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SOCIO-TECHNICAL APPROACHES TO ASSEMBLY DESIGN

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Abstract

The assembly line has traditionally been considered the most efficient way of organizing assembly operations. However, efficiency measurement has most often been limited only to the measurement of direct costs. Moreover, implied in the assembly line method are certain assumptions about people. Changes in labor force values and a rising level of education are making us rethink those assumptions. These changes, together with a total economic cost measurement which includes such factors as turnover, supervision and quality, make alternative assembly designs feasible. Two examples of alternative ways of organizing assembly operations are discussed in some detail.

Introduction

For several years, social commentators have drawn our attention to the human costs associated with assembly operations in industry. Words like "de-humanizing", "soul-destroying" and "mindless" have become standard to our vocabulary in describing the relationship between people and assembly lines. These criticisms of the assembly line have generally been judged by businessmen and engineers to be either false or misguided. Even among those engineers and managers who were not happy with the current state of affairs, the prospect of developing a viable alternative to the assembly line for production seemed unlikely. However, recent developments in certain European companies such as Volvo and Philips as well as in certain American firms appear to be showing us otherwise.

These organizations are not philanthropic in nature. They are companies which, like any other, have to make profits, and they are demonstrating that the traditional assembly line can be replaced and a viable replacement found. In this paper, we explore, with the aid of case studies describing developments at Philips and Volvo, the underlying rationale of the assembly line. This rationale includes both value assumptions about people and basic economic considerations. It will be shown that different assumptions about workers in conjunction with a consideration of economic costs hitherto not calculated may lead to alternative forms of work organization which are more productive. Furthermore, it will be argued that the conditions which stimulated a rethinking of assembly design in Europe are emerging in the United States. Therefore, it is important to give these recent European developments our serious consideration. A major part of all industrial work in the United States consists of assembly operations. According to the United States Census of Population for 1970 there were 463,208 persons working as assemblers in manufacturing industry.

Design Parameters for Assembly Operations

Assembly operations are distinguished from other manufacturing methods such as chemicals or machine processes by the fact that cycle times are not constrained by process requirements, such as cutting speeds, heat and press cycles, etc. Moreover, in most cases, assembly operations do not necessarily require special machinery or tools. Therefore, in assembly operations, the options for design variables, such as cycle time and layout are less limited.

The manufacturing engineer, when designing an assembly operation, must make decisions which address the following 4 parameters:

1. Interdependence of operations
2. Fractionization of operations
3. Size of labor unit
4. Mechanization

Until now, in cases where run quantities were reasonably large, the assembly line method, which prescribes that each man performs on each product continuously the same operation, or extensive mechanization have been the traditional choices among engineers. Let us now consider in greater detail how these traditional choices are related to the four design parameters mentioned above.

1. Interdependence of operations - Since the assembly of the total product can be divided in a number of ways, this makes it possible to design a flow of operations in such a way that the product is continuously being worked on. As a consequence, assembly line balancing techniques were developed. The choice of maximum dependency between operations is based on the need for minimum storage (e.g. tied-up capital), space and transfer costs, and maximum control over workers. Although the latter is not always explicitly stated, it may be the major reason for maximum interdependency. The mechanical pacing of the line accomplishes complete control over worker behavior in terms of speed, mobility and social interaction. This provides us with some insight into the value assumptions about people held by engineers in their designs. Either explicitly or implicitly, engineering decisions about systems design embody theories of human motivation. A number of years ago, a social scientist at M.I.T. formulated a classification of our underlying assumptions about the motivation of other people.(1) He said that we basically use either one of two different sets of assumptions about human behavior. He called one set "theory x" and the other "theory y." This conception has since become popularized in management thinking and has made its way into boardroom vernacular. "Theory x" describes assumptions made about people based on their inherent limitations. The average human being is lazy and dislikes work. He therefore must be coerced, controlled, directed and threatened

