shifo and the manufacturing text cited above say that FMS utilization rates run "as high as" 70-80% and 85% respectively.⁹⁰ However, the most careful and thorough study of U.S. FMSs found an average utilization rate of only 52%.⁹¹

The effect of increased utilization rates is usually augmented by the addition of a second or third shift of

⁸⁸ Groover and Zimmers, p.458.

⁸⁹ Gunn, p.126.

⁹⁰ Shaiken, p.143; Groover and Zimmers, p.458.

⁹¹ Ramchandran Jaikumar, "Postindustrial Manufacturing," Harvard Business Review, November-December 1986, p.70.

operation. This is because there is pressure to recoup the large investment FMS entails and because reduction in labor requirements makes late shifts easier to staff. The result of extra shifts and more intensive utilization is a need for fewer machines. Thus FMSs generally incorporate only about 1/4 to 1/2 the number of machines they replace or even fewer.⁹²

The benefit of needing fewer machines is, however, largely cancelled (except for the savings in floor space) by the higher costs of the machine tools and the equipment needed for their integration. Hardware costs for an FMS are roughly the same as for the set of conventional or NC machines to which it is an alternative.⁹³ And this does not take into account the relatively high costs of planning and installation for which figures are unavailable.⁹⁴

FMSs are often portrayed as the factory of the future in microcosm. As such, the idea that FMSs are approaching the definitive, optimal solution to scheduling problems is by implication extended to the envisioned automation of the whole factory. The substantial benefits of improved

⁹² Recent Trends, p.124; Shaiken, p.146.

⁹³ Recent Trends, p.115; Robert T. Lund and John A. Hansen, Connected Machines, Disconnected Jobs: Technology and Work in the Next Decade, Center for Policy Alternatives, Massachusetts Institute of Technology, 1983, p.26.

⁹⁴ Steven M. Miller, "Industrial Robotics and Flexible Manufacturing Systems: An Overview," p.42.

scheduling and automated work flow that have been realized in some cases have lent credence to this view.

But there have been limits to FMS scheduling and machine loading capabilities that should be pointed out. First, because the number and complexity of possible solutions to scheduling and routing problems increases very quickly as the number of machines in the system increases, FMSs have been limited to a size that is quite modest relative to automated systems with fixed routing of workpieces (such as transfer lines) and to plant operations as a whole.⁹⁵ They control only a small span of operations, being composed on average of only seven machine tools. In fact, as islands of automation in a conventional factory they can create bottlenecks downstream in the production process negating much of the benefit of shortened throughput time and reduced inventories within the FMS.

Second, the complexity of internal scheduling problems has forced the adoption of clearly suboptimal scheduling decision criteria. The character of the complexity was well expressed by an FMS specialist at Caterpillar Tractor:

If one wants to develop a sincere feeling of inadequacy, one should attempt an in depth analysis of a

⁹⁵ Paul G. Ranky, Computer Integrated Manufacturing: An Introduction With Case Studies, (Englewood Cliffs N.J.: Prentice-Hall International, 1986) pp.383-4; Stephen Miller, "Industrial Robotics and Flexible Manufacturing Systems: An Overview," in Paul R. Kleindorfer, ed., The Management of Productivity and Technology in Manufacturing, (New York and London: Plenum Press, 1985) p.35.

system of this complexity. One rapidly progresses from the tried and true conventional methods of cycle time, load/unload times and material handling analysis, to intuition and bad advice from onlookers, and into pure guesswork. The number of variables and possibilities are overwhelming. In short, more sophisticated planning and management tools are required.⁹⁶

Corroborating this characterization of the situation, two flexible manufacturing researchers describe the behavior of an FMS as "highly nonintuitive" and incomprehensible using conventional modes of analysis.⁹⁷ A John Deere executive has complained that the programming complexities of rescheduling to adjust for problems like machine breakdown sometimes threaten to bring the whole plant to a halt.⁹⁸

Such complexity has been coped with through simplification of machine loading criteria. The manager of the Manufacturing Systems Division of Cincinnati Milacron says that control programs have generally been designed to route parts so as to minimize the number of tool changes and that research is now being aimed at expanding software capabilities to take account of need priorities for

⁹⁶ Robert A. Berdine as quoted by Harley Shaiken, p.148.

⁹⁷ Stephen R. Rosenthal and Margaret B. W. Graham, "Institutional Aspects of Process Procurement for Flexible Machining Systems," (Manufacturing Roundtable, Boston University) as cited in James B. Pond, Flexible Manufacturing Systems in U.S. Falter as Operators Seek to Overcome Planning, Utilization Deficiencies," Metalworking News. Oct. 12, 1987, p.18.

⁹⁸ James Cook, "Back to Simplicity," Forbes, Aug. 25, 1986.

parts.⁹⁹ A survey of FMS users found that meeting due dates was more important to them than any other scheduling criteria including keeping machine utilization rates high and inventories low. Yet, as the authors of the survey study point out, very little FMS scheduling literature has been concerned so far with the problem of meeting due dates.¹⁰⁰ Thus the perception that control of work flows within the FMS is a model for total manufacturing plant control requires that formidable problems in developing adequate control logic and technology be discounted.

The FMS and Quality Control

Improved quality is another benefit usually cited for FMS technology as it is for all computerized manufacturing technology. But quality does not appear to have been an important factor motivating FMS installations. This is not surprising since the costs of failures in quality control have not been adequately captured by conventional accounting systems as was explained in the last chapter.

⁹⁹ Jeffrey Zygmunt, "Flexible Doesn't Always Fly," Across the Board, December, 1986, pp.55-56.

¹⁰⁰ Milton L. Smith et al., "Characteristics of U.S. Flexible Manufacturing Systems --- A Survey," in K. E. Stecke and R. Suri eds., Proceedings of the Second ORSA/TIMS Conference on Flexible Manufacturing Systems: Operations Research Models and Applications (Amsterdam: Elsevier Science Publishers B.V., 1986) pp.482,484.

Neither is it surprising that data on quality improvement due to FMSs is scarce.¹⁰¹

There is reason to question, however, how far the FMS makes a contribution to quality beyond that of the individual CNC machines it incorporates.¹⁰² The FMS is, first and foremost, a means of automating work flows between machines and its significance lies in its potential for combining scheduling flexibility with higher levels of automation and productivity. The role of quality control within the FMS is then primarily to enable the system to operate continuously without being threatened by shutdowns for checking, adjusting and troubleshooting. The capabilities of automatic quality control techniques developed for the FMS may well end up making their own contribution to quality, but so far they appear mostly to aim at serving the need for automaticity that FMSs have created in the first place.

Many advanced FMSs incorporate as one of their work

¹⁰¹ In a study of 13 advanced computerized manufacturing systems (not necessarily FMS) quality benefits were not usually thoroughly studied in the planning stages although quality improved in all cases. Paul Quantz, in CAD/CAM Manufacturing Strategies, (Pensauken, N.J.: Auerbach Publishers, 1984), p.8.

¹⁰² It is perhaps significant that a textbook on computerized manufacturing lists improved quality as a benefit of NC technology but not of the FMS. (Groover and Zimmers, pp.149-50, 458-9)

stations a coordinate measuring machine (CMM)¹⁰³ which is essentially a specially anchored platform which supports a workpiece to be measured and a robot-like device designed for precise rectilinear movements. This robot can be programmed to contact various points on a workpiece with a probe, registering the precise coordinates at each contact. The coordinate measuring machine holds the three dimensional "blueprint" of the workpiece in its computer memory, compares it to the readings, and analyzes the results. Though there is a potential for CMM measurements to be automatically translated into corrective action at the trouble-causing machine tool, this capability seems to lie in the future since discussions of the CMM's role in FMSs speak of display of results at terminals and their relay to the supervisory computer where they can be further analyzed.¹⁰⁴ It would then be left to the system operators to take appropriate action.

¹⁰³ In the survey by Smith et al., 8 out of 19 FMSs were found to have inspection stations. Most inspection machines used by FMSs are CMMs.

¹⁰⁴ Paul G. Ranky, The Design and Operation of FMS, (IFS (Publications) Ltd. and North-Holland Pub. Co., 1983) p.49; E. T. Treywin, "Automatic Inspection and Control of Products As Part of a Flexible Manufacturing System," in H. S. Warnecke and R. Steinhilper, eds., Flexible Manufacturing Systems, (IFS (Publications) Ltd., UK, Springer Verlag, 1985). Modern Machine Shop's NC/CIM Guide at page 258, describes a system for cylindrical parts where a laser gauging system can transmit a message to the machine to change tools in cases where the part is oversize.

Adaptive control is another commonly used technique in FMSs which plays a role in quality control. It is designed to keep the rate of metal removal high while avoiding premature tool wear or tool failure by adjusting cutter speeds and workpiece feed rates to machining conditions as measured by variables such as torque or tool deflection. As mentioned above, the development of adaptive control has encountered severe difficulties. The fundamental problem is that "despite the weight of brainpower and the vast research effort applied, our understanding of the simplest of metal cutting operations has advanced very little in forty years."¹⁰⁵ The form of adaptive control which would be the most useful for quality control is in-process measurement and compensation for tool wear. Unfortunately, although "much work has been devoted to this area....progress has been slight --- and very slow."¹⁰⁶ Practical forms of adaptive control have the more modest goal of keeping the torque limited to a rather unscientifically chosen safe level to avoid risk of tool failure and prolong tool life. The time of tool failure cannot be predicted for an individual tool. It can happen

¹⁰⁵ Peter F. McGoldrick, "The Adaptive Control of Machining in Flexible Manufacturing Systems," in A. Raouf and S. I. Ahmad, eds., Flexible Manufacturing: Recent Developments in FMS, Robotics, CAD/CAM, CIM, (Elsevier, 1985) p.135.

¹⁰⁶ Ibid.

without warning, quite early or late, often as a result of no assignable cause.¹⁰⁷

The ultimate goal of FMS machining control research is to eliminate the human link in quality control through automatic correction of problems before they produce defects. To achieve this, a way is needed to measure a part either while it is being machined or very quickly after each operation is completed but before the part leaves the machine. Immediate feedback to the machine's controller would allow adjustments to be made during machining or enable an additional corrective cut to be made. This type of control has already been achieved in the relatively simple case of cylindrical parts, but is unlikely to be achieved in the foreseeable future for prismatic (flat surfaced) parts.¹⁰⁸ While automatic quality control technology struggles to keep up with the ambitions of total FMS automation, the efficiency of some FMSs has suffered. The Allis-Chalmers system had to be shut down every sixth part to allow for manual inspection with down time at 50% to 80% for some of the key

¹⁰⁷ McGoldrick, p.138.

¹⁰⁸ Treywin, pp.191-92; NC/CIM Guide, pp.257-58; McGoldrick, p.139. Part alignment and dimension checks can be made while the part is still on the machine by a device called a surface sensing probe which can be mounted by the tool changer in the machine tool spindle. Use of these probes is considered essential for FMS efficiency but entails additional steps in the production process which is presumable why Modern Machine Shop counsels only sparing use of these probes for dimensional measurement. NC/CIM Guide p.258.

machines.¹⁰⁹ Hughes Aircraft experienced difficulties with variances between the 9 machines in its system resulting in frequent need for manual positioning and checking.¹¹⁰

The FMS and Worker Participation

Reduced labor requirements have been one of the major motivations for installing FMSs.¹¹¹ This is expected since FMSs are not only more highly automated than the equipment they replace, they are in part the product of a philosophy of engineering design which places intrinsic value upon the elimination of the need for workers. Advises Modern Machine Shop, "everything must happen automatically. Let the computers do the work; minimize human intervention."¹¹²

Labor savings have often been even greater than anticipated and tend to increase with time.¹¹³ One source places the labor reduction potential at around 30% or higher, but much larger reductions have been realized. In a sample of 20 FMSs in various countries, the total number

¹⁰⁹ Shaiken, pp.149-50.

¹¹⁰ Zygmunt, p.53.

¹¹¹ Recent Trends, p.112; Donald Gerwin and Jean Claude Tavondeau, "Uncertainty and the Innovation Process for Computer Integrated Manufacturing Systems: Four Case Studies," (unpublished mimeo, March 1981) as cited in Shaiken, p.143.

¹¹² NC/CIM Guide, p.231.

¹¹³ Recent Trends, p.117.

of operators was 290 compared to 1,140 for the former or alternative conventional systems.¹¹⁴

The managerial focus on labor reduction potentials is coupled very naturally with the goal of reducing the skill levels of machine operators as well as worker participation in decisions concerning conditions and methods of work. Many people argue that computerized manufacturing technology creates jobs for people with higher skills, either within the same firm or in the wider labor market, and that it mostly eliminates extremely routine and hazardous work. Whether or not this is true for the economy as a whole, managers presiding over the computerization of metal machining appear to have concentrated mainly on the new opportunities to reduce the need for skill.

Case studies of the character of work for those who operate FMSs have painted a dismal picture. When workers at the Allis-Chalmers system were interviewed in depth and filled out an extensive questionnaire, most were found to be dissatisfied with most aspects of their jobs and almost all felt their skills were underutilized. Compared to a large sample of workers representative of American workers generally, they scored below average in their sense of challenge, chance for promotion and autonomy. FMS operation was divided into four separate jobs: repairman,

¹¹⁴ Recent Trends pp.124,125.

operator, loader, and tool setter, with only repairmen expressing above average job satisfaction.¹¹⁵ At another heavy equipment producer, the FMS displaced skilled machinists and replaced them with narrowly trained operators, creating a much clearer separation of planning and execution:

Once the FMS went on line, management prevented workers from making process improvements by encouraging them not to make any changes. "If it ain't broke, don't fix it" became the watch word. The system had four operators per shift, each of whom was responsible for checking gauges, changing hydraulic fluid and parts like drill bits, and making simple diagnoses when something went wrong. These tasks, as specified by management, were very procedural, and no operator had the discretion to change procedures. If anything, the complexity of the FMS forced operators to stick more rigidly to procedure than they did at the stand-alone CNC machining centers.¹¹⁶

Still another study of an FMS described the nature of the character of work this way:

The older jobs on conventional machines had a high degree of autonomy, discretion, freedom of movement, responsibility, group interaction and control. The new jobs on the automated machines required, in contrast, the performance of prescribed functions including limited judgement, some conceptual skills and abstract reasoning, carried out over long periods of monitoring vigilance in isolation. The key job characteristic in the eyes of management was "responsible behavior" that safeguarded the investment in the machines and the product.¹¹⁷

¹¹⁵ Melvin Blumberg and Donald Gerwin, "Coping With Advanced Manufacturing Technology," (paper, School of Business Administration, University of Wisconsin, December 1980) as cited in Shaiken, p.151.

¹¹⁶ Jaikumar, p.71.

¹¹⁷ from an unpublished study at the MIT Center for Policy Alternatives cited by Lund and Hansen, p.65

A broad survey of experience with the most advanced computerized manufacturing technologies (including FMSs) in several of the largest diversified manufacturing firms suggests that these case studies are representative. It concluded that there is a tendency for the new technology to reduce the number of moderately skilled jobs relative to the number of unskilled and highly skilled jobs. In the context of machining, this meant a widening gap between the few highly skilled maintenance, programming and set-up jobs and the routinized operator jobs.¹¹⁸

While FMS operator tasks are less skilled and more routine than traditional machining tasks, they have also been noted for subjecting workers to a new kind of stress due to the fact that much of the work consists in monitoring the system and reacting to malfunctions. Workers will experience long periods of relative inactivity punctuated by short periods of crisis in which they will be called upon to quickly solve an often unpredictable problem in a very complex system in order to avoid extremely expensive down time. Worker inefficiencies become much more apparent when they hold up the flow of an FMS than they do in traditional batch manufacturing. When workers are not very skilled or well trained, anxiety can be especially great. One study of eight FMSs observed that the high level of automation decreased both worker and

¹¹⁸ Lund and Hansen, pp.66-70.

supervisor involvement in the machining process leading to insufficient practice in troubleshooting.¹¹⁹ Thus managers appear to be underestimating, as they did with stand-alone NC machine tools, the degree of skill needed even for jobs which have been simplified as far as possible.

Yet there is something of a consensus among expert observers that the use of FMSs as well as other computerized manufacturing technology does not require the deskilling and routinization of factory floor jobs.¹²⁰ Some recommend that FMS operation be organized so that workers are involved in programming, set-up, quality control, and maintenance. In addition, the worker's role in monitoring and maintaining system efficiency can be facilitated and more fully acknowledged by providing ready computer terminal access to information on various aspects of system status and function.¹²¹

The implications of FMS technology can also be evaluated by considering it within a wider context. Some of those who have studied the impact of computer technology on the character of work and organizational structure have focussed on key process industries such as oil refining,

¹¹⁹ Rosenthal and Graham as described in Pond, p.18.

¹²⁰ See, for example, the computer conference comments of Steve Miller, Jan Helling, John Ettlie and Peter Unterweger in Robert U. Ayres et al., Robotics and Flexible Manufacturing Technologies: Assessment, Impacts and Forecast, (Park Ridge N.J.: Noyes Publications, 1985) pp.206-7.

¹²¹ Recent Trends, p.134.

paper making and chemicals because they are the most advanced in their degree of computer control. They observe a profound change in the nature of work which is making Tayloristic principles obsolete, even irrelevant. In particular, they see that work no longer involves execution of tasks in the physical sense at all but monitoring, problem solving and learning --- activities for which the calculation or supervisory enforcement of standards of worker output is extremely problematic.¹²² Furthermore, because automatic, computer controlled systems are so tightly integrated, workers must be aware of interrelations between various parts of the system and between their duties and those of others. They must therefore be able to communicate well with other workers and take advantage of the computer's ability to generate information on operation of the whole system and its components. In this setting, many of the control functions of supervisory and managerial personnel are absorbed by the computer software and the workers who interact with it on the spot in solving

¹²² See Larry Hirschhorn, Beyond Mechanization: Work and Technology in a Postindustrial Age, (Cambridge, Mass.: The MIT Press, 1984) especially chapter 7, "Beyond Simple Labor". Chapter 9, "Technology, Consciousness, and Developmental Work," discusses in detail the psychological process of learning in the new environment. Instead of a return to the traditional type of skill denoted by the term craftsmanship, new automated systems force those who operate them to continually reconceptualize the interrelationships of events within them as when malfunctions unforeseen by engineers occur and characteristics of inputs and outputs change. Lund and Hansen (p.74) also see a strong tendency for new technology to require conceptual and creative thinking for workers.

problems. Thus some researchers would see the FMS as ultimately conducive to greater worker participation and the organization of autonomous work groups.¹²³ Still, given the evidence concerning actual FMS practice, it must be concluded that the new generation of flexible automation represented for managers the minimization of the scope for worker participation in decision-making and liberation from the need for worker skill.

FMS Flexibility

Flexibility is, of course, one of the distinguishing features of the FMS and one of the most important reasons for installing it. It is important to remember, however, that it is not flexibility per se which is new --- for traditional batch manufacturing was even more flexible --- it is a high degree of flexibility combined with the

¹²³ The recent work of Shoshana Zuboff exploring the potential of computerized systems to make information accessible to workers who then have the tools to begin spontaneously taking over management functions is described in Daniel Goleman, "Why Managers Resist Machines: Automation lets low-level workers make decisions. Many executives don't like that." New York Times, Feb. 7, 1988. Larry Hirschhorn describes experiments that have been carried out mostly in process industries in which workers were organized into self governing groups and paid salaries on the basis of number of skills learned. Functions of supervisors are usually scaled down and redefined. Beyond Mechanization, chapters 11 and 12. Some evidence is given in Richard Walton and Gerald Susman, "People Policies for the New Machines," (Harvard Business Review, March-April 1987) that at least some of the recent FMS installations have been accompanied by broadening of skills and formation of autonomous work groups. Most of the 16 implementers of advanced technology in the study had moved in this direction and 4 of the 16 had installed an FMS.

intensive machine utilization and rapid throughput of flow line production.