with punishment. Nothing short of this will do the trick. Moreover, "theory x" suggests that the average person not only needs this, but he prefers it, because of a natural human tendency to avoid responsibility, renounce ambition and seek security above all else. Adherents to "theory x" may not state it quite that way. Indeed, lip service may well be paid to the exact opposite. But in the end, the ethic of the "mediocrity of the masses" prevails during the act of decision making. "Theory y", on the other hand, describes something quite different. In an equally hard-nosed way, "theory y" is predicated on a belief in human potential. Thus, the average human being does not naturally dislike work but, depending upon the conditions he faces - conditions capable of alteration - he may well learn to dislike his job and avoid work. Furthermore, he does not need external control but is capable of exercising self-direction toward goals to which he is committed. Moreover, "theory y" suggests that under the proper conditions people not only accept responsibility but learn to seek it. And finally, "theory y" embraces the assumption that creativity and ingenuity are not scarce commodities. Instead, they are evenly distributed in the population but are now not fully utilized. They require working conditions which will release them in the interests of both the individual and his or her organization. Given these two theories, a recent UCLA survey of design criteria used by production engineers and systems analysts is revealing.(2) The study clearly indicates that those responsible for the design of work systems tend to be operating in the "theory x" mode. The findings do not differ from a survey on the same topic conducted 20 years ago.(3) These studies, to our knowledge, are the only ones which explore the assumptions about people held by production engineers. For instance, in the 1976 survey, the sample closely adhered to the statement "There should be close supervision, tight controls and well maintained discipline". The contrasting statement was "there should be loose supervision, few controls and a reliance on employee self discipline." In another example, production engineers strongly believed that "Jobs should be clearly defined, structured and stable", as distinct from "Jobs should be flexible and permit group problem solving." In concluding this discussion of "theory x" and "theory y" we would like to suggest that from our examples, it can be shown that designing systems on the basis of "theory y" assumptions is technically feasible and can lead to outcomes which are economically viable.

2. <u>Fractionization of operations</u> - The assembly line principle that each man has to perform the same opera-

tion on each product implies a maximum level of fractionization of work. In this case the operations' cycle time equals the output rate of the finished assembly. For example, for an output rate of 100 T.V. assemblies an hour, the cycle time of each station on the line would be 0.6 minutes. A shorter cycle time would result in waiting either for products or for workers. While longer cycle times would violate the principle that each worker performs the same operation on all products. The rationale for maximum fractionization is a minimum learning time and low skill requirements, or as Davis (4) put it:

> "Individuals are assigned work in such a way that they can be treated as interchangeable. Each man is given only one single thing to do; many man are available ('in inventory' as it were) to do that thing if the first man fails. The human operating units are given narrow tasks of responsibilities and are seen as having narrow capabilities and small utility to the organization. Most current industrial training schemes are based on this spare parts concept"

Fractionization of operations applied not only to conversion operations but to planning and control operations as well. Scientific management states that planning and control should be separated from the actual execution of work. One of the arguments for this principle, not always explicitly stated, is the "theory x" conception of workers. The "theory y" approach to worker motivation together with the recent developed cybernetic view of optimal task decision making (5) may lead on many occasions to the delegation of decision-making to the level at which those decisions are to be executed. In the professional jargon of job design, job enlargement refers to the defractionization of conversion operations while job enrichment implies the adding of planning and control functions to the job.

3. <u>Size of labor unit</u> - Choosing the size of the labor unit involves deciding between assigning production tasks to individuals or groups. Conventional assembly designs generally embody the principle that each individual should be accountable for a specific task. The implications of this important choice are not always fully realized. Underlying it are critical assumptions about workers. The first, which is deeply embedded in our American culture, is that individual motivation is stronger than that which obtains in groups. While it is generally agreed among industrial engineers that individual incentives are superior to group incentives, one should bear in mind that this might be a self-fulfilling prophesy. That is, should we in fact be surprised that people are more responsive

to individual incentives when, in the vast majority of cases, the structures in which they work were designed to precisely achieve that effect? Even in cases where group incentives exist, groups are still considered as collections of individuals instead of alternative operating units with unique properties of their own. The second assumption or, more accurately, design practice, is that human components are treated in the same fashion as machine components. Assembly line design is based on an average cycle time, which is the same for all operators, and on an average speed of individuals during the course of the day. But from practice, we well know that "average" is a statistical concept only. In reality, variations between workers and individual variations over time result in line stoppages, waiting times and expensive buffer stocks. Assignment of tasks to groups offers the possibility that the above variations will be managed and absorbed by the group through mutual assistance, job rotation and related forms of joint action. A third consideration in the choice of labor unit size concerns the coordination and supervision of operations. Obviously, the greater the number of operating units, the greater are the costs associated with coordinating and supervising those units. Hence, where conditions are favorable to the creation of work teams, group units are preferable to one-man units. The size of the group should not be so large that members cannot sustain close and continuous personal relationships, but neither so small that defection of one member can endanger the group existence. In general the optimal size would be between 6 - 12 members. However, under certain technological conditions groups might have to be larger.(6)

4. Mechanization - One way of coping with, or rather avoiding the complexities of incorporating people into a production process is to mechanize it. This ultimate solution, however, is not usually economically feasible. There are certain instances where the more expensive solution of mechanization was chosen as a means of eradicating labor practices which could not be remedied otherwise. However, in general, frequent changes in production design - a characteristic of the electronic and automotive industries - and low run quantities make mechanized assembly prohibitive. While there are many instances where increased mechanization eliminates tedious, repetitive work, and creates more skilled, trouble-shooting jobs, there are also cases where the remaining manual work becomes even more tedious, rendering man a complete extension of the machine. For example, in a highly mechanized auto plant with work cycles of 36 seconds, employee resentment against job monotony and their dependence on a high

speed line resulted in neglect, sometimes deliberate, on the part of workers, causing an estimated loss of $160 millions in production.(7)

Total Cost Measurement

Let us now turn to a consideration of the criteria against which alternative combinations of these design parameters are evaluated. Obviously, cost criteria are involved here, but the comprehensiveness of such criteria in current practice leaves much to be desired. For instance, in 1957, The Industrial Engineering Journal published an article by Davis which argued for the use of total economic cost measurement in job design, but a survey just completed last month revealed that until now, most U.S. engineers continue to consider only direct costs like number of products per unit of time and capital utilization. Such a total economic cost measurement should include the following costs.(8)

1. Direct labor costs - This refers to labor time per unit and includes waiting times resulting from balance delays and variance in work speeds.

2. Capital equipment costs - These include both machine hours per unit and downtime costs.

3. Work-in-progress costs - These costs refer to the capital tied-up by products in process and increase with the size of buffer storage.

4. Space costs - These are determined by the type of layout and again are dependent on the size of buffer storages.

5. Inventory costs - These costs depend on the size of production runs and fluctuations in product demand; they are closely related to the next cost factor.

6. Set-up costs of the production system after each schedule change.

7. Materials handling costs

8. Operation and maintenance costs - These costs will be influenced by the amount and nature of the equipment used in the system.

9. Planning, supervision and control costs - Overhead costs for supervision and planning administration are mostly considered as constant and therefore not included in evaluations of alternative work systems. We shall show in examples to follow, however, that these are variable costs and dependent on our choice of production mode.

10. Turnover costs - These costs include recruitment, placement and training, and loss of production during on-the-job instruction. One should not underestimate these costs, particularly since 50-100 percent turn-

over rates are not uncommon in simple assembly work.

11. Absenteeism - These costs are to some extent represented in direct labor cost since absence increases manpower required. However, in practice, absenteeism is compensated for in general by increased reliance on higher-paid utility workers.

12. Quality costs - These may be influenced by the type of work system employed because it may provoke various forms of neglect by workers which impact on quality.