There are several kinds of flexibility, the benefits of which are often strategic in nature and usually difficult to measure. In one sense, flexibility means that an FMS does not need to be scrapped or completely rebuilt as does dedicated equipment when there is a major product design change. Thus an FMS can be a hedge against market instabilities although the heavy investment involved tends to increase risk. Another type of shorter run flexibility allows easy introduction of slightly revised part designs or new part designs that share basic characteristics of the family of parts for which an FMS is designed. The more broadly defined the part family, the more potential there is for new part introduction. Some FMSs produce only 4 or 5 part types and others several hundred. A third type of flexibility is the ability to freely change the proportions in which the various parts are produced and to process them in any order or lot size as production needs or customer demand dictate.

FMS Success and Failure

The overall success of FMSs in the early 80's is very difficult to judge since information useful for evaluation, especially on failures,¹²⁴ is quite scarce and success can

¹²⁴ Recent Trends, p.123

(and should) be measured according to many criteria. Part of the problem, well publicized in press treatments of FMSs, is that conventional accounting systems fail to capture many FMS benefits. The value of flexibility and reduced lead time in meeting a varied and changing demand, and of improved quality for increased customer satisfaction and reduced quality control costs are often unknown. On the other hand, the size of the investment in items such as planning, training, auxiliary equipment and adaptation of plant infrastructure and managerial practices is often underestimated.¹²⁵

In the early 1980's, FMS technology was still quite young, but it had captured the imagination of management elites as the wave of the future, essential for competing with Japan. The Japanese were then perceived as overtaking the U.S. in automation. But despite the fact that some of the most dramatic examples of the FMS were Japanese, computer technology was considered America's home turf and a source of comparative advantage that could be drawn upon to overcome the Japanese challenge.¹²⁶ A little later, in the mid 1980's, there began to appear hints of failure and stories of flexibility overestimated, misunderstood and underutilized. Experts at Ingersoll Engineers, Inc.

¹²⁵ Recent Trends, pp.115-16.

¹²⁶ For this sense of American advantage in automation technology see "The Speedup in Automation," Business Week, Aug. 3, 1981.

claimed that 50% of FMSs fail "according to many estimates"¹²⁷ and that "many FMS installed at present are an economic disaster."¹²⁸ Such judgements finally began to penetrate the mood reflected in the business press which had been filled with exclusively with reports of dramatic success. As a result, the Japanese example in this area also began to appear as a standard for success and a guide to reform.

Computer Aided Design

While the development of computer control was making flexibly automated manufacturing possible in the metalworking industries, computer aided design and engineering (CAD and CAE) were also emerging. Though we are mainly concerned with management of the production process, CAD must be included in this discussion because it is a core element in the overall vision of the factory of the future as it developed in the early 80's. Its computers use much of the same numerical data on parts to manipulate graphic designs that other computers use to

¹²⁷ Donald B. Ewaldz, Director, Ingersoll Engineers, Rockford, IL, "Keys to Implementing Flexible Manufacturing Systems," article 3.1.7, in CAD/CAM Management Strategies, (Pennsauken, NJ: Auerbach Publishers, 1984) p.5.

¹²⁸ P. Dempsey (Chief Executive of Ingersoll Engineers), "Why Designers of FMS Ought to Consider Integration," FMS Magazine, April 1984 as cited in Recent Trends, p.86. Ramchandran Jaikumar says that many FMSs performed worse than the conventional equipment they replaced. p.69.

control robots and machine tools, thus raising the possibility of direct translation of design ideas into machine motions. In the early 80's, the term "CAD/CAM" (CAM standing for computer aided manufacturing) was widely popularized as a label for the first efforts to link computer aided design with computerized manufacturing as well as the idea that these links would become very close as software and computing capabilities increased. Though CAM is commonly defined to include all of the technologies so far discussed in this chapter, CAD/CAM systems as the term is used in the industrial marketplace do not include actual machine tools, robots and FMSs. They are design systems with some capabilities related to manufacturing such as part programming, process planning and tool design.¹²⁹

The first computer aided design systems were demonstrated in the early and mid 60's and development of appropriately capable computers enabled the first commercial introductions of complete systems in the late 60's and early 70's.¹³⁰ These systems were very costly (over \$1 million)¹³¹ and the market for CAD/CAM in the early 70's was still, from the perspective of the 80's,

¹²⁹ One book on CAD/CAM barely mentions even these types of capabilities. Stuart Hubbard, CAD/CAM: Applications for Business, (Phoenix: Oryx Press, 1985).

¹³⁰ Hubbard, pp.3-7.

¹³¹ Ibid.

"virtually nonexistent."¹³² The appearance of moderately priced systems in the late 70's¹³³ brought total CAD/CAM sales to \$.7 billion in 1980 and \$1.6 billion in 1983.¹³⁴ The growth potential suddenly seemed tremendous as the number of firms marketing computer aided engineering and CAD/CAM systems went from 20 in 1981 to over 100 by the end of 1983¹³⁵ A marketing study projected the number of CAD/CAM systems in use to rise from under 5,000 in 1981 to 190,000 in 1995 and total 1995 sales to reach \$10 billion.¹³⁶

CAD facilitates both the creation of initial drawings and the production of final blueprints as well as performing many kinds of graphical manipulation and analysis in between. Drawings done freehand on the computer screen can be transformed into precisely shaped and dimensioned designs with the addition of a few

¹³² John Teresko, "CAD/CAM Goes to Work," Industry Week, Feb. 7, 1983, p.46. The industry was characterized as less than a decade old in 1983 in "Solid Growth Seen Ahead for Automation Products," American Metal Market/Metalworking News, Oct. 10, 1983.

¹³³ 1987 NC/CIM Guide, p.196.

¹³⁴ Mark Sfiligoj, "Competition, Technology Seen Vastly Changing Manufacturing," American Metal Market/Metalworking News (hereafter AMM/MN) Nov. 28, 1983. Software costs were between \$15,000 and "well over \$100,000" by the start of 1984. Bruce Vernyi, "Cost, Tough Times Deter Buys of CAD/CAM Systems," AMM/MN Jan. 30, 1984, (concerns small "contract shops").

¹³⁵ Sfiligoj.

¹³⁶ Teresko; "Solid Growth Seen Ahead".

numerical inputs. Once a design is complete, simple computer commands allow the CAD user to study it from almost any perspective, without having to do more drawings. Two dimensional representations of an object are automatically integrated to form a three dimensional image on the screen which can be rotated and viewed from any angle. Scale can be changed at will. The object can be sliced through at any point and the resulting cross section generated. Geometric transformations can be carried out such as the creation of a mirror image of the original design. When a physical drawing or blueprint is desired, it is simply printed out automatically, eliminating the bulk of human drafting work. Drawing details may be printed selectively to produce a clearer view of certain aspects of a design.

Once a design seems satisfactory, it can be functionally tested in several ways without having to build a prototype. For example, deformations resulting from specified physical stresses can be simulated and patterns of thermal and electrical conductivity due to part shape and the characteristics of materials can be graphically represented. The mating of different parts can be tested on the screen as well. Analysis of complex objects can be aided by highlighting their different components in various colors. Some systems can even show how several connected parts will function together or simulate the flow of gases and liquids through a part.

CAD systems also aid design with their data storage and access capabilities in at least two important ways. First, out of what may be many thousands of existing part designs, the computer can retrieve the ones with characteristics similar to the part being designed. It has been found that in many companies, only 20% of the parts initially thought to require a new design actually need one. Of the remaining parts, half could be built using an existing design and half could be built with an edited version of an existing design.¹³⁷ Second, an easily accessed data base on characteristics and costs of materials can increase the quality, speed, and cost-sensitivity of design.

CAD also has the potential to radically improve the flow of design information throughout the firm. Confusion due to design changes and the time it causes to be spent on tracking down and checking information are reduced since new designs replace records of the old ones at the time of revision and are instantly available to anyone with a computer terminal. A single, up-to-date, universally accessible information source also improves the design process itself. Engineers working on interrelated parts of a project can keep abreast of each others work and join efforts with colleagues in other computer-linked plants. Process engineers can see product designs as they evolve,

¹³⁷ Gunn.

allowing them to begin process designs earlier and to make suggestions to the product engineers about ways to increase manufacturability. People on the factory floor can also contribute their perspective to the design process.¹³⁸

Reported productivity gains from CAD have been enormous. A 3 or 3 and 1/2 fold increase in productivity is widely considered easily and commonly achievable.¹³⁹ 20 to 1 and 30 to 1 improvements have not been unusual.¹⁴⁰ The ease of drawing, manipulating, and testing designs and the ability to exploit existing designs means that many more design alternatives can be considered. CAD should therefore improve design quality as well as shortening design lead times. One example of CAD productivity which is relatively modest in statistical terms but which is nevertheless impressive because of the complexity and scale of the design task involved is the reduction of total

¹³⁸ Harley Shaiken, however, has noticed a tendency in some places for CAD to alienate designers from the shop floor. Despite increased means for communication, designers may be tempted to rely on the design optimization capabilities of the computer and forgo consultation with shop floor personnel. Also, since the routine aspects of design are automated, a designer is confronted with design decisions at a much faster rate, disrupting the subtle interplay of drawing and the slow maturation of design ideas. Shaiken, pp.222-27.

¹³⁹ Gunn; Daniel F. McCosh "CAD Comes of Age," Ward's Auto World; Shaiken, p.221.

¹⁴⁰ Shaiken, p.221.

design time for one car model at GM from 24 weeks to 14 weeks.¹⁴¹

As the name implies, CAD/CAM systems are supposed to link design with manufacturing. The comprehensive and integrated numerical description of a part created by CAD is useful for the design of tools and fixtures and the programming of NC machines used to make the part, as well as for programming robots and other material handling devices that will manipulate and transport the part. Programming may be conceptually aided by simulation of the motions of robots, machine tools and other equipment. If programming and tool designs already exist for parts that are similar to the one being worked on, they may be retrieved and edited by computer just as the part designs themselves are.

Another component of CAM less directly related to CAD is the use of the computer to plan the sequencing of operations on a part. This may be as simple as planning the routing of a part to various factory work stations based on processing plans for previously made, similar parts, or may involve a complex simulation of the progress of a variety of parts through a flexible manufacturing cell or system. Researchers are trying to create software that will be able to generate optimal processing plans for a part given information on manufacturing facilities.

¹⁴¹ Gunn, p.121.

The dream of CAD/CAM users is to automate the link between CAD and CAM, eliminating the need to have skilled people interpret design information in order to formulate process plans and program manufacturing equipment. But the integrated use of CAD with CAM had not yet developed very far as of early 1983. Such integration was still in the "early planning stage" at most firms with both CAD and CAM¹⁴² and, as an executive at Pratt and Whitney said a year later, "a company applying [CAD/CAM] to ten percent of its designs today is way ahead of the field."¹⁴³

Computerized manufacturing expert M. Eugene Merchant stated in 1983 that the most important problem waiting for solution in the field of factory automation was "the integration of geometric modeling and design of products with the rest of the system." This link had essentially only been achieved in the design and manufacture of printed circuit boards and appeared substantially more difficult to achieve for mechanical products. Merchant predicted that the ability to fully integrate CAD and CAM was still five years away.¹⁴⁴

CNC machine tool programming in particular still requires human judgement and knowledge of materials and

¹⁴² Teresko, p.47.

¹⁴³ William C. Skinner, Executive Vice President, Pratt and Whitney, "Don't Neglect Design in Automating a Plant," AMM/MN, Jan. 16, 1984.

¹⁴⁴ J. Russell Kraus, "Integrated mfg. 5-yrs away," AMM/MN, Sept. 19, 1983.

machining techniques. Says Modern Machine Shop, "the full marriage of part design and NC parts programming has been virtually limited to specialized and relatively small scale applications such as turning, punch press work, and mold and die work."¹⁴⁵ Even where NC programs cannot be automatically generated from part designs, however, CAD can speed up the programmer's work. Ingersoll Milling Machine Company, for example, reported a 300% increase in part programming productivity.¹⁴⁶

The rise of CAD in the early 80's played a vital role in crystallizing and completing the vision of "computer integrated manufacturing" (CIM), a term that gained wide currency in the early 80's as a name for the unified computer coordination and control of the entire manufacturing firm. Traditionally, engineering and manufacturing departments accomplished their tasks sequentially and largely in mutual isolation. Engineers would assume the right to determine product specifications and leave manufacturing personnel to figure out how to meet them, giving them little opportunity to seek design changes based on manufacturing difficulties. CAD/CAM promised to get rid of this rigid and sometimes conflictual arrangement. However, the new computer integration of engineering and manufacturing could be looked at in

¹⁴⁵ NC/CIM Guide, p.203.

¹⁴⁶ Teresko, p.45.

different ways. It is possible to focus on the ability of the computer to make decision-making less compartmentalized and more participatory by providing ready access to information accross hierarchical and departmental boundaries. But far more powerful in management's mind has been the image of command and control that CIM creates in which managerial directives are translated without delay or distortion into a million coordinated actions of a huge manufacturing apparatus.

The old Tayloristic image of the manufacturing organization as a machine was being reborn in the early 80's in a more seductive form. This time, the machine would be real. It seemed to some that within the century, mmanufacturing would go the way of agriculture, reducing manufacturing employment to less than 5 percent of the workforce. Only a small group of highly skilled engineers, maintenance technicians, and executives would remain. Unions would become "the VFW's of tomorrow."¹⁴⁷ But the manufacturing division would not be taken for granted as in the past and left to crank out the goods while more dynamic arenas of financial, legal, and marketing competition absorbed all the attention of top management. The new

¹⁴⁷ William H. Slautterback, chairman of the advanced technical committee of Computer Aided Manufacturing International, (a nonprofit organization devoted to furthering cooperative research and development activities of firms with interests in CAD and CAM) as cited in Mark Sfiligoj, "Competition, Technology Seen Vastly Changing Manufacturing," AMM/MN, Nov. 28, 1983.

manufacturing machine would be a flexible, strategic tool responding quickly to creative visualizations of products to fill suddenly appearing market niches. The manufacturing executive would be drawn back to the factory albeit in mediated form on the computer screen. This seemed to be the image a CIM expert had in mind when he predicted that "the people operating and running Donkey Kong or Pac Man today will be running (the) companies (of) tomorrow."¹⁴⁸

¹⁴⁸ Ibid.

REVIEW

THE FOUR PATHS OF REFORM AND THE TAYLORISTIC TRADITION

In the first chapter, we looked at the Tayloristic tradition in American industrial management and how developments since Taylor's time in technology, bureaucratic control and labor-management relations all served largely to extend and reinforce this tradition. In the next chapter, we will look at the Japanese model of manufacturing management as it was articulated in American management literature beginning in 1980. What is the relationship between the Tayloristic and Japanese models and the four avenues of manufacturing reform explored in the last four chapters? In brief, the answer is that all four of them either challenged the Tayloristic model or pushed its application into new domains, sometimes both at once, and that each of these paths of reform had its counterpart element within the Japanese model which seemed to confirm its visions and realize its goals. Up to the time of the Japanese challenge in the 80's, the four paths of reform had developed almost entirely independently of each other. But under the influence of the Japanese model, they were combined into a coherent reconceptualization of the manufacturing process and how it should be managed.

The heart of the original Taylor system was the separation of planning from execution and the use of scientific, experimental method (1) to formulate comprehensively detailed, optimal work methods and (2) to provide the objective productivity standards considered the key to formulating pay incentives to motivate workers. In broader terms, the Taylor tradition asserted the self sufficiency of the engineer in determining the best way to do things and saw the restriction of workers to the execution phase of work as the best way to harness worker energies. The ideal, of course, was never entirely achieved in practice. Wherever managers and engineers could not anticipate problems or analytically grasp the production process in all of its details, workers' skill and judgement were relied upon.

Each of the four avenues of manufacturing reform had important implications for how far the planning aspects of work could and should be limited to the upper reaches of a hierarchical manufacturing organization. The dream of the flexibly automated plant, for example, carried the Tayloristic vision to its extreme, holding out the possibility of virtually eliminating the human execution of task (and its supervision) altogether and replacing it with mechanical execution of task. No longer would there be any room for failure to separate planning from execution and the resulting dependence on workers to make up for the gaps and mistakes in engineering and process planning. Total

automation would force engineers to anticipate almost all possible problems and devise automatic means of correcting them.

Not only would engineering responsibility for execution of task become complete, much of the former domain of planning would itself be automated. The manual scheduling methods of conventional manufacturing would disappear along with the elaborate shop floor record-keeping systems that supported them. They would be replaced by the logic contained in FMS control software. Quality control planning was also expected to be largely absorbed by the domain of process engineering through use of automatic inspection (eventually to approach 100%) coupled with automatic process adjustment. The integration of computer aided design with computer aided manufacturing even threatened to do away with most process planning making it nearly an automatic byproduct of design.

The reality, impressive as it was, lagged far behind the dream. In practice, severe limits to the new technology's automatic scheduling and quality control capabilities call into question the viability of futuristic visions of total factory automation. There is also evidence that the design of operator jobs associated with the most advanced forms of flexible automation has not taken adequate account of the need for human problem-solving skill in getting the new systems to run productively. In the early 80's, however, none of this had

much damping effect upon belief in the imminent realization of the completely computerized factory of the future.

Worker participation experiments and the Quality of Work Life movement pulled managerial ideology in an opposite direction, directly challenging the traditional paradigm. They challenged most strongly the assumption that worker motivation is best secured through extrinsic monetary rewards without involving workers in the planning aspects of work. The leaders in participatory work reform saw two basic reasons for the failure of the conventional system to motivate workers. First, compensation had never been put on a genuinely scientific or objective basis, and arbitrary, unilateral demands by management (eg. speedups) had built up worker distrust of management and produced bitter conflict that cut deeply into productivity. Second, motivation was related to intrinsic as well as extrinsic rewards of work, in particular, scope for the exercise of skill and opportunity to gain a sense of respect, status, and participation within the immediate work group and the larger authority structure of the firm.

Another basic assumption of the Tayloristic tradition challenged by the Quality of Work Life movement was that managers and engineers could plan production so comprehensively that worker judgement and problem-solving were unnecessary. Worker participation programs revealed that workers' intimate involvement with production processes enabled them to solve significant problems. They

strengthened the perception that "the worker knows her/his job best," a contrast to the view that industrial engineers should be able to optimize methods through research without substantial or continuing input from the worker.

The contradictions between the visions of computerized automation and worker participation were flat and unequivocal. While a balance between the values of automation and participation might be abstractly conceivable, neither vision offered a principle of mediation or concept of integration. A kind of middle ground, however, was held by the independent visions of scheduling and quality control reform. These two reform programs did not focus on automation or participation as values in themselves. But in pursuing better control over the timing of production activities and better control of product characteristics, they developed approaches that had substantial but relatively subtle implications for participation and automation. Both scheduling and quality control are arenas in which there is tension over the degree to which there should be separation of planning and execution but in which the solutions proposed have been framed in terms of how well they solve specific scheduling and quality problems. Thus, the MRP "crusades" and the leading quality experts' critical perspective on the evolution of the quality control function offer both support and challenge to the Tayloristic manufacturing paradigm but do so in their own distinctive terms.