In addition to these quantifiable factors, there are a number of intangible costs also involved, such as the potential of the production system to cope with changes and the willingness of employees to work overtime or on shifts. It should be emphasized that we are not referring to job satisfaction per se, but strictly to costs. While we think that the creation of job satisfaction can be a legitimate objective of companies, in this paper we are addressing ourselves only to costs resulting from low employee commitment.

We shall present two examples which will illustrate that when all of the above costs were considered in the design of major assembly operations, the assembly line was abolished. Both examples were selected because there is a substantial body of published information describing them. Though a number of American experiments using alternative forms of assembly have been undertaken or are currently underway, hard data on design parameters and costs have been less available. Nevertheless, there are some noteworthy examples which deserve attention here.

At a Harman International plant in Bolivar, Tennessee, a voluntary system was established among its 800 employees to devise their own arrangements for assembling auto mirrors, supervising themselves and making other changes in the work area.(9) This experiment is currently underway under the joint sponsorship of Harman and the United Auto Workers. Two other projects involving the UAW were undertaken with GM but have been discontinued.(10) The first took place in 1973-74 and involved small-groups among a workforce of 200 in the assembly of truck chassis for custom camper vehicles. It was judged successful by both the union and management. The project was discontinued because of the low demand for custom recreation vehicles. The second experiment was at GM's Truck and Coach Division and affected a total work force of 400. Team methods were employed for body fitting, trim work and assembly, but the project was abandoned, most likely due to low product demand. Further experimentation with alternative assembly methods are currently underway at General Motors, but information on them is unavailable at this time.

There are also several examples in the garment industry, the most recent being Levi Strauss & Company (11) and the R.G. Barry Corporation.(12) At a Levi plant in Albuquerque, New Mexico, 32 sewing machine operators were allowed to form more autonomous work teams and take charge of production scheduling in their groups (along with less supervision and the removal of timeclocks). Over the experimental period, monthly turnover was 2 percent lower than the rest of the plant. The project was undertaken in 1974, later abandoned, and reintroduced this year. At R.G. Barry in Columbus, Ohio, 350 employees were formed into small teams to assemble and package slippers. The groups had greater discretion in the allocation and scheduling of tasks, and minor maintenance responsibilities. After 12 months, significant quality improvements were achieved, though return on investment has been less than expected.

Experiments with alternative forms of assembly methods have been carried out during the last decade by IBM, TRW, Motorola, Corning Glass, ATT, (13) and others. These examples reflect a growing awareness of changes in the labor force and a greater sensitivity to related costs in American industry. Firms are now exploring work design options in assembly which heretofore were thought impractical. It is too early to tell if this is a trend. What is clear, however, is that alternative designs for product assembly will continue to challenge established notions of the "real" costs associated with capital and labor. Let us now turn to our detailed examples.

<u>'Work Structuring' in TV Assembly</u> (14)

Philips Corporation, the electronics and electrical appliances manufacturers, employs roughly 400,000 people, of whom 90,000 reside in the Netherlands. The company has a reputation for the considerable responsibility it takes regarding its employees' interests.

At the end of the '50s when Philips went through a period of great expansion, especially in TV manufacturing, problems of meeting delivery times and quality standards, coupled with high turnover among production workers, resulted in a fresh look at the assembly line concept.

A committee consisting of behavioral scientists and engineers came up with a solution which was hardly revolutionary but gave considerable improvement over the old assembly line. (15)

The original TV assembly was conducted on a moving belt line with 104 stations, each manned by one worker, and with a cycle time of 1.5 minutes. Quality was controlled at the end of the line. The line suffered from frequent stops due to waiting times for supply and the variations in workers' speed between stations.

In the new design the line was divided in five short lines with buffer-stocks of one hours work (40 TVs) and quality control between them. Interstorage and space costs, of course, increased but were more than compensated for by decreased waiting times and increased quality. Moreover, morale of the workers in the smaller groups proved to be higher.

This experiment stimulated numerous others under the common denominator of 'Work Structuring'. Work structuring refers to the design of job content and the delegation decision-making in such a way that it matches the ambitions and capabilities of the worker while maintaining or improving efficiency.