Material Requirements Planning (MRP) was clearly an attempt to centralize planning capacity and control, thus supporting the conventional Tayloristic manufacturing model. Scheduling, or, more broadly, production control was an area of manufacturing which had resisted to a substantial extent, attempts at rationalization and management through imposition of a hierarchical chain of command. Lower level personnel (not necessarily workers but certainly their immediate supervisors) typically had to supplement the orders coming from above with their own judgement about work priorities. Frequently, the stated work priorities were out of date and production goals unrealistic. People had to rely on experience and informal communication networks to discover which orders were needed when and how badly. The essential problem was the complexity of the manufacturing environment --- typically, there were scores or hundreds of product variants with hundreds or thousands of components, each of which must be manufactured in several steps or purchased from a supplier. The production control and scheduling function attempts to bring components together in time for assembly and shipment of the final product to the customer without incurring excessive expenses in stockpiling supplies. All kinds of production and delivery delays and changes in customer demand disturb original schedules, and adjustments are normally carried out through a combination of ad hoc expediting and a rippling of information through the

informal network. MRP is designed to replace the confusion of this piecemeal and reactive communication system with rapid computer computation and transmission of all of the myriad consequences to the schedule of each production delay and demand shift. No longer do factory floor personnel have to second guess the formal schedule. They have only to follow it since it accurately reflects real, current requirements throughout the production system.

Experience with MRP, however, revealed that the timing and coordination of manufacturing suboperations in an environment of uncertainty was more complex and harder to exert completely rationalized control over than was originally thought. It turned out that there were a large number of considerations entering into the determination of work priorities which had to be carefully balanced according to the situation. Even if much of the logic of decision could be simulated by the computer, no computer generated schedule could be entirely trusted. A particularly acute problem was that the computer could not be programmed to determine when it would be best to disrupt the production process and switch jobs to accommodate new priorities and when it would be best to resist adapting to changed priorities to maintain stability and order on the shop floor.

With maturity of the MRP movement came the realization that MRP, in order to be effective, must be regarded not as a way of generating orders for the human organization to

execute but as a tool of an organization which is still ultimately responsible for scheduling decisions. It came to be recognized that in order to elicit the cooperation needed to make the system function, the many people using it had to be thoroughly educated to its methods and purposes, and that the logic of the computer programming had to be transparent so people could combine the computer's capacity for computation with their own judgement. MRP, then, was quite compatible with conventional Taylorism as it was originally conceived, but its users ended up demonstrating limits to the Tayloristic model and the need to develop employee knowledge of how the production system as a whole is coordinated.

Quality control is, in part, an engineering profession. But it is a relatively young branch of engineering and one that plays a special role vis-a-vis the more established engineering groups in the firm. It has been charged with searching out and controlling exactly those aspects of manufacturing which other engineers do not or cannot control. For this reason, quality control is not in a good position to assert the power of engineers to plan processes in such complete detail that workers can be confined to routine execution of task. Nevertheless, the history of the quality control function shows a repeated tendency, especially in the earlier years, to overemphasize aspects of quality control which are least threatening to

engineers' and managers' monopoly on planning in the conventionally organized manufacturing firm.

The first type of organization for quality control conformed quite well with the ideas of Taylor. A central inspection department was set up to screen the output of the production department with a workforce of inspectors whose tasks were as rationalized and routine as those of production workers. In this arrangement, the quality and production planning functions were divided from each other, echoing Taylor's proposed system of functional foremen, each separately and independently responsible for a different aspect of production. Tension was created, however, between the inspection and production departments, the latter pushing to keep to the schedule and maximize output, and the former causing delays by preventing shipment of defectives and subtracting them from output. But the advantage of this system for those wishing to preserve the Tayloristic mode of control was that compensation methods and productivity standards could be kept free of ambiguity. The absence of complex quality considerations in the work of the production department supported the illusion or pretense of complete managerial specification of task (or, what amounts to the same thing, complete and uniform worker knowledge of work methods) which allowed managers to focus narrowly on the speed of workers and machines and the number of units they produced. In other words, the inspection department form of quality

control allowed production managers to avoid confronting quality problems and kept inspectors focussed on the symptoms of production process lapses rather than their causes.

After WWII, quality control began a gradual integration into the activities of the production department, enabling it to take on a more diagnostic function. The establishment of the quality control profession in the late 40's was in large part based on the rapid diffusion of statistical process control, a technique for monitoring and analyzing variations in processes and investigating their sources. By its nature, it was most effectively applied by people directly engaged in the production process, but the rush to implement statistical control largely met with failure on the shop floor.

The reasons were ironic. In the conventionally managed firm, it was assumed that simple execution of task as defined by management was sufficient to prevent defectives. Managers therefore attributed most problems to lack of worker motivation and reacted to them by pressuring and exhorting workers to be more diligent. In the absence of managerial study of problem sources, the workers were left to exercise initiative in solving problems on their own. SPC, although it was an investigative tool, was introduced as a more mechanical way of making decisions about when to adjust processes. Workers saw it as a usurpation of their skill, and an added job burden. Both

workers and supervisors, furthermore, could not trust and did not fully understand statistical techniques, seeing a conflict between being told to control process variations through the taking of samples, and being held responsible for meeting specifications on each individual product.

The failure of SPC to take root on the shop floor went nearly unremarked in the literature of the quality control profession, but quality control engineers were more concerned in the 40's and 50's about establishing and promoting the new statistical techniques as the symbol and basis of their own professional skills. Their success, as reflected in growing staff departments and status, seemed to negate any sense of failure to diffuse their techniques. Thus quality control tended to range itself alongside the other engineering functions, diluting its potential to bring shop floor initiative and problem-solving to bear on flaws in the production process for which the industrial, manufacturing, and product engineers are responsible.

The intense interest generated by reliability analysis in the late 50's was another development which focussed quality control on the power of engineers to control quality without having to elicit the participation of production personnel. Then, in the 60's, there emerged the "zero defects" movement which brought the focus back to the factory floor. It provided a system for collection of worker suggestions for correction of defect causing conditions, but it mainly emphasized the ability of workers

to eliminate all defects through increased attention and diligence. Yet as Juran and Deming pointed out, the vast majority of defects have nothing to do with worker motivation. Thus zero defects, while it was a start toward recognizing the role worker participation could play in quality control, was mostly a distraction from the real issues and essentially supported the managerial tendency to blame workers for defects, leaving belief in the Tayloristic notion of separation of planning and control virtually untouched.

The continuing tendency of quality control managers to focus on types of quality control which are least threatening to the conventional Tayloristic system such as post-process inspection, motivational programs and specialized engineering techniques, served as point of departure for development of a program of reform by leading authorities in the field. This program conceived quality control as a system for analyzing and correcting problems caused by flaws in the production process; a system in which most employees and departments would have their own specific share of responsibility and increased scope for exercising initiative.

Juran and Feigenbaum emphasized the need for progressive management to recognize the important impact that all departments -- production, sales, manufacturing engineering, product engineering, purchasing, personnel, etc. -- have on quality, as well as the need to assign

quality related responsibilities to each of them to be integrated into their ordinary work. The quality control department, they said, did not have the resources or the continuing direct involvement in operations needed to solve quality problems on its own. Nor could the quality function be fulfilled simply by having the quality control department play a policing role and "force" other departments to meet quality objectives. Cooperation would not be forthcoming unless top management gave each department a clear conception of what it must do to meet those objectives and incentives to do it. The role of the quality control department in a system of widely distributed responsibility would be to audit and evaluate the quality dimension of activities throughout the firm and to lead in proposing quality initiatives.

The quality control department would also serve as a source of expertise and training for other departments, each of which would need to learn the special techniques most useful for its particular work. Skills and responsibilities would need to be diffused not only through many departments but to all levels of the organizational hierarchy. Juran and Deming were strong advocates of teaching at least basic statistical and problem solving methods to the lowest level employees. In Deming's distilled vision, statistical techniques themselves were pitted against the traditional authority structure of the firm. Statistics represented to him the discovery of the

causes of defects through scientific investigation in which workers could participate. The traditional authority system represented the attempt to coerce workers into compliance with quality standards in disregard of the need to identify the causes of defects and whether workers or systemic factors were to blame.

Thus, quality control brought a critical perspective to the production process. It did not assume the sufficiency of engineering specifications and managerial instructions. Rather, it saw the manufacturing environment as one of continuously changing conditions and emerging problems whose complexity required the skilled and coordinated actions of all personnel at all levels of the hierarchy.

This view was reflected in proposals for new forms of cost accounting. Conventional cost accounting allowed the deficiencies of the production process to go unchallenged by focussing on the relation between total output and total costs or total output and the costs of various inputs such as labor hours or materials. In the background, was the implicit assumption that the manner of conversion of inputs into outputs was not an important problem, only the rate or intensity at which the conversion was accomplished. Quality cost accounting, on the other hand, was designed to measure the resources used up by activities which result from systemic deficiencies such as the production and

reworking of defective products, the sorting of good products from bad, and warranty repairs.

To conclude, in the 1970's in the field of quality control, it is probably fair to say that most quality control managers continued to emphasize forms of quality control that did not challenge conventional management institutions. Yet some of the most prominent writers in the quality control profession developed proposals that recognized the ineffectiveness of maximizing the separation of planning and execution in a complex environment where goals are not simple quantitative ones (such as maximizing the rate of production) and where there is a constant stream of problems requiring on site investigation and response.

We have just looked at four paths of reform in relation to the traditional Tayloristic separation of planning and execution. Tayloristic control of work is closely linked in the traditional manufacturing paradigm with the ideal of mass production of standardized products. Mass production is, in turn, associated with the traditional insulation of manufacturing control from short run shifts in the character of market demand. If a single standard product is being continuously produced, the only adjustment to market conditions that manufacturing need make is in the overall rate of production. Of course, the typical manufacturing business intermittently produces many

different products and product variations and must undergo considerably more complex adaptations to changing market conditions. But the conventional manufacturing paradigm has still guided managers toward maximizing the standardization of products and the scale of production and minimizing the frequency and complexity of responses to the market.

Three of the four paths of reform contributed strongly toward eroding the traditional focus on mass production as an ideal and toward increasing awareness of the feasibility and desirability of closely linking manufacturing control to the market. They helped, as a result, to bring manufacturing back into the sphere of business strategy and top management concern. New, computerized manufacturing technologies did the most in this regard because they were seen as potentially destroying the original efficiency rationale for mass production. They made it possible to increase product variety and tailor products more closely to customer preferences. Beyond this, they allowed rapid changes in the product mix and drastic reduction of the lead time and expense involved in introducing new designs.

MRP promised to bring the complexity of small and medium batch production under rationalized control. This enabled coordination of production plans with sales and financial plans, and made it possible to quickly and efficiently phase in production of new products or rearrange priorities on the factory floor in response to

demand shifts. Lead times for customers could also be shortened and made more predictable.

The agenda for progressive quality control included expanding the quality control function beyond the bounds of meeting product specifications to evaluating specifications in terms of their impact on the functional adequacy and lifetime expense of product use in the field. Results of field research would be used to target quality control efforts in the factory and to link quality control to marketing strategy.

When managers began to learn about Japanese manufacturing techniques, the implications of the four paths of manufacturing reform for the Tayloristic, mass production paradigm of manufacturing became more apparent and coherent. The images and concepts of Japanese manufacturing that we will explore in the next chapter provided a holistic vision of flexibility and efficiency, combining innovations in worker participation, programmable automation, quality control and production and delivery scheduling. Without Japanese market success and the vision of manufacturing it brought in its wake, American managers undoubtedly would have remained in the old framework of thought much longer, making piecemeal concessions to its inadequacies in practice, and only slowly coming to perceive the interconnections and larger implications of the four avenues of reform.

CHAPTER SEVEN
THE AMERICAN DISCOVERY OF JAPANESE APPROACHES
TO MANUFACTURING MANAGEMENT

Crystallization of Consensus on the Reasons
for Failure and the Need to
Learn from the Japanese

1980 was the year in which general business opinion crystallized around the idea that American managerial methods and institutions needed fundamental, rapid reform and that Japanese management was fundamentally superior. Far more seriously than ever before in the twentieth century, business was charged with, and charged itself with, a general failure to serve its function in organizing production to meet contemporary standards of efficiency and technological innovation. And for the first time in this century, the managerial practices of a foreign nation came to be generally perceived as a model for American management. Ezra Vogel's book Japan As Number 1, published in 1979, was designed to shake Americans from their complacency. In the introduction it was noted that Americans still showed little sense of need to learn from

Japan except in matters of culture and the arts.¹ By late 1980 and early 1981 the tide of interest in how the Japanese organize their practical affairs was running so high as to provoke warnings of faddism and simplistic imitation. In 1981, technical study tours to Japan had become common. Japan Air Lines alone planned 50 such tours for 1981 in contrast to two years earlier when "this sort of thing never happened."² The explosion of interest in Japanese management was clearly registered in the Business Periodical Index:

TABLE 2. PUBLICATIONS ON JAPANESE MANAGEMENT

Year (Aug.-July)	Number of Articles Appearing Under the Heading "Management---Japan"
77-78	10
78-79	9
79-80	8
80-81	20
81-82	47
82-83	43

Between the summers of 1980 and 1981, a new consensus on the need for managerial reform was both reflected and strengthened by a series of major cover stories and special reports in the general business press: "The Reindustrialization of America" Business Week, June 30,

¹ Ezra Vogel, Japan As Number 1: Lessons for America (Cambridge: Harvard University Press, 1979; Harper and Row, Colophon Books, 1980), p.4.

² New York Times, Sept. 3, 1981, p.44.

1980; "Managing Our Way To Economic Decline," Harvard Business Review, July-August, 1980; "The U.S. Productivity Crisis," Newsweek September 8, 1980; "Overhauling America's Business Management," New York Times Magazine, January 4, 1981; "How Japan Does It," Time, March 30, 1981; "The New Industrial Relations," Business Week, May 11, 1981, and "Working Smarter," a series in Fortune running from June 15, 1981 through August 24, 1981. What do these early diagnoses of the managerial crisis have to say about the reasons for American failure and Japanese success?

The first Business Week article, a special issue report nearly 90 pages in length (including advertisements) faulted management first of all for lacking the entrepreneurial spirit and long term view needed to allocate sufficient resources to R & D and updated equipment. Second, it identified the need to turn around adversarial labor-management relations, largely by building on existing quality-of work-life experiments that give shop floor workers more control over their conditions and methods of work while promising increased flexibility (relaxed work rules), productivity, and quality in return. Little mention was made of Japan except as regards the necessity to develop an analogous national consensus on the need to increase productivity.

Business Week also elaborated upon the ideas of Robert Hayes who with William Abernathy wrote "Managing Our Way To

Economic Decline," for the Harvard Business Review.³ This was perhaps the first important indictment of American managerial techniques as the primary source of America's general competitive decline. It was written by two prominent professors of business administration at the Harvard Business School, one of them (Hayes) a former director of its international senior managers' program. The article appeared to be based on a growing and substantial body of opinion among European, Japanese and American executives and was later chosen unanimously by the HBR editors and an independent panel (a rare event) as the best article to appear that year in the Harvard Business Review.⁴

Hayes and Abernathy criticized the American preoccupation with short term financial results for causing a lack of willingness to invest in new technology. They went further, linking this to an overreliance on quantitative financial and marketing analysis to make investment decisions. Business schools, they said, were guilty of producing graduates that were too narrowly

³ Apparently, this was a very influential article. Hayes was also relied upon in the New York Times article (by Steve Lohr) and the Newsweek article listed above. Hayes was also interviewed for U.S. News and World Report: "Major Cause of Business Problems: Poor Managers," December 8, 1980, pp.69-71. Hayes and Abernathy published two columns based on their HBR article in the New York Times, "Economic Sceme: Management Minus Invention," August 20, p.D2, and "Economic Scene: Results Now: Pay Later?" August 22, p.D2.

⁴ "Letter From the Editor," Harvard Business Review, Jan.-Feb., 1981.

trained in quantitative analysis and too credulous about its powers. Corporations, they said, were guilty of promoting too many people with purely legal, financial or marketing backgrounds into top management positions to the detriment of those with production experience. The result was that managers, conceiving of themselves as all-purpose (highly mobile) business professionals, attempted to run their businesses by the numbers, breaking them up into profit centers and into divisions that could be bought and sold like financial assets in an investment portfolio. But without intimate familiarity with customers and technology, said Hayes and Abernathy, managers lacked the vision and confidence to invest in technological innovations that would lead the market by serving needs it didn't know it had or didn't know were capable of being fulfilled.

The perspective of Hayes and Abernathy was in large part an outgrowth of earlier research by Abernathy and Wickham Skinner,⁵ (also a professor at the Harvard Business School) which was part of a larger body of work developed over the 1970's that in various ways had approached the question of how to integrate technological considerations into general business strategy.⁶ Both Abernathy's and

⁵ Skinner's views, similar to those of his colleague Hayes, were featured in Robert Lubar, "Rediscovering the Factory," Fortune, July 13, 1981, which was part of the "Working Smarter" series.

⁶ This work was reviewed by Alan Kantrow in the "The Strategy-Technology Connection," Harvard Business Review, July-August, 1980.

Skinner's work can be interpreted as a response to the acceleration during the 60's and 70's of technological and market change and the associated proliferation of products and market niches. These trends had made the traditional strategy of exploiting scale economies with highly refined and mechanized processes difficult to maintain. Abernathy, in his 1978 landmark study The Productivity Dilemma⁷ had detailed the way in which the auto industry had arrived at a design configuration for the automobile that allowed it to mass produce standardized functional components using traditional technology while at the same time attempting to serve and define various market segments with a multiplicity of superficial convenience and styling features. In this context, top auto industry executives had become content to tame the complexity the managerial task by taking the functions and capabilities of their manufacturing plants as given. The result was that they let themselves be overtaken in the market. Auto industry management, according to Abernathy, had failed to understand that changes in product design and technology had finally created the need for major investment in a corresponding reorganization of manufacturing.

Skinner, in his study of plants in a cross section of

⁷ William Abernathy, The Productivity Dilemma: Roadblock to Innovation in the Automobile Industry, (Baltimore: Johns Hopkins University Press, 1978).

industries,⁸ observed that most companies were attempting to deal with technological change and the ever finer segmentation of markets by stuffing more and more new processes and products into existing plants, most of which had originally been designed for relatively routinized, high volume production at minimum cost. In the new environment, however, there were many products that had to be made in smaller volumes, and many for which timely delivery, custom features, the latest technology, and unusually high quality standards were of more importance than low cost. Skinner found that when a factory contains too many fundamentally different processes or too many products with different volume, delivery, and quality requirements, the manufacturing control systems start to break down. Most plant managers, said Skinner, clung to the high volume, low cost model of production and tried to devise all-purpose management systems (typically with computers) that would allow a multiplicity of process technologies to be aggregated into a single large scale production unit. Such systems, it was thought, should be capable of satisfying the goal of minimizing costs while simultaneously maximizing quality and delivery performance for each product, something which ignored, according to Skinner, the usually necessary tradeoffs between these

⁸ Wickham Skinner, "Manufacturing -- Missing Link in Corporate Strategy," Harvard Business Review, May-June 1969, and "The Focused Factory," Harvard Business Review, May-June 1974.

goals. With different priorities for each of several product groups, scale economies were, said Skinner, illusory. He found the typical result of failure to focus a factory on limited groups of processes and products to be an overly complex, bloated and ineffective managerial apparatus.

Nor could the design, layout and staffing of a plant serve all purposes at once. There was, in particular, a conflict between low volume, customized production requiring broadly skilled workers and general purpose equipment, and high volume production requiring only narrowly skilled workers and specialized equipment. Skinner saw that the tradeoffs to be made in the organization of manufacturing were appreciated even less by top management than by plant managers. The result was unwillingness to invest in separate, appropriate facilities for groups of products and processes with similar managerial requirements.