In 1970 the Board of Management committed itself formally to work structuring by encouraging experiments and making special budgets available for compensation of initial product losses during experiments. The major reasons for work structuring at Philips were the following:

1. Changes in labor force.
   a) Increasing level of education and the consequence of rising expectations. Most young workers have some years of secondary education. The typical semi- or nonskilled industrial task does not match the capabilities of these workers, resulting in wasted talent and increased turnover.

   b) Changing values. It is ironical that the value system often referred to as "the Protestant ethic" which created the affluent Western society, is undermined by its own achievements. New emerging values involve equality of results instead of equality of opportunity, participation instead of hierarchy and direct satisfaction (e.g. in work) instead of deferred gratification.

As a result of these new values and needs of the labor force it became difficult to fill certain jobs since workers refused to do that kind of work. For example, in one assembly plant located in an area with 25 percent unemployment, the most repetitive and tedious jobs remained vacant. It is apparent now in Western Europe that importing foreign labor was, at most, a temporary solution and created a host of other problems.

2. Turnover and absenteeism.
   Both phenomena are of course partly the behavioral reactions of the labor force to the changes mentioned above. The considerable costs of turnover have long been recognized at Philips. Studies by the psychological department showed that turnover was related to the ill-matching of workers capacities and job demands.

3. Sub-optimal production systems as a result of inflexibility or hidden costs.
   The industrial and management engineering department at Philips (TEO) developed a growing awareness that design evaluation should not be based only on direct unit costs but should also properly look into such factors as: the adaptability of the production system to disturbances or new developments, supervisory costs, throughput times, waiting times as result of disturbances, etc.

4. Change in management values.
   While changing values of both management and workers are of course part of the same cultural change, the resulting attitudes of management toward the organization of work should be mentioned separately. At Philips work structuring was and remains at management's initiative and not labor's, both in terms of policy

statements and stimulating experiments.

In 1969 one of the department chiefs of the TV plant decided to try out how far one can go with work structuring. During the nine years following the experiment, in which the long assembly lines were subdivided into 'mini' lines, not much had happened in TV assembly. Largely due to technological developments (integrated circuits) cycle time was increased from 1.5 minutes to 3-4 minutes and the TV apparati were assembled on mini lines consisting of 30 stations.

The department chief started experimenting with the design parameters for assembly operations: mechanization, fractionization and interdependency of operations and size of labor unit.

It was clear that the relatively short product life cycle and the complexity of its assembly made mechanization unfeasible.

Minimum fractionization - that is, total assembly of a TV apparatus by each worker - was considered but the product was too complex, given the labor force and the length of training in proportion to the product life cycle. In order to obtain some degree of fractionization while not creating the interdependency of operations characteristic of a line, the fourth design parameter, the size of the labor unit was reconsidered. As a consequence, work groups were established. This was partly based on the view that the social isolation of the individual was a negative feature of single-man labor units.

At this point the personnel department became involved. With its help the optimal size of the work group was determined as seven. Moreover, they became deeply involved in all personnel and organizational development aspects of the project.

Line management and industrial engineering at Philips were well aware of the fact that every work-system is a socio-technical system involving both technological and socio-psychological variables. In the design phase both sets of variables should be addressed simultaneously as part of a joint design. Too often socio-psychological variables are explicitly considered only when they manifest themselves in terms of grievances, turnover, strikes, etc. and then referred to the personnel department as their problem.

The new design for the TV assembly as compared to the old situation is depicted in the following table.

TABLE 1: OLD VERSUS NEW DESIGN OF TV ASSEMBLY OPERATION

Design Parameters	Mini Lines	Work Groups
Fractionization of work		
- cycle time	3-4 min.	20 min.
- task rotation	sporadic	regular
- delegation of planning and control	none	quality control, ordering of materials, distribution of work, etc.