Skinner and Abernathy had thus demonstrated that an ignorance of technology at top levels of management had resulted in poor productivity and slowed innovation. To this conclusion, Hayes and Abernathy had added the observation that the quantitative techniques so favored by legal, financial and marketing experts were well suited only for estimating costs and customer demand in the context of well known technologies and established mass markets. They were quite ill suited, on the other hand, to

support the technological entrepreneurialism for which the challenge was the long term development of entirely new markets.⁹

Hayes and Abernathy and all of those exploring the strategic management of technology made little or no mention of Japanese management. Yet the picture of Japanese management in Vogel's book as well as in other available accounts¹⁰ presented a clear contrast to Hayes' and Abernathy's description of American management. Most of the employees of major Japanese industrial firms were lifetime employees who had been trained in a wide variety of tasks and functions and who were intimately familiar with their firm's production processes, products, customers and supplier networks by the time they reached the top.¹¹

⁹ "The New Industrial Competition," Harvard Business Review, September-October, 1981 by Abernathy, Kim Clark, and Alan Kantraw also found mismanagement of technology to blame for America's economic decline citing both the failure to organize operations effectively and to grasp the strategic implications of accelerated technological change, particularly the relationship between innovation in product technology and restructuring of production processes. This article won the award for best HBR article of 1981 suggesting the success of the Hayes/Abernathy perspective in leading a new consensus.

¹⁰ These include the writings of Peter Drucker, the premier American management guru. See, for example, "What We Can Learn From Japanese Management." Harvard Business Review (HBR) March-April, 1971 and Management: Tasks, Responsibilities and Practices, (New York: Harper and Row, 1974).

¹¹ This was noted publicly by Labor Secretary Ray Marshall: New York Times, March 24, 1980, IV p.2; Also see "Some of Japan's Major Companies Are Moving Engineers Out of Their Field and into the Executive Suite," Wall Street Journal, July 23, 1980, p.26.

Moreover, the Japanese, by most accounts, made decisions by consensus after long and careful probing of the nuances of every alternative. This they did with an eye on the long term growth of a company with which they all identified and were never likely to leave. To position oneself in technologies and markets by buying and selling divisions as if they are holdings in a portfolio was apparently alien to the Japanese way of thinking. The favorable view of Japanese management's ability to make far-sighted, informed decisions on technology was supported by a major scholarly article on Japanese technology in the October 1980 issue of Scientific American which closely linked the willingness to invest in new technology to Japanese employment security and employee commitment to the firm.¹²

Not only did Japanese management style contrast with Hayes' and Abernathy's description of top executive alienation from technology, but the results in terms of investment in new technology were also in the public eye.

¹² James Abegglen and Akio Etori, "Japanese Technology Today". This article was part of what was reported to be the largest advertisement ever placed in a periodical and was sponsored by a group of 16 Japanese manufacturing companies who were motivated in part by a desire to demonstrate that their market success was based on real production achievements rather than subsidies, low wages, etc. The willingness to invest in new technology was also loosely associated with employee security and commitment in Christopher Byron, "How Japan Does It," cover story, Time, March 30, 1981, p.59. "The U.S. Productivity Crisis" in Newsweek (Sept. 8, 1980) made the link as follows: because of the relatively heavy use of bank financing and consequent lack of pressure to make profits in the short run, Japanese companies could afford to invest for the long run, stabilize employment and secure employee loyalty.

There were, as discussed in chapter 2, examples of Japanese technological superiority in several industries, most notably steel, but the most salient Japanese lead was in robots. Cover stories on the explosive growth of the robot industry in Business Week and Time in 1980 prominently featured the extremely wide, three to one lead Japan held in the number of robots installed.¹³

The many cases of the quality superiority of Japanese goods (some of which were reviewed in chapter two) were also powerfully suggestive of the superiority of Japanese management, more so than was the fact that Japanese goods were lower in price, a fact which was easily explained away by unfair trading practices, government subsidy, low wages or the high dollar. The 1979 book Quality is Free¹⁴ by Philip Crosby undoubtedly helped to reinforce the idea that the quality deficit was a sign of inadequate managerial techniques. It focussed attention on the fact that defect prevention generally reduces overall costs rather than raising them. Quality Is Free became in 1980, probably the first book on quality control to come out in mass market paperback.

¹³ Ottot Friedrich, "The Robot Revolution," Time, Dec. 8, 1980; "Robots Join the Labor Force," Business Week, June 9, 1980.

¹⁴ Philip Crosby, Quality is Free, (New York: Mentor/New American Library, 1979). This book was referred to in Fortune, "The Battle for Quality Begins" Dec. 28, 1980.

A concern about American industry's ability to be competitive in quality began to gel visibly in 1980 and 1981. Fortune announced in December 1980 that "the battle for quality begins" reporting that in the previous several months, many top executives had carried out reorganizations to give quality higher priority. It cited a particularly provocative speech by Robert Reich, then director of policy planning at the Federal Trade Commission, that painted a picture of generalized American failure to be competitive in quality.¹⁵ Also late in 1980, the American Society for Quality Control (ASQC), partly in response to a sense of growing dissatisfaction with the quality of American goods, conducted a survey of public perceptions that revealed that foreign goods were considered equal in quality to American goods by 48% of the American public and better than American goods by 27%, with about half perceiving American quality dropping.¹⁶ This result was reported in both the Wall Street Journal and the New York Times.¹⁷

It was natural then, that much of the early critique of American management and attention to Japanese management techniques focussed specifically on quality control. It

¹⁵ Another early article on the quality problem was "Why U.S. Goods Are Out of Favor," U.S. News and World Report, May 11, 1981, pp.81-83.

¹⁶ S. L. Binstock, "Americans Express Dissatisfaction With American Goods," Quality Progress, Jan. 1981.

¹⁷ WSJ, Dec. 10, 1980, p.20. The New York Times article was mentioned in Binstock.

was a minor historical accident that some of the most respected authorities in the field of quality control were also the most qualified to speak about Japanese practices. J. M. Juran, the foremost authority on managerial aspects of quality control, was a major figure in the history of Japanese quality control and had been reporting regularly to the West on developments there since the early sixties. Another of the grand old men of American quality control, W. Edwards Deming, had consulted and lectured in Japan since 1950 and was revered there as one of the fathers of quality control. The advice that Juran and Deming had been giving for many years was suddenly keenly sought after by top managers of leading corporations and disseminated widely in the business press as both Japanese secrets and American best practice.

Deming got the most attention because an award in his name is given annually in Japan to the company with the highest quality achievement. An NBC documentary, aired in June 1980 and entitled "If Japan Can, Why Can't We," depicted Deming's wisdom and statistical quality control as perhaps the biggest key to Japanese manufacturing success.¹⁸ Deming was also featured in articles in the New York Times and the Wall Street Journal during the mid 1980

¹⁸ The program spurred an article in Fortune, July 28, 1980 entitled "Productivity in Prime Time" which complained of lack of specificity about what it was that Deming was offering. However, the transcript was requested more times than any documentary in NBC's history. (David Halberstam, "Yes We Can!" Parade, July 8, 1984)

to mid 1981 period.¹⁹ Juran was cited in both Fortune (Dec. 28, 1980) and Newsweek (Sept. 8, 1980)

Japanese superiority in quality seemed to be fundamentally due to the fact that quality was a higher managerial priority in Japanese firms. This was apparently translated into action by workers on the line who undertook, out of their devotion to the firm's success and with greater scope for initiative, to prevent defects. This, it was commonly noted, decreased reliance on an imperfect inspection organization to weed defects out before they reach the customer. But discussions of Japanese quality control gave by far the greatest prominence to quality control circles, small groups of workers who meet together outside of their regular jobs to discuss and analyze causes of quality problems. The effectiveness of circles in improving productivity was also well publicized and they were obviously close in spirit to some of the Quality of Work Life programs at General Motors and elsewhere. There was already a modest but quickly growing number of companies who were trying the circle concept by 1980 so that the question of the feasibility of adopting Japanese management techniques was not quite so much in question here as it was for such features of the Japanese firm as lifetime employment and management by consensus. The

¹⁹ "Stiff Competition: Japanese firms' stress on quality control is reflected in dogged vying for award," WSJ Sept. 24, 1980, p.52; NYT, May 10, 1981, section III, p.6.

quality circle suddenly became by mid 1981 the centerpiece of the American QWL movement.²⁰

There were thus three basic strands in the 1980/81 diagnosis of an American management crisis. The first was generated by a group of management scholars studying the strategic management of technology and centered around the Harvard Business School. It held that top management had become alienated from technology, considering itself interchangeable between industries and becoming blinded to the opportunities of opening up new markets with new technologies in its overreliance on quantitative analytical techniques and focus on the short term bottom line. The second strand was the perception that antagonistic labor-management relations and mind-deadening routinized jobs were sapping productivity and that the QWL movement needed to expand rapidly to turn the situation around. The third strand was the belief that quality had not been taken seriously enough as a competitive factor and that reform of quality control management would be necessary.

Underlying most of the critiques of American management was also something deeper, a sense that arrogance and complacency had let us sweep our faults under the rug, that problems had not so much to be discovered as confessed, and that there was a need to return to basic values. These basic values seemed to be community,

²⁰ Charles Burck, "Working Smarter; Introduction" Fortune. June 15, 1981, p.68.

democracy, and discipline. Community: A way had to be found to inspire greater worker identification with the firm and commitment to its goals. Management had to commit itself to invest for the long run and be willing to get involved in the details of production. Democracy: Employees at all levels had to open up lines of communication and be given the opportunity to contribute their knowledge and take initiative. Discipline: Labor had to moderate its bargaining demands to save their firms while management had to cease abdicating its responsibility to manage for quality and technological advance.

Business Week²¹ evoked all of these values when it proclaimed the need for a new social contract in which consensus about the common interest would be based on greater fairness in giving societies' groups an equal voice and a just reward for their contribution to the common good. The Japanese were perceived to have a sounder social contract. In Time's opinion,²² it was the value of teamwork, a blending of community and commitment which were seen at the root of Japanese worker participation, control of quality and the willingness to invest and innovate for the long run.

The attraction of the American business community to Japanese management was therefore tremendously powerful

²¹ "The Reindustrialization of America," Business Week, special issue, June 30, 1980.

²² Byron, "How Japan Does It," Time, March 30, 1981.

because Japanese success seemed tied not just to the alien characteristics of their culture but to a realization of the deepest values that Americans sought a return to in this period of self examination.

The Art of Japanese Management

Many people first became acquainted with the characteristics of Japanese business organizations through Ezra Vogel's Japan as Number 1 which became a bestseller and came out in paperback in 1980. Most, however, undoubtedly learned much of what they knew from two books which came out in the spring of 1981: Theory Z by William Ouchi and The Art of Japanese Management by Richard Tanner Pascale and Anthony Athos.²³ Vogel had devoted only one chapter to Japanese business, but these books were aimed specifically at the business community and represented the first major attempts to show Americans how they could begin to reform their managerial institutions to capture the best aspects of Japanese organizations. Both books portrayed a small group of successful American firms (especially IBM, Delta Air Lines, United Air Lines, Hewlett-Packard, Proctor and Gamble, and Kodak) as organizing and motivating their employees in ways that were more common in Japan. Thus, although the books were frequently associated with the idea

²³ Theory Z (Reading, Mass.: Addison-Wesley, 1981; New York: Avon Books, Jan. 1982); The Art of Japanese Management, (New York: Simon and Schuster, 1981).

that Americans should imitate the Japanese, they were clearly arguing for using an understanding of the virtues of Japanese organizations to inspire emulation of a certain species of American managerial practice. The arguments of the two books were quite similar, probably owing in part to the fact that Ouchi and Pascale had started a comparative study of Japanese and American firms together in 1973 which formed the basis for both books although Ouchi and Pascale subsequently parted ways in the middle of the research.

What did these books teach American managers? Partly, they simply explained some of the well known features of Japanese management that had already been summarized by Vogel. Foremost among these is the institution of lifetime employment which exists for male employees in the major industrial firms. Associated with this is the policy of promotion and pay increases based mostly on seniority rather than performance evaluations. Lifetime employment and seniority promotions create a large disincentive for employees to leave to join another firm in midstream and offer substantial rewards for staying and therefore promote loyalty and dedication to the firm's success. Because of the permanence of employees' attachment and the need to avoid layoffs, firms are willing to invest heavily in training over the length of a person's career and are highly motivated to invest for long term growth and expanded market share. The long run perspective of the firm is noted to depend upon the heavy use of bank

financing and the consequent lack of pressure to satisfy shareholders with high profits in the short run. So far, all of this makes perfect sense in terms of basic economic interests.

There are other features of Japanese business organizations that are not as directly connected to the structure of interests created by employment security. One is identification with the firm as a kind of family, a feeling evidenced in the degree to which employees' social lives center around the firm and which is reinforced by such things as provision of recreational facilities for employees and arrangement through the firm of group vacation trips and home financing. The formation of close mentor relationships also gives the Japanese firm a family aspect. Most employees, when they enter the firm, become attached to a special senior employee to whom they can expect to be able to express their feelings about both work and personal problems and from whom they can receive emotional support and fatherly advice.

Another well known feature of the Japanese firm is grass roots, small group decision making and responsibility. Decisions are arrived at slowly after the thorough discussion of all alternatives produces a consensus, with people of all ranks being offered a chance to voice their opinions. Low level groups often initiate and develop proposals and circulate them widely throughout the firm until they are given final review and approval at

higher levels. Leaders of groups are selected more on the basis of their ability to fashion compromise and consensus and maintain the group spirit than on the basis of their individual ability to make good decisions. Group responsibility means that individuals are not held directly accountable and that tasks are assigned to individuals within the group based not on rank or formal function but according to their ability and availability for the specific task at hand. Evaluation of the individual's abilities is based on long, intimate experience by other group members with his or her performance.

Family feeling and the decentralized group-based organization of work in the Japanese firm cannot be viewed as direct byproducts of lifetime employment and promotion on the basis of seniority, although they are supported by them. To mention one of the most important connections: where rank is linked mainly to seniority, better use is made of people's talents if they are assigned duties independently of their rank, something which is much more easily done if responsibility is placed upon groups thereby creating an incentive within the group to apportion work according to ability while preserving rank. Still, attempts to rationalize the character of relationships within the Japanese firm in terms of economic interests are inadequate. The emotional solidarity many Japanese employees feel with their firms and work groups and their renowned diligence has left Americans with the sense that

traditional Japanese cultural values have been transposed to function within industrial society. Essentially, Americans seem to have looked upon the phenomenon of the Japanese firm as a combination of transactional and mystical elements. That is, what cannot be explained by reciprocal investments of employees and management must be explained by an alien and sacred sense of devotion to work and unity with the group. This dichotomy of interpretation is implied by Vogel:

Before resorting to an explanation [of employee devotion] that centers on a semimystical "Oriental spirit" one might consider whether Japanese success bears any relationship to company management and treatment of workers²⁴

Note also the assumption that it is primarily "devotion" which needs to be understood and explained when examining Japanese management.

What, then, did the bestselling books of 1981 add to the previous dichotomized view of Japanese management? Essentially, they explained the character of decision making and communication within the Japanese firm as intrinsically valuable, both because it serves universal human needs and because it leads to better decisions. As Pascale and Athos conceive it, Japanese language and cultural symbols simply make it easier for people to recognize and cultivate certain aspects of human relationships within organizations which Americans tend to

²⁴ Vogel, p.132.

neglect and devalue.²⁵ They brought this point home by noting that American behavior is often more similar to Japanese behavior than we realize, that our images and rhetoric concerning how authority should ideally be exercised mask a reality in which actions are directed far more toward preserving the integrity of our human relationships than we commonly acknowledge. For example, Pascale and Athos describe the case of a firm whose top management frequently talks in tough disciplinary language even when employees who perform poorly are ordinarily given a lot of assistance and time to improve.²⁶

Going beyond the transactional view of dedication to the firm, Ouchi and Pascale and Athos depict the maintenance of group cohesion as something which must be attended to not because it facilitates a more energetic implementation of policy by its individual members but because the group itself is the irreducible implementer whose integrity is the absolute prerequisite for accomplishment of task. The Japanese work group and firm are conceived to exist on a foundation of emotional bonds, a sense of belonging, of being able to take part, of being understood and fairly judged by those who know one well, of being nurtured and guided to serve worthy social goals. The desire to be a part of such a group is common to all

²⁵ Pascale and Athos, p.83.

²⁶ Ibid., p.108.

people. Yet American culture, observe Pascale and Athos, places its highest value on individualism and self sufficiency while tending to label acceptance of any kind of dependency on the group as weakness and loss of the self. Both Ouchi and Pascale and Athos place great emphasis on the need for employees to identify with a firm's goals, to feel that what they spend their lives doing serves a higher purpose in the world than to make money for personal gain. In Japanese firms and those American firms that share their characteristics, they say, it is these higher goals which give the firm's subgroups not only a sense of meaning but a specific image of the firm's mission which binds their members in their daily work.

Ouchi and Pascale and Athos also try to show that the quality of communication and decision making is enhanced by the intimacy of human relationships that develop in the context of permanent attachment to the firm and the process of striving for group consensus. Communication in this context becomes more subtle and implicit fostering a better integration and use of people's knowledge and talents. Criticism is delivered indirectly or privately or in the guise of offers of help so as not to produce defensiveness and alienation. A fine sense of shame and responsibility to the group are relied upon to motivate people in a more finely calibrated way as compared to the common American tendency to vacillate between avoiding social discomfort by

giving no feedback on performance at all, and feeling compelled to directly confront and explicitly penalize individuals thereby causing dysfunctional and unnecessary humiliation. Rewards are also more subtle in the context of long term, group working relationships. People are more assured of having their contributions quietly recognized by their superiors and associates reducing the need to assert, as Americans tend to do more often, the superiority of their point of view on particular issues. Pascale and Athos find the Japanese to be better at listening and incorporating others' knowledge and opinions as a result. The allocation of tasks is also more flexible and finely attuned to individual abilities while deeper understanding and communication make coordination easier in accomplishment of complex projects.

Finally, Ouchi and Pascale and Athos describe the Japanese -style organization as being better able to incorporate intuition and judgement into decisions. Ouchi discusses how the strategic philosophy that emerges from a firm's historical experience is given greater relative weight in decisions than in the West. This becomes important when it is impossible to numerically measure a project's specific contribution to overall firm success. Though the Japanese have a passion for gathering data, Pascale and Athos find that they are more likely to recognize when the limits of logic and quantitative analysis are reached. They contribute an explanation of

the values of Japanese decision making from the point of view of Zen philosophy. Essentially, the Zen insight concerns the ability to wait for the right moment to make a decision and act. There are two sides to this. The situation within the environment needs to unfold to a certain extent until there is enough clarity to make a reasonable decision. On the other hand, the state of group dynamics must also be judged for readiness to coalesce around a response to a problem. The two sides are not completely distinct from each other. The situation clarifies as the members of the group gather and integrate their knowledge. Pascale and Athos find that in America, the art of waiting for the right moment to act is not nearly so well developed where it must compete with an ethic that calls for imposition of clarity and unity as quickly as possible wherever it does not exist and the unilateral generation of organizational action based on the individual judgement and analysis of the leader.

Theory Z and The Art of Japanese Management are general discussions of the character of communication and decision making in the Japanese firm, mostly among upper level white collar personnel. We will see that much of this character will be reflected in the management of specific technical functions. We will now move on to consider the Japanese organization of manufacturing.

Quality Circles

The single most publicized Japanese management technique in the early 1980's was quality circles, a program for encouraging the voluntary formation of shop floor worker groups to study and solve problems that are mostly of their own choosing using simple techniques learned in an initial training phase. Ouchi included an appendix on quality circles in his book because they embodied the virtues of group decision-making and communication as he saw them. Quality circles took their name from their origin in efforts of the Japanese Union of Scientists and Engineers (JUSE) in the 1950's and 60's to spread the knowledge of modern (American) techniques of quality control throughout industry. Seminars were used to teach these techniques to managers and engineers at all levels, but as the educational effort progressed, it was decided that vast numbers of foremen and ordinary workers also needed basic knowledge of quality control and radio and television courses were devised for them. Eventually, a special, practically oriented, quality control journal for foremen was launched by JUSE in 1962. It encouraged foremen to form quality control study groups with their workers.²⁷ The first circles were formed in 1962 and the number of officially registered circle participants grew

²⁷ J. M. Juran, "The QC Circle Phenomenon," Industrial Quality Control, Jan., 1967, p.331; Yasuo Sugimoto, "The Advancing QC Circle Movement," in Japan Quality Control Circles, (Tokyo: Asian Productivity Association, 1972) pp.5,6.

much more rapidly than JUSE expected, to about 71,000 in 1965, to 212,000 in 1968 and to 1,062,000 in 1980.²⁸ The number of unregistered participants was far greater. It was estimated that by 1978, about 1 in 8 Japanese employees were members of circles²⁹ and that by 1981, 77% of corporations with more than 10,000 employees had circles.³⁰ Most accounts of the growth of quality circles in Japan imply, no doubt partly for lack of more detailed knowledge, that the circles grew up as a direct result of the publication of the foremen's journal. However, a 1966-67 survey of early quality control circles found that 45% had been formed in response to managerial directive and that 21% had formed spontaneously, with the rest forming at management's "suggestion."³¹ Still, the major impetus (in the form of conferences for circle members and publicity for successful circle projects) as well as the training had come from outside the firm so that there was some degree of independent initiative and pressure from below. Though in some places, there had been a WWII or pre WWII tradition established of production workers meeting in groups to

²⁸ Olga Crocker, Johnny Sik Leung Chiu, and Cyril Charney, eds. Quality Circles: A Guide to Participation and Productivity, (New York: Methuen, 1984) p.13.

²⁹ Robert Cole, Work, Mobility and Participation, (Berkeley: University of California Press, 1979) p.137.

³⁰ Satoshi Bando, "Qualitative Change in the Labor Movement," Japan Echo 8 (1981) pp.30-37, as cited in Crocker et al., p.11.

³¹ Sugimoto, p.8.

solve problems,³² quality control circles were, in general, a distinct departure from a more conventional authoritarian mode of work organization.³³

The first knowledge of quality circles in the U.S. came from a paper published by Juran in 1967 in which he called quality circles a managerial "tour de force" and a sign that Japan was almost certainly headed for world quality leadership.³⁴ In the same year, as a part of its efforts to generate interest in quality circles, JUSE began arranging an annual trip by a group of managers and circle leaders to visit U.S. firms and chapters of ASQC at which overviews and case studies of Japanese circle activities were presented.

The first American circles were finally set up in late 1974 by Lockheed and Honeywell. Successes at Lockheed were well publicized and three managers of the program left the company to promote the concept. Though the first ASQC conference session on quality circles was held in 1976,³⁵ the Lockheed group found ASQC unresponsive to the idea of

³² Robert E. Cole, "Quality Circles," in Loren Walsh, Ralph Wurster, and Raymond Kimber, eds., Quality Management Handbook, (New York: Marcel Dekker, 1986), p.87.

³³ Sugimoto, p.5; Peter Drucker, "The Wrong Bottom Line," Forbes, May 25, 1981.

³⁴ Juran, "The QC Circle Phenomenon," p.336.

³⁵ Davida Amsden and Robert Amsden, "A History of Quality Control Circles," as reprinted in Quality Circles Papers: A Compilation, (Milwaukee: American Society for Quality Control, 1983).

promotion. As a result, they founded the separate International Association of Quality Circles (IAQC) in 1978³⁶ by which time there were about 25 companies experimenting with quality circles.³⁷ The number of firms with circles multiplied several times in 1979 and again in 1980 when quality circles suddenly began to be widely viewed as a quality control panacea.³⁸ In November, 1980 the ASQC finally set up a technical committee for the purpose of disseminating information on quality circles.³⁹ By mid 1982, somewhere between 1,000 and 7,000 firms had quality circle programs⁴⁰ including about 1 out of 2

³⁶ Amsden and Amsden, p.13. The former Lockheed managers all became consultants. Three firms offering expertise in quality circles and/or Japanese quality management advertised in the January 1979 and 1980 issues of Quality Progress up from zero in 1978. The number had grown to ten in January 1982.

³⁷ Frank Gryna, Quality Control Circles, (AMACON, 1981), p.15.

³⁸ Gryna, p.15; Crocker et al., p.28.

³⁹ Amsden and Amsden, p.13.

⁴⁰ Robert Cole gives an estimate of 1,000 firms for mid 1982 in "Quality Circles," Quality Management Handbook, p.85. In March, 1982 the IAQC had 3175 members, most of which had quality circle programs. Some of these might well be divisions or subsidiaries of other IAQC members. A survey taken for IAQC members placed the number of plants with circle programs at a little over 6,000 based on the assumption that the number of IAQC members with programs was a quite conservative estimate of the total number of firms with programs but perhaps not far off. (H. Ned Seelye and Joyce A. Sween, "Quality Circles in U.S. Industry: Survey Results," as reprinted in QC Sources: Selected Writings on Quality Circles, (Cincinnati: International Association of Quality Circles, 1983) Still another March-April, 1982 survey found that 14% of all corporations with over 100 employees had circle programs which works out to a

manufacturing firms with more than 10,000 employees.⁴¹ However, one survey showed that 45% of these firms had less than 10% of their workforce involved at this early stage of implementation.⁴²

The structures and the philosophies of American quality circle programs are quite similar to each other and at least outwardly similar to programs in Japan. Circles typically have 8 to 10 members with the foreman generally serving as leader. Although membership in a circle has been completely voluntary in the U.S., foremen are very often "urged" to start circles. Outside consultants are hired to help with initial training in about two thirds of the cases⁴³ and internal "facilitators" are always employed to help leaders to train circle members as well as to monitor group interactions and advise at circle meetings.⁴⁴ Training is usually about ten hours on average⁴⁵ and covers both group dynamics and problem solving methods. Circle

little less than 7,000 firms. (William C. Freund and Eugene Epstein, People and Productivity: The New York Stock Exchange Guide to Financial Incentives and the Quality of Work Life, (Homewood, IL: Dow Jones-Irwin, 1984)

⁴¹ Freund and Epstein, pp.127,28.

⁴² Seelye and Sween, p.191. See also Freund and Epstein, p.129.

⁴³ Crocker et al., p.36.

⁴⁴ Crocker et al., p.34.

⁴⁵ 30% of programs train their circle members 5 to 8 hours and 44% train them 9 to 10 hours. Seelye and Sween, p.192.

members are taught about the process of achieving consensus through eliciting each person's opinions, resolving differences by making sure that everyone understands what has been said and searching for facts that will decide the case. The ground rules for discussion are that only ideas will be criticized, not other group members. Members are encouraged to view the group's success as dependent upon everyone's contribution and ability to learn from and teach others. Problem solving starts with brainstorming where as many ideas as possible are gathered with a minimum of judgement as to their validity. The two most distinctive techniques taught are the making of cause and effect diagrams in which various possible causes of a problem are systematically categorized, and Pareto analysis where the few important factors contributing to a problem are ranked and sorted from among the many trivial factors that are also usually involved. Basic methods of collecting and recording data including graphs are also taught. Statistical process control is considered optional and even in Japan where the training is generally more technically advanced, control charts are used extensively by only a small minority of circles.⁴⁶

Circles usually meet for one hour a week during

⁴⁶ Robert E. Cole and Dennis Tachiki, "A Look at U.S. and Japanese Quality Circles: Preliminary Comparisons" as reprinted in QC Sources, p.209.

working hours⁴⁷ and can tackle any kind of problem they wish including those having to do with interpersonal relationships and the general workplace environment. At the end of the meeting, specific investigative tasks may be assigned to individual members to report on at the next meeting. When a solution to a problem is found, it may be unilaterally implemented by the circle if it requires negligible investment and is confined in its effects to the circle's work area. If the solution has more serious implications, consultations may be necessary with other circles or a presentation of research and proposed solution to management may be called for. At least at the initial stages, facilitators seem to play an important role in suggesting the limits to what a circle can attempt to do in terms of its own abilities and the degree to which certain decisions need to be made from a broader managerial perspective. Presentations to management are looked upon as a way not only of justifying a commitment of resources but as a way of developing workers' skills and confidence in speaking and working in groups. It is also the most important opportunity for upper management to give recognition to circle activities and achievements. Promoting quality circle activities and setting general guidelines for them is the responsibility of a steering committee made up of middle managers, union

⁴⁷ Seelye and Sween, p.192.

representatives, facilitators and sometimes circle leaders and members.

By most accounts, quality circle programs create organizational tensions caused by the fact that they function independently of the existing authority structure of the firm. Foremen who lead groups have typically been accustomed to functioning as order givers and disciplinarians, so the transition to consensus decision making with workers is often difficult. However, the training they receive along with facilitator guidance seems to be generally regarded as fairly effective in turning attitudes around. More serious, is the potential conflict with engineers, middle management, and staff who frequently do not receive training in quality circle concepts and can easily be made to feel that their prerogatives are being eroded and that successful analysis of problems by workers will make them look inadequate. If too many suggestions from circles are turned down without real care being given to explaining the reasons, circles can of course become discouraged. Top and middle management support and understanding of what circles are all about is always cited as a most critical factor in determining circle success. Starting circles for middle managers to give them an appreciation for the values of group problem solving is often suggested as a way of increasing their willingness to work with shop floor circles. About a quarter of quality

circle programs have such circles.⁴⁸ Interestingly, most managements have not demanded any sort of cost savings from their quality circle programs, feeling that they are very likely more than paying for themselves and speaking mostly of opening up lines of communication.⁴⁹ 66% of quality circle programs in one survey were rated "very successful" overall⁵⁰ while 28% of programs in another survey were rated "very succesful" in terms of productivity improvement.⁵¹

The key innovation of quality circles was combining the participatory values of the Quality-of-Worklife movement with the training of workers for engagement in a specific technical function --- quality control. Many of the academics, consultants and "human resource" specialists who had worked to promote QWL programs worked as well as to establish quality circles⁵² and it seemed by 1981 that quality circles had become the most identifiable symbol of the entire QWL movement.⁵³ On the other hand, quality

⁴⁸ Ibid., p.190.

⁴⁹ Gryna, pp.19-20.

⁵⁰ Seelye and Sween, p.192.

⁵¹ Freund and Epstein, p.133.

⁵² Wayne Rieker, "QC Circles' Trend in the U.S. --- A Concern," Annual Quality Congress Transactions, as reprinted in Quality Circles Papers: A Compilation, (Milwaukee: ASQC, 1983).

⁵³ Charles Burck, "Working Smarter," Fortune, June 15, 1981, p.68; General Motors used circles as a part of its QWL program (Gryna, p.17). Circles were very much in the

circles were sometimes perceived as being more restricted to solving purely technical problems.⁵⁴ Circles aimed more directly at the shop floor level than QWL programs that began with establishment of a QWL labor-management committee, a top level body under whose auspices lower level committees would later be formed to work on more local problems as progress was made in defusing antagonisms. Often, the technical side of quality circles was highlighted when Deming, the greatest champion of statistical quality control, was misleadingly credited with starting the quality circle movement in Japan. And since the giants of American quality control were so closely associated with quality circles, the quality control profession inevitably developed a special knowledge of and support role with respect to quality circles.

Not only did Japanese quality circles provide a massive and convincing demonstration of the benefits of integrating worker participation and quality control, they were clearly a means of moving in the direction of reforms that Juran, Feigenbaum and others had long advocated within their profession. First, quality circles broke from motivational programs of the past to emphasize an investigative approach to problems which was far more

spirit of the QWL work teams at Tarrytown described in chapter 3.

⁵⁴ John Simmons and William Mares, Working Together: Employee Participation in Action, (New York and London: New York University Press, 1985) pp.112-113.

realistic and productive according to Juran since the vast majority of problems were caused by flaws in the system rather than lack of worker diligence. Second, quality circles were clearly a vehicle for spreading the responsibility and capability for quality control from the quality control staff and inspection department to production and other line departments. Such a distribution of the quality control function was seen as necessary in order to place more emphasis on prevention as opposed to inspection and in order to place quality control in the hands of those whose continuous involvement in particular operations would enable them to control quality more effectively. Third, circles supported the distribution of responsibility for quality through training in quality control techniques. They could even serve to introduce statistical process control on the shop floor where it had failed to take hold during the original statistical process control craze after WWII.

The Japanese Management of Quality

Juran had attempted many times before the 1980's to call attention to the need to respond to the Japanese challenge in quality control. In so doing, he emphasized the role of quality circles, partly because they represented a dramatic and successful departure from Western conventions. Perhaps predictably, but to Juran's dismay, quality circles came to be seen as a panacea for

all quality problems although innovations at the managerial level were more critically needed in his view. There was also, however, keen interest in learning about other aspects of the Japanese approach to quality control. To some extent, the secrets of Japanese success could be learned from Deming, Juran, and Feigenbaum, each of whom was credited by the Japanese as being among their greatest teachers. In fact, Feigenbaum's trademark title for his systems concept of quality control management, "total quality control" (TQC), had been borrowed by the Japanese as a label for their own system. Feigenbaum, Juran, and Deming all experienced dramatic increases in requests for their consulting services in the early 1980's. Juran had over 100 meetings with top level executives in the 1980-82 period compared to less than ten such meetings in the previous five decades of his career.⁵⁵ Through the reports and seminars of Juran as well as other researchers and journalists newly interested in Japanese quality control, the general outlines, as well as many details of a fundamentally different Japanese approach to management of quality emerged in the early 1980's.

The most fundamental observation commonly made was that Japanese management placed a higher priority on quality than American management. The Japanese, it seemed, simply cared more about making high quality products and

⁵⁵ "Quality: The U.S. Drives to Catch Up," Business Week, Nov. 1, 1982.

had a firmer, more far-sighted grasp of the consumer's response to higher quality in the market. The intense Japanese focus on quality was very frequently illustrated by the vigorous competition for the annual Deming award given with great ceremony and publicity to the Japanese firm with the highest achievement in quality. More specifically, it was learned that quality control managers in Japanese firms reported directly to top management. Top management in turn, took the time to frequently review quality performance and promote a highly visible quality policy for the entire firm.⁵⁶

One of the overarching themes of Japanese concern for quality was prevention. Planning at the highest level of management annually targeted opportunities to lower total quality costs by improving efforts at prevention and decreasing the expense of appraisal and failure. In the Japanese factory, far more effort was devoted to preventing production of defectives as opposed to screening them out and reworking them after they are produced. Most dramatic, was the willingness of Japanese manufacturers to give individual workers the power to stop an entire production line when special problems prevented them from keeping pace while meeting standards. Also, workers were usually

⁵⁶ David Garvin, "Quality on the Line," Harvard Business Review, Sept.-Oct., 1983, p.68.

responsible for doing their own rework.⁵⁷ Thus, performance incentives for shop floor production personnel placed much more weight on quality than in the U.S. Japanese first line supervisors were found to feel at least as much pressure to keep quality levels high as they did to keep production rates up.⁵⁸

The extensive use of statistical techniques, especially statistical process control (SPC) was another widely publicized feature of Japanese manufacturing oriented toward prevention. Deming's teachings, assumed embodied in Japanese practice, emphasized the widest possible diffusion of statistical knowledge through the firm so that those most intimately involved with production processes would have the tools to root out causes of defects and bring those processes under tighter control.

The Japanese focus on prevention was manifested in many other ways as well. Where the consistency of incoming parts was not absolutely certain, they were subjected to 100% inspection to avoid problems further downstream in production.⁵⁹ Products tended to be designed with extra margins of safety, and reliability engineering was used

⁵⁷ Richard Schonberger, Japanese Manufacturing Techniques: Nine Hidden Lessons in Simplicity, (New York: Macmillan, The Free Press, 1982).

⁵⁸ Garvin, p.68.

⁵⁹ Robert Hayes, "Why Japanese Factories Work," Harvard Business Review, July-Aug., 1981; Schonberger, chapter 3; J.M. Juran, "Japanese and Western Quality: A Contrast," Quality Progress, Dec., 1978.

more extensively.⁶⁰ Quality control and manufacturing personnel were brought into the product design process to ensure that specifications could be practically and consistently met in production.⁶¹ New products were put through more rigorous testing and new processes were more thoroughly debugged.⁶² Preventive maintenance was far more frequently practiced. Finally, the Japanese trained their workers far more thoroughly.⁶³

The other overarching theme of the Japanese emphasis on quality was intense focus on customer response to the product. It was obvious that in autos, electronics, and other goods, the Japanese had outflanked American manufacturers by building up an image of superior quality. Generally, the Japanese tended to perceive much more clearly than Americans a close link between product quality and market share in the long run.⁶⁴ Looking more closely, it was found that this was very much by design as well as by instinct. Top management in Japan was accustomed to developing analyses of competitive position in critical product quality dimensions, keeping close track of progress

⁶⁰ Garvin.

⁶¹ Garvin; Juran, "A Contrast."

⁶² Juran, "A Contrast,"

⁶³ Garvin, p.72; Hayes, p.62.

⁶⁴ Frank S. Leonard and W. Earl Sasser, "The Incline of Quality," Harvard Business Review, Sept.-Oct., 1982; Schonberger, chapter 3; Hayes, "Why Japanese Factories Work."

in quality measures and annually targeting certain quality characteristics for improvement.⁶⁵ The study of consumer needs was found to be more probing and thorough. Groups of employees uninvolved in design would be selected to test products at home and be given genuine power in the decision to accept new designs.⁶⁶ Product designers would be assigned to work in the field among customers to give them intimate knowledge of real consumer needs and complaints. Serious efforts were made to collect data on consumer expenditures for upkeep and operation of products over their entire life cycle.⁶⁷

The individual practices supporting the Japanese focus on prevention and customer needs were not new to American managers, at least in theory. (One possible exception was giving production line workers the power to stop the line.) It was the focus itself and the coordinated use of these practices flowing from it that was new. Yet the Japanese focus was directly in line with what the American quality experts had been advocating for many years. The emphasis on prevention corresponded to the call of Juran, Feigenbaum and Crosby to evaluate the size of the different categories of quality cost in order to uncover the cost savings

⁶⁵ J. M. Juran, "Product Quality: A Prescription for the West: Part II, Upper Management and Employee Involvement," Management Review, June 1981, as cited in Crocker et al., p.18.

⁶⁶ Garvin.

⁶⁷ Juran, "A Contrast".

possible by shifting resources from inspection and remedy of failure to prevention. Likewise, the study of customer needs and the costs of product use was exactly the field of activity where Juran had urged American managers to look for the most profitable improvement opportunities since the late sixties. Both Feigenbaum and Juran had attempted in their work to get American managers to look at quality from a broader strategic perspective, to seek top management involvement in searching out key areas for action, in reducing quality costs and improving market position in quality. Finally, in the early 80's, it became known that a land existed where all of this was happening, and that the systems for quality control management recommended by the experts were more than parochially framed ideals that had to be compromised to serve other manufacturing values and business requirements.

Beyond the matters of focus, emphasis, and strategy, there is a deeper distinctiveness in the Japanese management of quality in terms of organization --- how decisions are made, tasks allocated and information gathered and shared --- and in terms of the meaning of quality itself. The Japanese quality control department is typically much smaller than in American firms. It has less responsibility for quality performance since this is distributed to the various line departments and to top management. It tends to act much more as a consultant or

as an independent auditor of quality results.⁶⁸

Furthermore, the need for independent quality experts is much less, since other technical, shop and upper management personnel are generally trained in statistical and other quality control techniques. (Recall the efforts of the Japanese Union of Scientists and Engineers to educate all Japanese managers in quality control in the 1950's and 1960's.)

There is also less need for a quality control department to attempt to impose discipline over other departments because upper management clearly sanctions and rewards their quality improvement activities. Neither does the quality control department have the responsibility of specifying their duties. Line departments propose specific quality improvement goals in response to more general directives from above. These goals may be translated into more specific, local goals by foremen and quality circles.⁶⁹

Quality control in Japanese firms is also accomplished with a greater degree of interdepartmental collaboration. The design of product and process involves the production department, purchasing, quality control and customer service. This decreases the probability of setting

⁶⁸ Sidney Rubinstein, "Quality Control Requires a Social and Technical System," Quality Progress, August, 1984; Schonberger, chapter 3; Juran, "The QC Circle Phenomenon,".

⁶⁹ Garvin, p.70.

unnecessarily difficult-to-meet specifications or creating a product that is uneconomical to service. Design personnel are also likely to take a broader and more collaborative view of their work because of having worked with customers and on the shop floor. Engineers and quality control specialists are commonly available to consult with quality circles on special problems.⁷⁰ In general, there is much less problem than in the U.S. with conflicting departmental objectives and viewpoints.

Thus the quality function is far more distributed among the production and the other line departments and integrated into their ordinary work which is itself integrated through interdeprtmental consultation and collaboration. The integration of quality control into other activities is supported further by a better directed and more immediate feedback of information on quality outcomes to those who play a role in producing them.⁷¹ For example, workers are given the responsibility for checking and adjusting their own work rather than leaving it to inspectors.⁷² Production line defects are made traceable to individual work stations.⁷³ Selected indicators of

⁷⁰ Cole, Work, Mobility and Participation, p.162; Rubinstein, "Quality Control Requires a Social and Technical System," Quality Progress, Aug. 1984, p.22

⁷¹ Juran, "A Contrast."

⁷² Rubinstein, "Quality Control Requires a Social and Technical System."

⁷³ Hayes, "Why Japanese Factories Work."

quality are calculated and displayed prominently on scoreboards in the shop.⁷⁴ Inspection is used not only to screen good output from bad but is designed to provide quick feedback to production personnel on how they are doing.⁷⁵ Everywhere, visibility seems to be the goal.⁷⁶ This is supported by a serious attention to housekeeping which often astonishes visitors to Japanese factories. Information also flows more directly between field and plant. Far more specific data about failure rates and modes is fed back quickly to the plant,⁷⁷ and sometimes directly to the particular work group involved.

The high degree of integration of the quality function within the Japanese firm was noted to extend as well to the relationship between a Japanese firm and its suppliers. American firms tended to follow a transactional, even adversarial approach whereby acceptable quality levels were specified in the contract and suppliers were required to have proper written procedures, organizational structure and documentation for quality control. In contrast, the Japanese tended to look at the specific skills of suppliers' employees, the capabilities of their processes,

⁷⁴ Schonberger, chapter 3.

⁷⁵ Garvin, p.20.

⁷⁶ Schonberger, chapter 3..

⁷⁷ Hayes; Garvin, p.70.

and their managerial philosophies concerning quality.⁷⁸ Japanese firms expected to have a close working relationship with their suppliers, consulting with them about problems and potentials for improvement. While Americans often feed back incoming inspection data to their suppliers to stimulate improvement, the Japanese have been noted for their feed back of detailed data on failure during assembly and in the field, a more meaningful spur to improvement and aid to problem diagnosis.⁷⁹

The Japanese usually called their overall system either "total quality control" (TQC) or "company-wide quality control" (CWQC) to signify its integrated and broadly conceived character. Feigenbaum's 1961 book Total Quality Control was influential in Japan and was the source for the label they gave their system. But as both Juran and a leading Japanese authority on quality control noted, Japanese TQC was far different than what Feigenbaum had advocated, namely the detailed specification and allocation of quality related duties and tasks by the quality control staff.⁸⁰ Feigenbaum had been among the first to grasp the necessity for the integration of the quality related tasks of the various departments and saw it as a complex problem

⁷⁸ Juran, "A Contrast" p.14; Garvin, p.73.

⁷⁹ Juran, "A Contrast," p.14.

⁸⁰ J.M. Juran, "Then and Now in Quality Control: Remembrance and Prognosis," Quality Progress, Feb., 1976, p.9(note); Kaoru Ishikawa, What is Total Quality Control?, (Englewood Cliffs: Prentice-Hall, 1985) p.91.

is systems design. What Juran had advocated was much closer to what the Japanese accomplished. He had suggested that each department propose annual quality objectives just as they do budgets and that they be given specific incentives by top management to meet these objectives. He saw a need for widespread training in appropriate quality control skills (down to the lowest levels) to support such a line assumption of responsibility for the quality function. The Japanese thus realized the goals of both Feigenbaum and Juran: a comprehensive system of quality management relying on a thorough integration of quality control activities into the ordinary work of line departments. But they did it through massive company-wide training in quality control techniques and a highly collaborative, consensual mode of decision making that Americans would not have believed to represent a practical model of quality control had market defeat not made it seem absolutely necessary to emulate.

There is one more distinctive element of Japanese quality management --- what was referred to earlier as the "meaning of quality." This is not easy to put one's finger on although it is evident in much that has been written about Japanese quality management. The Japanese manufacturer's pursuit of quality goes beyond simply bringing costs down through an emphasis on prevention and strategically positioning the quality characteristics of products for the market. And it goes beyond training all

employees in quality control techniques and working collaboratively to set goals and share information. Hayes called it the impulse to pursue "the last grain of rice in the lunchbox." A manager at GM called it the sense of work as a Zen experience.⁸¹ The Japanese management of quality seems to have both an ethical and aesthetic character. Often, this is expressed crudely as a kind of zealous perfectionism with the implication being that perfection or "zero defects" must become the new American managerial standard. One moves closer to the essence of the Japanese approach to quality, however, when one focuses on the orientation toward continual improvement.⁸² This manifests itself both at the level of the annual top management audit of quality in which opportunities for reduction of quality costs and improvement of market position are broadly targeted, and at the level of the shop floor where there is a greater effort to generate small improvement projects and a greater management willingness to invest in them.⁸³ There is also a commitment to continual upgrading of employee skills in quality control as well as other areas.⁸⁴ The Japanese look at quality control not as the

⁸¹ Hayes, "Why Japanese Factories Work"; David Halberstam, "Yes We Can!," Parade, July 8, 1984.

⁸² Schonberger; Juran, "A Contrast."

⁸³ Juran, "A Contrast."

⁸⁴ Rubinstein, "Quality Control Requires a Social and Technical System." Continual training was a part of Deming's philosophy. ("What Top Management Must Do,"

satisfaction of predetermined design and performance standards but as a continuous pushing back of the limits of their ability to control manufacturing processes and to bring the priorities of process control into direct correspondence with consumer needs. If one looks at the manufacturing business as a complex web of activities, each linked to many others in means/end relationships then one can begin to see how difficult it is to direct each activity so as to serve the ends of all of the myriad activities downstream from it while making best use of the capabilities of all of those activities upstream from it. The inability to predict all of the consequences of manufacturing activities, particularly the production of defects, seems to be recognized in the Japanese emphasis on prevention and perfection. Perfection is a way of coping with the limitations of knowledge in the face of complexity. The Japanese gather extensive data on quality costs and consumer preferences but they know that the numbers cannot capture all of the inefficiencies caused by even minimal deviation from specifications.⁸⁵ (eg. the extra time it takes to make a part fit) or the long run market consequences of seemingly small differences in the

Business Week, July 20, 1981).

⁸⁵ The following two articles suggest this perspective: L. P. Sullivan, "Reducing Variability: A New Approach to Quality," Quality Progress, July 1984; Hitoshi Kume, "Business Management and Quality Cost: The Japanese View," Quality Progress, May 1985.

way products function. As Deming says, the "invisible numbers must be taken into account." "Who can put a price on a dissatisfied customer and who can figure out the cost of a dissatisfied customer?"⁸⁶

This last quote suggests an intrinsic as well as an instrumental value of quality. Quality is in fact the central value of Japanese manufacturing. For the Japanese, "all problems are quality problems."⁸⁷ When quality control is successful, there is no wasted motion, no time lost, the bullseye is hit every time and productivity is thereby enhanced. When product design is also closely tailored to the needs of the customer, there is a sense of direct service, of a clarity of purpose and the meaning of work that goes beyond the goal of producing profits and wages. While economic success is a precondition and goal of the viable manufacturing firm, the sights of Japanese managers and workers are set more squarely on the physical dimensions of the processes they work with and the on the needs they serve. By contrast, American manufacturing personnel have looked on their work as involving necessary and serious conflicts between quality and profit. Lower level employees in particular do not participate in and cannot understand the decisions to compromise or neglect standards in order to meet schedules or save money. As a

⁸⁶ Deming as quoted in Halberstam, "Yes We Can!" p.5.

⁸⁷ Robert Hayes, "Why Japanese Factories Work," Harvard Business Review, July-Aug., 1981.

result, they must simply accept directives from their superiors with a certain degree of cynicism and take their paychecks as certification of the value of their services. That the business of business is to make money, not useful products is an idea that is infused more deeply into the everyday American working experience.

Americans, however, proved quite susceptible to the new quality religion. The moral overtones of calls to improve American quality suggested quite clearly that financial success would not come to those who pursued it too directly and who did not genuinely care for quality in and of itself. The Japanese seemed to have proven it.

There is substantial evidence that American top management began to adopt many of the key features of the Japanese philosophy of quality management in the early 80's. By 1982, research showed that American manufacturers were beginning to emphasize prevention over inspection and to broaden their view of the quality function as something extending beyond the production department to engineering, customer service and other departments. Associated with this was an elevated status for the quality control department as quality control became viewed as a less narrowly technical function that had to be strategically guided by top management. These shifts in approach, however, were still, in 1982, characterized as being mostly

in the "idea stage."⁸⁸ By 1985, changes in quality management philosophy were more clear. In October 1985, Quality Progress, the principal trade periodical of the quality profession, published a special issue heralding an American "quality renaissance." This was done in concert with the publication in Fortune of a 24 page advertising section sponsored by a group of the most prominent American manufacturers to put forward their new approach to quality management.⁸⁹ Its principal themes were 1) the reduction of quality costs through better prevention, 2) the valorization and leadership of quality control by top management, 3) the commitment to continually improve quality 4) more participative forms of work organization and 5) closer working relationships with suppliers. Juran also noted several specific trends including movement toward strategic top management planning of annual quality improvement, the introduction of managerial incentives for quality results, increasing efforts to train non quality specialists in quality control techniques, particularly

⁸⁸ Leonard and Sasser, "The Incline of Quality," Harvard Business Review, Sept.-Oct., 1982.

⁸⁹ Jerry Bowles, "The Renaissance of American Quality," an advertising supplement to Fortune, Oct. 14, 1985. (sponsored by AT&T, Metropolitan Life, General Motors, AMP, McDonnell Douglass, Rockwell International, Chrysler, Lockheed, Caterpillar, Motorola, Polaroid, Dow Corning, Hughes Aircraft, and Kodak) It was stated in this supplement that a five year national corporate and public awareness program for promoting the "quality renaissance" was launched in 1985 under the sponsorship of the ASQC with the president of AT&T as its first year chairman.

statistical process control, the use of interdepartmental teams formed to tackle specific quality improvement projects, new efforts to develop accounting systems to capture quality control and failure costs, and of course, the use of quality circles.⁹⁰ Juran found it hard, however to be optimistic about the pace of change, mainly because of a lack of top management training and experience in the quality field. Despite the encouraging trend, Juran predicted that Americans would be the rest of the twentieth century in catching up with the Japanese.

Japanese Production Scheduling and Control

Interest in Japanese methods of production and delivery scheduling lagged the interest in Japanese quality control and worker participation by one to two years. This was probably due in part to the fact that scheduling is a more esoteric topic that has no obvious and direct link to the outward manifestations of poor management such as poor quality products or outmoded technology. It may also have been due to the fact that production and inventory control professionals were still preoccupied with MRP. They were devoting their attention in 1980 to figuring out how to get all of the constituencies of a complex manufacturing organization to support and work with MRP schedules and to expanding the MRP framework to encompass financial as well

⁹⁰ J.M. Juran, "Catching Up: How is the West Doing?" Quality Progress, Nov., 1985.

as manufacturing plans. There also seems to have been an absence of any professional in the field who had a longstanding involvement with Japanese industry as there was in the case of quality control. Still another possible factor was the recentness of the development of the Just-in-Time (JIT) production system which was gradually evolved at Toyota between 1960 and 1972. Japanese publications concerning the JIT system first began to appear in the mid 1970's.⁹¹

Significant professional interest in Japanese Just-in-Time production did, however, begin about 1980,⁹² which was also the year that GE began what was probably the first JIT program outside of Japan.⁹³ Most of the early publicity about JIT production was based on what was known about Toyota's system of production which was the model for other Japanese firms.⁹⁴ The news about Toyota was shocking because it turned basic assumptions about mass production on their head. Parts were manufactured in very small lots

⁹¹ Schonberger, p.17.

⁹² Ibid.

⁹³ Mehran Sepehri, Just-in-Time, Not Just-in-Japan, (Falls Church, VA: APICS, 1986), p.1.

⁹⁴ Among the earliest American publications on JIT to appear were Yasuhiro Monden, "What Makes the Toyota Production System Really Tick?" Industrial Engineering, Jan. 1981 (probably the first U.S. publication), "Adaptable Kanban System Helps Toyota Maintain Just-in-Time Production," Industrial Engineering, May, 1981, and "How Toyota Shortened Supply Lot Production Time, Waiting Time, and Conveyance Time," Industrial Engineering, Sept., 1981.

just before they were needed. The resulting work-in-progress inventories were almost nonexistent by American standards. Even suppliers often delivered in tiny lots several times a day. Production operations and deliveries were so precisely coordinated that they could not have been guided by formal schedules. Instead, work centers only produced small containers of parts one by one in response to signals that containers had been emptied by the work centers which they supplied. (The Toyota JIT system is called Kanban after the Japanese word for "card" since cards were used as the signals to produce.) Since work centers normally make a number of different parts, such responsiveness required an amazing ability to switch from job to job very quickly. Despite the number of trips made to deliver parts between operations, the economy of synchronized production with drastically shortened throughput time.

The first crop of American publications concerning JIT appeared in 1981. By 1983, U.S. firms were "just beginning, slowly and tentatively, to experiment with [JIT]."⁹⁵ In that year, the book that still stands as the primary reference work on JIT was published⁹⁶ joining

⁹⁵ Robert W. Hall and Jinichiro Nakane, "Management Specifications for Stockless Production," Harvard Business Review, May-June 1983, p.90.

⁹⁶ Robert W. Hall, Zero Inventories, (Homewood, IL: Dow Jones-Irwin, [Oct. 17,] 1983).

another major book published on the subject in 1982⁹⁷ and two books on the Toyota production system.⁹⁸ These books formed the basis of an educational crusade launched by the American Production and Inventory Control Society in October, 1983.⁹⁹ By 1985, "as many as 250" of the Fortune 1,000 were considering implementing JIT. The number of published articles on Japanese production and inventory control tracked the explosion of interest in JIT:

TABLE 3. Publications on the Japanese JIT System

<u>Year (August to July)</u>	<u>Number of Articles in the Business Periodical Index</u>	<u>Heading</u>
1980-81	0	Inventory
81-82	2	Control
82-83	10	"
83-84	21	"
84-85	29	"
85-86	46	Just-in-Time
86-87	43	"

The most radically new aspect of JIT was that it held out a physical image of the ideal production process as a guide and measure of progress in the coordination of manufacturing activities. This image was of the factory as a network of material flows as though each work station was

⁹⁷ Richard Schonberger, Japanese Manufacturing Techniques: Nine Hidden Lessons in Simplicity, (New York: Macmillan, The Free Press, 1982).

⁹⁸ Yasuhiro Monden, Toyota Production System, (Industrial Engineering and Management Press, 1983); Shigeo Shingo, The Toyota Production System, (Japan Management Association, 1982).

⁹⁹ Sepehri, p.25. This is the same association that launched the MRP crusade in the early 70's.

part of one great factory assembly line simultaneously producing many different products. Richard Schonberger, one of the most noted authorities on JIT, pictures the factory's networks as the rivers and streams of a great river basin, asserting that "we need to have concrete visualizations of what we are striving for."¹⁰⁰ Robert Hall, the leading authority on JIT, called his book "Zero Inventories" to evoke another key part of the image. Inventories are production flows that have been "dammed up" and accumulated into stocks. According to Hall, the level of inventories is a measure of production efficiency, and zero inventories, though not literally attainable, is "a guide to constant improvement, by big steps and small ones, to bring ourselves ever closer to the ideal."¹⁰¹

Inventories, according to the JIT philosophy, are the root of all evil. They represent waste because they create a need for large storage facilities, and a large group of time consuming activities and specialized personnel which do not add value to the product. Not only do inventories have to be moved to storage areas and back between operations, but they have to be counted and recounted and often rechecked for their location and condition. Furthermore, they create confusion on the shop floor and obscure the relationship between factory operations because

¹⁰⁰ Schonberger, p.130.

¹⁰¹ Hall, p.2.

each operation produces for inventory rather than directly feeding its output to the following operation. Inventories prevent delays that would occur if work centers attempted to tightly couple their operations, but the process irregularities (eg. machine breakdowns and parts drifting out of tolerance) that would cause the delays are therefore slow to be discovered and corrected.

All of the focus on the physical image of the ideal production process with its network of flows and minimal inventories contrasts strongly with the conceptual framework of MRP and conventional production and inventory control. What the production process should look like was irrelevant for them. The coordination of operations in MRP was only a matter of time coordinates on a piece of paper, each work center being given its own discrete instructions to follow irrespective of what upstream and downstream processes seemed to be doing on the shop floor.

MRP, like JIT, aimed at lowering inventories by triggering the production of inputs just before they are needed. But MRP practitioners still assumed that large batches are much more economical to produce than small ones. MRP was therefore used to generate schedules that allowed enough lead time for such large batches to be finished by the time they were needed. Extra lead time also had to be added in to protect against unforeseen delays. Thus, the principles of the traditional economic order quantity (EOQ) formulas still applied under MRP. In

other words, inventory levels were set so as to balance the costs of high levels of inventory (inventory holding costs) against the costs of low levels of inventory (frequent set-ups and risks of shortage).

From the JIT point of view, however, the costs associated with low inventory levels are not only to be calculated but to be attacked and eliminated so that a one-by-one flow of workpieces from work center to work center eventually becomes possible. For this to become a reality, each work center must become able to fabricate on short notice any part demanded of it from among those that it is assigned to make. There are two complementary ways of reaching this goal. (1) Improve the capacity of each work center to respond to the demands placed upon it. This can be done by reducing the time it takes to switch between jobs (ie. reducing set-up costs) and by refining processes to the point where the chance of delay caused by breakdown or production of defects is reduced virtually to zero. (2) Make the demands placed on work centers reasonably steady in terms of the mix of parts and overall production rate.

We will now examine each of these two halves of JIT production strategy more closely. A basic tenet of JIT philosophy is that set-up times do not have to be taken as given; that with sufficient focus on the problem, engineers can usually reduce set-up times drastically by one to two orders of magnitude, from several hours to several

minutes.¹⁰² It is emphasized that reducing set-up times is often a long, sometimes gradual process that requires study of the way machines are used in a particular context.¹⁰³ The range of parts a machine is called upon to produce and the similarities between the set-ups must be analyzed. Manufacturing engineers in Japanese JIT production firms are much more involved on the factory floor in making modifications to machines than are American manufacturing engineers,¹⁰⁴ and they often work closely with machine operators who have responsibility for their own set-ups and frequently have the insights needed to make improvements.

The costs of producing and transporting parts in small batches also needs to be brought down by making frequent transport more economical. This can be done by moving related work centers closer together and by having people pick up and deliver parts from several work centers at once. Some economy is gained by having parts made in such small quantities that they can be quickly and easily transported by hand without having to use a forklift truck.

If parts are to be made only in response to immediate need, processes must also be made extremely reliable through quality control and preventive maintenance. Hall states flatly that quality circles have been essential to

¹⁰² For examples, see Sepehri, pp.4-11,19.

¹⁰³ Hall, p.273.

¹⁰⁴ Japanese Productivity, Report of an APICS study tour to Japan in March, 1982, (Falls Church, VA: APICS, 1983) p.16.

the achievement of true JIT production,¹⁰⁵ for the number of small problems to be solved is too great to be dealt with exclusively by quality control specialists and engineers who are not in constant contact with particular processes. Statistical quality control is used extensively to provide early warning of changes in conditions that could eventually result in production of defects. There is also much use made of foolproofing devices (such as fixtures that don't accept parts that don't meet specifications) and warning lights and buzzers that alert workers to correct problems as soon as they appear. Preventive maintenance is pursued much more assiduously in Japanese firms, with careful records being kept of procedures performed and the frequency and types of malfunction. Workers are again relied upon to assist in diagnosis and to carry out routine maintenance checks. This gives them the capability to fix many problems quickly without having to call and wait for assistance.

Product and process engineers also play an important role in increasing process reliability. Japanese manufacturing engineering, and production personnel work closely together to ensure that processes will be easy to monitor and that machines will be easy to adjust and maintain. JIT also makes it crucial that product

¹⁰⁵ Hall, p.174. See also Mehran Sepehri, "Quality Control Circles: A Vehicle for Just-in-Time Implementation," Quality Progress, July 1985.

specifications be set in cooperation with manufacturing engineers and shop floor personnel so that requirements are well understood and as easy to meet as possible.

In a JIT production system, there is constant pressure to increase reliability and flexibility of processes. Often, this pressure is purposely increased by removing a portion of the buffer inventories that remain between operations. In response to this, work centers must gear the rate of production of their various outputs more closely to the rate at which they are used in subsequent operations. Keeping up the required average rate of production becomes insufficient because the pace must be met hour by hour, for example, rather than day by day. There is less ability to tolerate unusually long set-ups, extra adjustments, quality checks, and the like. This situation is a stimulus to engineers, supervisors and quality circles to reduce set-up times even further and eliminate more sources of variability in the process. When problems surface and become solved as a result of systematic withdrawal of inventories, progress is made toward the continuous flow/zero inventory ideal.

Productivity is typically increased at the same time because reducing the variability of a process usually simplifies and speeds it as well. Quality circles and supervisors often draw on the expertise of industrial engineers to help them streamline tasks using traditional Tayloristic analysis. Thus, inventory reduction is

regarded as a device for spurring continual productivity improvements. A very frequently used analogy for this process is the lowering of a river's water level to expose the rocks below the surface.

If work centers are to flexibly and reliably respond to the demands placed upon them, they must also be subject to a reasonably predictable magnitude and mix of demands that will allow them to plan for an appropriate complement of personnel, equipment, and tooling and to develop a regular and controllable rhythm of work. To achieve this, the final product production schedule is "levelled" so that approximately the same amount of each final product is produced every day. The rates of production are revised every 10 to 30 days or so. Although this smooths out the fluctuations in market demands, it tracks demand more closely than conventional large batch production in which, for example, one model is produced one week and another model the next. Final product inventories are lower as a result. In the case where production is based on customer orders rather than sales forecasts, orders are accumulated for a short period of time and the demands for the various end products spread out evenly over each 10 to 30 day period of the production schedule. Even though the production of some orders may be delayed, customer service is likely to improve because the time required for production has been shortened by the reduction of work-in-progress inventories.

The creation of a level schedule commonly presents the challenge of designing a mixed model final assembly line on which various models progress through work stations in a sequence which repeats itself several times daily. Just as with individual machine set-up times, special attention needs to be focused on perfecting quick changeover between models and balancing work loads at each station in this more complex situation. Since assembly is more labor intensive than parts fabrication, this may not be too difficult --- eg. workers might simply pick up different tool.

Once a level final assembly schedule and mixed model final assembly line has been established and the processes at the work centers which feed into it have been made flexible and reliable, the system can be run in a tightly coordinated fashion while accepting a modest amount of variation in the demands placed upon it. Between schedule changes, production rates at work centers can generally be adjusted by about 10% in either direction in response to demand changes and production problems.¹⁰⁶ More substantial changes in production rates of any of the various components and end products must be responded to by redeployment of workers and equipment. To facilitate such reorganization, foremen rather than staff are given the responsibility to carry it out. Flexibility is enhanced by

¹⁰⁶ Hall, p.132.

emphasizing the training of workers in a wide variety of tasks¹⁰⁷ and investing in small, inexpensive machines that can be easily moved or recombined and economically held as reserve capacity.

With sufficient flexibility and reliability, and sufficient planning for expected rates of production, each work center can track actual needs as they are experienced on the shop floor instead of being governed by a schedule. There is little need to keep track of individual work center output or efficiency since all activity in a plant is geared closely to the rate of production on the final assembly line.¹⁰⁸ The emphasis is shifted from "reporting and controlling" to "planning and executing."¹⁰⁹

In the fully developed JIT production system, parts are only fabricated in direct response to signals that they have been used by a subsequent operation. This is called a "pull" system as opposed to a "push" system in which parts are made according to a schedule in anticipation of need. But production of parts can be triggered by a schedule and still begin to approximate the character and benefits of JIT production. Where a level schedule for final assembly can be established and the reliability and flexibility of most processes has been substantially improved, the

¹⁰⁷ Many Japanese companies adjust pay according to number of skills learned. (Schonberger, p.135)

¹⁰⁸ Japanese Productivity, p.18.

¹⁰⁹ Ibid.

schedule, although it anticipates the needs for components, does not do so by much because of shortened lead times. The schedule is therefore more accurate while being subject to less disruption because of the increased reliability of processes. As a result, the need for work-in-progress inventories is reduced. By contrast, production according to schedules made under ordinary conditions is subject to far more disruption due to greater volatility in the rates of production of final products, the need to plan for needs that are further in the future because of longer lead times, and more frequent delays due to unreliability of processes. Higher inventory levels must be built up to compensate for all of this instability.

The coordination of activities in the JIT production system is facilitated by a comprehensive and thoughtful effort to make the relationship of all activities on the factory floor clearly visible to all who work there. Meticulous housekeeping and clear designation of the places where each item is kept is the foundation of this effort. Lack of clutter and dirt cuts down on confusion, reduces mistakes and increases the ability to spot lubricant leaks and other abnormal conditions. Inventories are used as the most important visual signal of work status. They are placed in containers of standard size so they can be counted at a glance. In Toyota's Kanban system, cards are hung prominently on posts at each work station showing how much of each item currently needs to be produced. Often,

there is a kind of electric scoreboard in the middle of the floor showing the rate of production of final products and indicating delays or impending shutdown at individual work centers. Lights operated by workers at production line work stations indicate problems so that workers can shift from their station to help out.

The vision of work flow without inventories which guides the organization of internal activities extends as well into the plants of suppliers. The JIT manufacturer thinks in terms of linking and synchronizing the processes in its own factories with those in its suppliers' plants, and the supplier network is seen as part of an integral industrial unit which must be developed as a whole.

The pursuit of this vision is predicated on the stability of relationships with suppliers. In Japan, large manufacturers are bound to their suppliers by ties of mutual loyalty, and suppliers that are the sole source of the parts they make are the norm. This contrasts with the typical American practice of taking bids from several suppliers on each job to get the lowest possible price and buying the same item from several suppliers in order to provide insurance against supplier failure or attempts to gain bargaining leverage. In Japan, however, there is much less priority placed on the ability to get a lower price by switching suppliers. Close, long term working relationships are valued more highly because they offer the

opportunity to guide the development of supplier capabilities and gear them more closely to the firm's particular quality and delivery requirements. Not only purchasing agents, but engineers and production personnel work with the supplier so that both supplier and customer develop familiarity with each others' operations.

Japanese JIT manufacturers such as Toyota have attempted, though with only partial success, to get their suppliers to adopt JIT within their plants. They know that if suppliers meet JIT quality and delivery requirements by keeping large inventories on hand and performing exhaustive final inspection, they will end up paying most of the cost of these inefficient practices in the long run. JIT manufacturers have therefore made substantial efforts to educate their suppliers to the JIT approach, sometimes by bringing in supplier personnel to work in their own plants.

The first step toward JIT production for suppliers is the development of quality control capability, just as it is for the large manufacturer itself. The ultimate goal for the large manufacturer in developing supplier quality control is to avoid having to inspect incoming shipments (an additional inventory-creating step). The high degree of reliability that needs to be achieved to reach this goal is dependent upon the supplier reducing its reliance on final inspection and getting its processes under very tight control. Familiarity with supplier operations helps the JIT manufacturer to educate the supplier in quality control

and sometimes to diagnose and solve its quality control problems. Suppliers' quality performance is also enhanced by attempts to take advantage of the supplier's expertise by stating specifications in a general way. The supplier can determine the remaining specification details to make quality control simpler (and production less costly). After quality control, the most important step in moving suppliers toward JIT capability is giving them a stable and timely projection of needs so that they can develop a reasonably level schedule of their own. This, of course, depends on the degree to which JIT production has developed in the large manufacturer.

Delivery scheduling is another part of JIT production which needs to be closely coordinated with suppliers. Often, suppliers will deliver parts only when they receive a signal from the specific work centers they supply in the customers plant just as any other work center on the customer's shop floor. Transport of small shipments several times per day from supplier plants is facilitated in Japan by the willingness of the highly dependent supplier to locate its plants near the customer's plants. Both the proximity and stability of the supplier network enables the development of truck routes that allow shipments to be picked up from several plants and delivered together.

Development of Automation Through JIT Production

As progress is made in reducing the level of inventory that needs to be accumulated between a sequence of operations, those operations become more and more synchronized. That is, work centers come close to producing each item only while it is being used by downstream processes and switching over to produce different items almost simultaneously with the work centers they supply. One way of approaching such tight synchronization is by developing more specialized machinery. A work center may discover how to avoid entirely the problem of set-up for certain parts by devising a separate machine for making them. Since the level schedule makes demand for each individual part slow and steady and because they need only limited capability, these machines do not have to be very sophisticated or expensive. They are usually designed by in-house engineers to suit the pace and character of production anticipated for the plant. Production personnel including quality circles work closely with the engineers in developing their specifications. This gets around the problem of not being able to automate because the machines available on the market are designed for a higher rate of production and broader capabilities and are therefore expensive.

When synchronization reaches an advanced stage, opportunities to physically link different stages of the production process begin to present themselves. A relatively simple way of doing this is to link existing

dedicated or highly specialized machinery. Another way is to segregate groups of similar parts that follow very similar processing sequences and manufacture them in "group technology cells." Reduced diversity of parts and standardization of processing sequence allows tighter coordination between processing steps.

When processing steps are grouped together in a cell, quality control may be expected to improve. The effect of deviations at one stage can be easily observed at another stage, and there is more opportunity for machine operators to provide immediate feedback on each others' work. This situation can generate ideas for simple ways to prevent defects such as designing the process of loading workpieces into machines so that the results of the previous operation are checked. When quality can be tightly controlled through several stages of processing at once, the stage has been set for automation. This, of course, suggests a principle which is opposite to American ways of thinking in which improved quality is almost always thought of as a result of automation, not its precondition.

Another beginning step toward automation is the streamlining of workpiece positioning at each station in the cell. Gradually, ideas can be generated for mechanizing the transference of workpieces between machines. For this, ways must be found to match or at least to compensate for any difference in the length of the work cycle at each machine. The material handling

equipment that Japanese JIT firms use is generally relatively simple and designed in-house. As a matter of strategic philosophy, major pieces of automatic equipment are not acquired until a process has been rationalized and refined to the point where the capabilities required of the equipment can be precisely specified in terms of production rate (it cannot be too fast to work in synchrony with surrounding processes), ability to link with other equipment, ability to hold appropriate tolerances, and degree of flexibility with respect to workpiece configuration and other characteristics. Machines are not thought of as ways to deskill workers, but as solutions to production problems which workers have helped to reduce and clarify as a result of rationalizing operations through JIT production.

Thus, continual efforts toward increasing reliability and synchrony amount to an evolution toward automation --- as Hall puts it, JIT production "becomes a philosophy of debugging the way to automation."¹¹⁰ The end result of such a process in a Toyota engine plant was described by Hall as follows:

[The plant] produces six-cylinder engines, 1,500 engines per day with two shifts and 161 total employees. One afternoon the author observed 48 people working--28 in final assembly, 9 in test, 3 at material handling, and the rest roaming through several acres of equipment, keeping it tended.

The Kamigo plant is highly automated, but there are no robots, and none of the equipment is programmed by advanced

¹¹⁰ Hall, p.145.

methods. The equipment appears to be 1950's vintage equipment, all modified and connected by transfer lines and devices developed in-house. The sensors and signaling system employ very little that cannot be purchased in an ordinary hardware store. This plant was developed by stockless [JIT] production, and it reached a state of full automation about 1966.

Block castings enter the plant fresh from the foundry and emerge as finished engines 6 and 1/2 hours later. From pouring the block until it is mounted in a vehicle averages 36 hours. Physically crude it may be, but no offloading and reloading interrupt the progress of material through the Kamigo plant. The defects in the system are minor because it was developed by carefully applying what was available to the needs of the production process--no technological overkill.

Linking all this equipment together required modification to balance the cycle rates on all machines.¹¹¹

The signaling system referred to in this passage consists of devices that allow workers to oversee the operation of many machines at once. Although this type of automation lacks sophistication, its limitations are overcome by the use of lights and buzzers which can be relied upon to call attention to the need to change tools and make adjustments. Heavy use is made of devices to shut down machines automatically when they malfunction. Japanese workers are typically well enough trained to respond quickly to problems of a variety of machines.

The Japanese Use of Programmable Automation

In the early 80's, a large part of Japan's advantage seemed to stem from its willingness to invest for the long term. Robots appeared to be a prime example since Japan was frequently cited as having a three to one lead in the

¹¹¹ Hall, p.146.

number of robots installed.¹¹² Even more impressive, were the futuristic factories of Fanuc and Yamazaki, to which no other factory in the world could compare in degree of metalworking automation. One of the Fanuc factories consisted of 60 flexible manufacturing cells and 101 robots that machined parts and assembled them into electric motors. People performed maintenance during the day and left the factory to operate by itself at night. Fanuc claimed that another of its factories with 30 machining cells and a number of material handling robots required only one tenth the capital investment and one tenth the labor force of a conventional plant with similar capacity. A Yamazaki factory with 65 CNC machine tools and 34 robots was designed to be run largely by remote control from corporate headquarters. Its labor force of 215 supposedly compared to a labor force of 2,500 in an equivalently productive conventional plant. Another Yamazaki plant with the capacity for untended night shift operation was reported to make parts in three days that would have taken three months in an ordinary plant.¹¹³

Against this kind of backdrop, visitors to Japan were surprised to find that the general level of technical sophistication in Japanese plants seemed approximately the

¹¹² Friedrich, p.74.

¹¹³ Gene Bylinsky, "The Race to the Automatic factory," Fortune, Feb. 21, 1983.

same as in American plants.¹¹⁴ This conclusion must have added support to the consensus that America's lead in computers and software, and its ability to innovate were key potential advantages over Japan. Gradually, however, it was discovered that there were lessons to be learned from Japan about how to apply the new technology. As early as 1981, a distinctively Japanese approach to automation was suggested in the literature on Japanese quality control¹¹⁵ and, as we saw, in the literature on JIT production. A different approach was also suggested by Hayes who, on a tour of Japanese plants, had noted many more untended machines¹¹⁶ and greater use of machines designed in-house¹¹⁷ though without making a connection to the JIT system.

The role of robots in Japanese manufacturing has rarely been interpreted within the JIT framework, yet there

¹¹⁴ Surprise at the lack of Japanese advantage in the sophistication of production equipment was expressed by Hayes in "Why Japanese Factories Work". The surprise of the early 80's was also recalled in Ernest Raia, *JIT U.S.A. Purchasing*, Feb. 13, 1986, p.50; A 1981 study tour to Japan by the National Machine Tool Builders Association found U.S. and Japanese production technology roughly equivalent. (David Noble, *Forces of Production*, p.341.)

¹¹⁵ Kaoru Ishikawa, "Company-Wide Quality Control-Revolution-Management," *Annual Quality Congress Transactions 1981*, as reprinted in *Quality Circles Papers*, pp.27-8; Crocker et al., p.24; The Japanese view of quality control as a precondition for automation was well described later by David Garvin in *Managing Quality: The Strategic and Competitive Edge*, (New York: Macmillan, The Free Press, 1988) p.211.

¹¹⁶ Hayes, p.60.

¹¹⁷ *Ibid.*, p.64.

has been substantial evidence available since the early 80's that such an interpretation is appropriate. One report on the Japanese use of robots emphasized that highly effective quality control and preventive maintenance, along with standardized work procedures and timely delivery of materials were the foundation on which the best Japanese robot installations were established. Elsewhere, it was noted that in Japan, there was especially wide use made of robots for simple parts transfer operations¹¹⁸ and a relatively heavy emphasis on application as opposed to sophistication.¹¹⁹

Robot population counts themselves pointed to a different Japanese approach to robots. The first clue was that it was harder to define what is meant by "robot" in Japan.¹²⁰ The Japanese Industrial Robot Association counted several times the number of robots in Japan than fit the Western definition.¹²¹ Many of the Japanese robots, it was noted, were actually simple parts transfer devices that were not programmable or that required a human operator to function. By some estimates, Japan did not

¹¹⁸ Tech Tran Corporation, Industrial Robots: A Summary and Forecast, 2nd ed., (Naperville IL: Tech Tran Corporation, 1983) p.3.

¹¹⁹ Ibid., p.167.

¹²⁰ U.S. Dept. of Commerce, "A Competitive Assessment of the U.S. Flexible Manufacturing System Industry," p.32.

¹²¹ Schonberger, pp.122-23; "Robots Join the Labor Force," Business Week, June 9, 1980, p.64.

even have a lead in robots.¹²² According to a strict definition of robot, Japan actually uses fewer of them in a materials handling capacity than Western industry.¹²³ The large number of simple machines only marginally considered robots suggested that Japanese robots in general were being used to solve relatively limited, well defined problems that had been framed in the course of evolution toward JIT production. In fact, the question was eventually raised whether the Japanese might not be neglecting the benefits of the newer, more flexible assembly robots in its bias against automating complex human tasks until they have been simplified and streamlined by conventional means.¹²⁴ Apparently, the Japanese are more likely to use robots to replace dedicated machinery. It has been found in an internationally comparative study of the use of programmable automation in the auto industry, that robots were used to increase flexibility by replacing dedicated equipment in about 50% of Japanese installations, while in the U.S., robots were almost always used to replace people. The same study also noted that people-replacing robots tended to replace fewer people per robot in Japan because

¹²² Harley Shaiken, Work Transformed, (Holt, Rinehart, and Winston, 1984) p.164.

¹²³ Susumu Watanabe, "A Synthesis of Findings," in Susumu Watanabe, ed., Microelectronics, Automation and Employment in the Automobile Industry, (John Wiley, 1987) p.182.

¹²⁴ Robert Poe, "Inflexible Manufacturing," Datamation, June 1, 1987.

processes were already more automated due to the development of many simpler kinds of equipment developed largely by quality circles.¹²⁵

As the discussion in the last chapter made clear, flexible manufacturing systems (FMS) are capable of eliminating virtually all work-in-progress inventory and organizing a continuous flow of workpieces between work stations. Advances in FMS technology were therefore sometimes seen as complementary to the development of JIT production¹²⁶ or even as a substitute for it.¹²⁷

But in the mid 80's, it was discovered that American and Japanese FMSs performed very differently from each other. A shocking report of detailed research on over half of the FMSs installed in both the U.S. and Japan was published by Ramchandran Jaikumar in November 1986.¹²⁸ Physically, the FMSs were found to be quite similar --- an average of 6 machines per system in Japan and 7 per system

¹²⁵ Watanabe, pp.186,87.

¹²⁶ Schonberger, p.126; Mehran Sepehri, "JIT and FMS: A Working Team for Factory of the Near Future," Production and Inventory Management and APICS News, April 1985, p.8. A paper by a Toyota employee on the JIT system was included in a collection of technical papers on FMS under the guise of representing another approach to FMS production. Atushi Masuyama, "Idea and Practice of Flexible Manufacturing System of Toyota," in A. Raouf and S. I. Ahmad, Flexible Manufacturing: Recent Developments in FMS, Robotics, CAD/CAM, CIM, (Elsevier, 1985).

¹²⁷ Sumer Aggarwal, "MRP, JIT, OPT, CIM?" Harvard Business Review, Sept.-Oct. 1985, p.16.

¹²⁸ Ramchandran Jaikumar, "Postindustrial Manufacturing," Harvard Business Review, Nov.-Dec. 1986.

in the U.S. The products made on them were similar as well. Yet the Japanese FMSs produced an average of 93 parts while U.S. systems produced an average of 10. 22 new parts were introduced into the average Japanese FMS per year while only 1 part per year was introduced into the average American FMS. At the same time, the productivity of the Japanese systems was far greater. Their utilization rate averaged 84% over two shifts compared to only 52% for American systems, while one third of the Japanese FMSs could operate untended at night. None of the American systems could do so.

The poor performance of the American FMSs was attributed by Jaikumar mostly to the level of operator training and the character of the tasks given to operators by management. 40% of workers at Japanese firms were college educated engineers compared to 8% of American workers. All Japanese workers were trained on CNC machines, while only 25% of American workers were. American workers were restricted to following pre-established procedures while the Japanese workers were responsible for writing new programs and were expected to work as a creative team in devising ways to improve performance.

Thus, the source of Japanese success with FMS technology was little different from the source of Japanese success with conventional technology --- well trained employees integrated into small groups geared toward

achieving a physically defined ideal of performance. In this case, Jaikumar identified untended operation as the critical lodestar of development, although 100% up-time and maximum flexibility were important goals as well.

American firms seemed to lack any such guiding developmental goal. They appeared to conceive their FMSs to be optimized at the design stage and to believe that after installation, performance standards should be met by routine operation. This attitude helps to explain the paradox that American systems were generally designed for far more flexibility than their users were prepared to exploit and took over four times as many hours of work to develop, install and get running. As it turned out, some American firms began, in the mid 80's, to complain that their systems were not even flexible enough by their own standards, let alone Japanese standards.¹²⁹ The problem appeared to be that the parameters of FMS flexibility had been set in terms that were too general and open ended, resulting in insufficient focus on the specific dimensions of flexibility needed.

Initial difficulties with full-scale FMSs, as well as their enormous expense, steered the manufacturing automation market toward small flexible manufacturing cells in the mid 80's. The suppliers of FMSs began to stress concepts such as "appropriate flexibility" and a modular,

¹²⁹ Jeffrey Zygmunt, "Flexible Doesn't Always Fly," Across the Board, Dec. 1986.

developmental approach to building larger systems.¹³⁰ This was noted to be the typical Japanese approach to FMSs.¹³¹

Cell by cell automation was sometimes seen as a way to ameliorate problem of a lack of continuity in the personnel assigned to design and manage American FMSs. Special project teams would typically be formed to design the FMS and then disband, often dispersing back to other firms after operation began.¹³² The learning involved in setting up the FMS was therefore lost to those who had to use it. Japanese design teams, on the other hand, stay with the system for a substantial period of time as operators. Building up factory automation cell by cell began to be recognized as a way of developing the experience of employees who are closer to operations and involving them in tailoring the new systems to detailed manufacturing needs. These needs could get overlooked in large system

¹³⁰ Zygmunt; Mark Sfiligoj, "In FMS Circles, Bigger May Not Always be Better," American Metal Market/Metalworking News, June 1984).

¹³¹ "Flexible Manufacturing , Inflexible Management," Technology Review, July 1985, p.79; James B. Pond, "Flexible Manufacturing Systems in U.S. Falter as Operators Seek to Overcome Planning, Utilization Deficiencies," Metalworking News, Oct. 12, 1987, p.22.

¹³² Jaikumar, p.71; James Pond, "Firms Learn About Potentials of FMS, But Organizational Problems Hamper Realization of Successful Utilization," (based on an interview with Margaret Graham and Stephen Rosenthal, authors of a study of 8 FMSs entitled "Institutional Aspects of Process Procurement for Flexible Machining Systems," Manufacturing Roundtable, Boston University) Metalworking News, Oct. 12, 1987, p.22.

design¹³³ which is usually dominated by computer specialists rather than manufacturing engineers because of the complexity of the programming and communication networks involved.¹³⁴

Some FMS users also began to backtrack toward a JIT approach to automation.¹³⁵ John Deere which had been one of the most celebrated pioneers in FMS technology underwent an especially dramatic change in philosophy. Although its FMS had performed adequately by financial standards, vice president James Lardner observed that the same economies could have been achieved at perhaps one fifth the cost by simplifying shop floor organization in line with JIT concepts.¹³⁶ In particular, he said, parts could be redesigned to be simpler and share more common features. This would allow them to be classified into groups with similar machining requirements and produced together in

¹³³ Zygmunt, p.54; Robert E. Harvey, "Bottom-Up Automation," Metalworking News, May 11, 1987.

¹³⁴ Harvey, p.20.

¹³⁵ F.L. Caldwell, managing director of Ingersoll Engineers, a manufacturing consulting firm, described preparing clients for automation through improvement of housekeeping and moving sequential work areas together, and then beginning with small manufacturing cells.(Zygmunt, p.54) Another consultant, Rex Peterson of Micro Managers Inc., a firm specializing in technology integration, talked of rearranging equipment and focusing on production flow before beginning to automate.(Harvey, p.20)

¹³⁶ James Cook, "Back to Simplicity," Forbes, Aug. 25, 1986; Lauri Gieson, "Deere Abandoning Focus on Flexible Manufacturing Systems," American Metal Market/Metalworking News, March 24, 1986; Zygmunt, p.54.

manufacturing cells using much less expensive equipment. As explained above, group technology cells are one of the key devices for bringing sequential operations closer together, increasing synchronization of operations, and cutting inventories under JIT production. Another new Deere priority became the reduction of set-up times to set the stage for advanced automation.¹³⁷

By all accounts, most U.S. firms tend to think of exemplary automation in terms of pre-engineered, complete systems that wholly replace the systems that preceed them. However, there are recent signs that the tide of opinion is beginning to turn against the idea of giant leaps into total automation and towards simpler, more piecemeal automation that complements development of existing processes toward JIT production. Says a vice president of the Boston Consulting Group, "In the last five years there's been a shot of insight into how the Japanese have reduced their costs." "We've learned it doesn't always require massive investment and fully automated production systems."¹³⁸ No longer do the Fanuc and Yamazaki factories represent the essence of the Japanese approach to automation.

Business Week recently published a special report on the "productivity paradox" which maintains that most of the

¹³⁷ Zygmunt, p.52.

¹³⁸ "Upgrading of Factories Replaces the Concept of Total Automation," The Wall Street Journal, Nov. 30, 1987.

drive to automate in the early and mid 80's was misdirected because it was targeted primarily at labor replacement.¹³⁹ The most telling and best known example of failure of the conventional approach to futuristic automation is GM's Saturn plant which performed poorly in comparison to the GM-Toyota joint venture in California which used the JIT system.¹⁴⁰ The Wall Street Journal and Business Week both cite several examples of a small new crop of plants that are rejecting total automation in favor of a strategy of reducing inventories, improving quality control, increasing flexibility and setting up participatory work groups, the basic elements of the JIT system. Thus, Japanese principles of management, transplanted to American soil in the early 80's, continue to bear new fruit as the coherence of those principles becomes better understood and Japanese manufacturing continues to demonstrate superior performance.

¹³⁹ "The Productivity Paradox," Business Week, June 6, 1988.

¹⁴⁰ "The Productivity Paradox," pp.100,101,112; David Forbes, "The Lessons of NUMMI," Business Month, June 1987.

CONCLUSION

The Taylor paradigm is grounded in the view that production organizations function best when there is complete separation of planning and execution and when those who plan have both the ability to measure the performance of those who execute and the power to determine their rewards and punishments. It is believed that the elimination of all planning and discretionary elements from work tasks (since such elements take highly variable amounts of time) allows productivity standards to be more easily set and rationalized. Work standards represent both the ability of planners to optimize and precisely to specify job methods and the basis for proportioning rewards to worker performance.

One of the most important aspects of detailed specification of the tasks of individual workers is that theoretically it relieves workers of the need or responsibility for actively coordinating their work with the work of others. It is presumed that managers will preplan the actions on the shop floor so that they mesh smoothly, even without awareness on the part of workers of how their work is related to the work of those around them. The assembly line has become the symbol of modern

production partly because it suggests the possibility and efficiency of perfectly integrating individual work efforts without significant coordinative interaction between workers.

Curiously, the Taylor paradigm not only atomizes workers, it fractionates the planning function as well. Taylor recognized how complex the coordination and specification of worker tasks would be without reliance on worker initiative. As a result, he advocated placing workers under a group of eight specialized functional foremen. Later, the bureaucratic corporation tended to develop separate units to plan each phase and dimension of production, each of these entities jealously guarding its right to make decisions within a designated sphere. We have seen how the organization of quality control and scheduling have both fit this pattern. Thus, in the Taylor paradigm, work, whether of the planning or executing variety, is seen as dividing naturally into largely independent components. One aspect of this independence is the organization of activities into rigid sequences. To take a most important example, manufacturing personnel must begin their work only when process engineers have finished theirs, and they in turn must wait upon the finalization of designs by product engineers. This is as commonplace as the expectation that execution of task follows planning or that a worker on an assembly line starts his/her task only when the preceding workers have finished theirs.

In Japan also, there is a positive correlation between hierarchical level and planning responsibility. Also apparent, however, is the Japanese emphasis on developing the capacity and motivation to make contributions to planning at all levels of the organization. There is specification of task from above, but there is also the expectation that the word from above is not the final word, that those who follow instructions will be capable of improving those instructions. Nor have the Japanese lacked the ability to measure worker performance and to reward and punish it proportionately. But the Japanese do not try to facilitate the measurement of performance and reward by removing scope for initiative and setting fixed performance standards.

Some have seen in Japanese production management mainly a more subtle means of discipline and control, and no doubt the Japanese paradigm does operate as a mechanism for the social control of the work group and the firm, both interpreted and constructed as an analog of the family. But also fundamental is a distinctive view of the locus of knowledge and learning in a production organization. It is not considered possible for managers to adequately specify ahead of time all of the tasks of those in their charge. Progress, especially, is held to depend on a stream of grass roots initiatives. Consequently, workers at the lowest level are trained in solving problems while those with more technical training and status are expected to

work in close concert with shop floor personnel. People at all levels of the organization work in groups, not only to enable a more efficient communication of instructions, greater flexibility in deploying workers, or tighter social control, but also in order to facilitate the drawing and integration of knowledge from every niche in the producing organization. In Japanese manufacturing firms, more use, not less is made of time and motion studies and all the formal techniques of scientific management. But those techniques are not used exclusively by industrial engineers but by workers as well in efforts to streamline their own tasks.

Grass roots initiative has yet another dimension in the Japanese manufacturing paradigm. It does not remain confined to improvement in the workers' individual tasks considered in isolation. Rather, initiatives are directed largely toward the improvement of production as a system. Workers are not expected to possess an analytical grasp of the system comparable to that of upper level management. However, we have seen how the Japanese organization of both quality control and scheduling causes the character of the overall system to be reflected in the relationships that the shop floor worker can see between his/her work and the work of others immediately upstream and downstream in the production process. There is much emphasis on mechanisms for immediate feedback on quality problems and on matching rates of production and consumption at successive stages of

production thus making concretely visible the level of systemic coordination and performance.

From the shop floor, the striving for better quality and synchronization of operations does not always appear to improve the productivity of individual operations. Rather, workers perceive that it contributes most directly to the per-unit value of output in terms of quality and the timeliness of delivery, either for the consumer or for the next operation. However, defect-free production and greater production flexibility provide benefits to the system that may not be directly calculable or immediately apparent --- benefits in the form of ease of manufacture, customer satisfaction, and reduction of the need for the ancillary activities of inventory management and quality control with the complexity and confusion they add to the shop floor. Productivity is thus enhanced for the system as a whole, not by directly focusing on increasing the individual work station's ratio of units of output to units of input, (simple "quantitative" productivity) but by improving the per-unit value of the output. But even the "quantitative" productivity of individual manufacturing operations is improved indirectly by establishing defect reduction and minimal set-up time as primary shop floor goals. For it turns out that the analysis of the causes of defects and the difficulties involved in switching from production of one item to another tends to suggest innovations that simplify and streamline operations. It

turns out that productivity is not the most useful conceptual guide to ways to improve productivity.

Thus, in the Japanese manufacturing paradigm, quality and synchrony are used as concrete shop floor goals, making work into a developmental activity and guiding development toward the enhancement of systemic performance. This contrasts with the Taylor paradigm's focus on predetermined time, methods, and quality standards, and on increasing efficiency, operation by operation, by installing new equipment or by increasing worker diligence through improved discipline or the introduction of incentives.

The shop floor goals of quality and synchrony serve not only a systemic integration and development function but a motivational function as well. They are dynamic and multifaceted and present a continual challenge and a field for the exercise of skill, knowledge and initiative. Their elevation to first level priority also makes the demands on the worker more consistent and gives workers' tasks more integrity. In the typical manufacturing environment, workers are often forced to make sacrifices of quality in order to meet work quotas or delivery dates and to shift priorities abruptly between making a quick response to demand and preserving the stability and efficiency of long production runs. The decisions to sacrifice quality and shift work priorities are made by managers according to criteria that workers are not in a position to understand; hence the inclination to internalize work standards and

goals must be frustrated. In the Japanese paradigm, quality and flexibility are consistently pursued because they are regarded as virtually intrinsic to the advance of productivity, certainly in the long run. This perspective translates into job requirements that are not arbitrarily shifting and conflictual but stable and integrated, allowing workers to grasp the criteria for the successful performance of their jobs.

Finally, the effort to synchronize operations and the search for the causes of product defects encourages a collaborative, group-based organization which makes work more socially rewarding. Long before 1980, experiments had been tried with the formation of work groups that could reduce monotony by rotating tasks among their members or by permitting informal interaction that would overcome the worker's sense of isolation. The Japanese manufacturing paradigm has instituted work groups not as an artificial social device but as a logical outgrowth of the need to share information, investigate problems and improve coordination.

In the Japanese manufacturing paradigm, not only shop floor workers but also managerial and engineering personnel work collaboratively to coordinate production. Problems are regarded as typically systemic in character, requiring the continual integration of knowledge and perspectives from many quarters. There is no deep fractionation of managerial functions or keenly guarded boundaries of

authority between those responsible for different phases and branches of production. Quality control and scheduling, for example, are regarded as closely interrelated rather than mutually isolated functions as they tend to be in typical American firms. Neither is a rigid sequence adhered to in the progression from product engineering to process engineering to manufacturing to sales and service. Collaboration between each of these phases is considered essential to development of the manufacturing business as a system and is fostered by the circulation of engineers to the shop floor and the sales field.

The systemic/developmental concept is also applied beyond the boundaries of the firm, in its connections with suppliers and customers. With both groups, relationships are less purely transactional than they tend to be in a firm guided by the Taylor paradigm where the only overlapping concern of producer and consumer is price and number of units exchanged. Japanese firms attempt to achieve a continuity and mutual loyalty in their relations with suppliers and customers that will allow them to develop detailed reciprocal understandings of needs and capabilities. Close working relationships with the supplier network extending to exchanges of personnel are geared toward improving systemic productivity and ability to meet customer needs through collaboration on solving quality problems and bringing supplier operations into

synchrony with internal operations. Customer experiences with products are very closely studied with mechanisms established to feed information back to product engineering and the shop floor, while the flexibility of manufacturing processes is molded to track the pattern of customer demands.

To sum up, the Japanese manufacturing management paradigm is a systemic/developmental paradigm in which both the development and coordination of the system derives substantially from interdepartmental and shop floor collaborative initiatives rather than being the product of comprehensive design imposed from atop the organization by a central authority or by a series of technical authorities with jurisdiction over conceptually independent dimensions of the manufacturing enterprise. The complexity of problems (and opportunities) which stems from their systemic character is the very thing which requires collaborative grass roots initiative. The new manufacturing paradigm is thus based on a fundamentally different view of the organizational locus of learning and knowledge needed for the development and coordination of a large manufacturing system. The great innovation of the Japanese is to devise a system in which systemic values in the form of quality, flexibility and synchrony have been brought concretely and visibly to the "local" level.

The Japanese manufacturing paradigm became powerfully influential partly because it offered solutions to problems

of system development already posed in the United States. Attempts at computer controlled time phasing of operations under MRP failed when grass roots knowledge of how to determine work priorities could not be integrated with computer directives and when the perspectives of manufacturing, sales, and other divisions could not be incorporated into MRP system design. And MRP was often not fully implemented because the lack of systemic vision at the grass roots level undermined adherence to its ground rules. In quality control, Juran and Feigenbaum both articulated a vision of a system for quality which would compel a far wider distribution of responsibilities for quality across departments and down to the shop floor, simultaneously with better integration of quality-relevant activities around problems defined for the system as a whole. These problems in the development of systems in the fields of quality control and scheduling remained mutually isolated and parochial concerns until the Japanese example demonstrated how quality systems and scheduling systems were interdependent and could be best organized by breaking with assumptions about the efficacy of top-down and fragmented planning in the Tayloristic mode.

Before 1980, advocates of worker participation were speaking eloquently of how worker participation supported the dignity and personal growth of employees and reduced the bitter antagonism of worker-manager relations; and they could cite many examples of how expanded participation

could tap into hitherto neglected worker knowledge and creativity to improve productivity. Yet the Japanese version of worker participation linked it for the first time to the specific technical requirements of quality and scheduling systems. Worker participation then began to be seen as an indispensable element in all facets of the projected overhaul of American management.

Because it cuts to the core of American beliefs about technology, perhaps the crowning achievement of the Japanese manufacturing paradigm was the reorientation of perspectives on automation. We saw how rapidly emerging electronic control technology was interpreted in the early 1980's as making imminent the economic replacement of the human organization by a complex of flexible and self-correcting programmable equipment. But the tide has now turned in favor of the systemic/developmental view of manufacturing in which the economic use of automation is most likely to occur in the context of the development of consistent quality and process synchrony through collaborative management and expanded worker participation.¹

¹ It should be noted that the technology we are speaking of here concerns the manufacture of discrete products rather than continuous processes as, for example, in the paper and oil refining industries. Experience with computer control technology in these kinds of industries seems to have independently engendered substantial recognition of the expanded potentials they offer for worker participation because of their ability to convey large amounts of information on systemic performance to the individual worker and the necessity for system

We should not expect most American manufacturing organizations to embody the Japanese manufacturing management paradigm in the near future. Our manufacturing and business institutions are too deeply rooted for that. But hopefully we have been able to show that the Japanese paradigm is a coherent one and to suggest that its coherence will lend it a persistence and force that goes beyond the fadism that periods of crisis give rise to. This study shows that Japanese managerial concepts represent both profound innovation and an evolutionary advance toward the more effective management of large systems.

Beyond this, Americans, for the first time since management became a subject of discourse, have borrowed managerial ideas from abroad in a significant way, and this while communication technologies and international trade are racing ahead. Americans are now learning how to learn and the learning will continue at an accelerated pace.

development of designing jobs that allow shop floor personnel to experiment, learn and initiate improvements.

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