TABLE 1: OLD VERSUS NEW DESIGN OF TV ASSEMBLY OPERATION (cont)

Design Parameters	Mini Lines	Work Groups
Interdependency between operations	high, no buffers however not mechanically paced	low, groups are self contained
Size of labor unit	1	7
Level of mechanization	manual	manual
Job consultation	none	1.5 hours once every two weeks

Each group was responsible for the complete assembly of a TV apparatus including quality control, ordering of materials and scheduling. The new design was approved by higher management and $30,000 were allocated for initial costs of the redesign, mostly for an entirely new lay-out. It was decided to start with one experimental group consisting of volunteers but which was, in all other aspects, a group of average workers. After a year a second group was added and one year later an intensive evaluation of the project was made by the industrial engineering and the personnel departments. As a result certain cost components proved to be higher in the new design but others were lower. The following table lists the different cost components.

TABLE 2: COST COMPARISON OF OLD AND NEW DESIGN

Cost Component	
Reduced for groups	Increased for groups
direct labor hours (by better utilization of manpower)	floor space costs
indirect costs (planning, supervision and control)	equipment costs (lower utilization)
absenteeism	inventory costs
learning and training cost (lower turnover)	work in progress (tied-up capital)
	time for worker consultation
	wages (worker moved to higher salary class)

It appeared that the total economic cost per TV apparatus which includes all costs enumurated above, was about 10 percent lower when produced by work groups. Thus, working with autonomous groups proved to be a viable alternative for the assembly line. Of course it is not proposed here that the assembly should be totally abolished. What we do argue is the point that there is more than one way to organize assembly operations.

Philips measured the attitudes of workers both in the experimental groups and on the lines. Their responses indicated that none of the group workers wanted to return to the old system. Furthermore, younger workers on the lines also wished to join the groups. However, while group work was preferred it raised the expectations of its participants for even more influence on decision-making. The new way of working had changed them. This finding illustrates a crucial point. Experiments of this kind should not be an ad hoc but part of organizational development and learning. The organization of work should be a continuous process.

Auto Assembly at Volvo-Kalmar (16)

Volvo AB is Sweden's largest manufacturing company. It's annual sales in 1975 were double those of 1970, reaching $2.3 billion. The company has 40,000 employees, with an additional 30,000 persons dependent on subcontracts. The Volvo organization has a complex structure yet it is closely integrated in its operation. There are 26 production units in Sweden, each contributing to the manufacture of automobiles in large series. Volvo has been successful in coordinating these highly interdependent units, and has acquired over the years the reputation of being an efficient, technically modern and socially progressive company.

The creation of their new auto assembly plant at Kalmar was a radical departure. Nevertheless, it was an extension of earlier efforts within the company to experiment with alternative forms of work design along with general environmental improvement. The decision to build the Kalmar plant in its present form went further because Volvo management had to come to grips with an emerging and potentially grave manpower problem. In the late 60's and early 70's it was becoming increasingly apparent in Volvo, as well as many other Swedish companies, that absenteeism, turnover and recruiting problems were having costly effects on production. In 1969, turnover reached 55 percent, with absenteeism averaging 20 percent. Put simply, very few Swedes were willing to work on assembly lines. At Volvo, this became a matter of such concern that these costs were the subject of extensive investigation.

Few companies attempt to compute the real magnitude of costs to the organization associated with absenteeism and turnover, and Volvo's studies were revealing. They found that not only did recruiting, training and administrative costs have to be included, but also the effects of a less competent workforce as well. Thus, such things as quality control, rejects, adjustments and other forms of inferior productivity had to be taken into account.

A fuller appreciation of these costs led Volvo management to review their options in meeting a long-range plan for expanded operations. Because reliance on significant numbers of migrant labor would have to decrease in future years, auto assembly work had to be made more attractive to the more highly-educated and demanding Swedish workforce.

When the decision was made to build a new auto assembly plant in southern Sweden, an opportunity presented itself to attack worker dissatisfaction and rising costs at the fundamental level of basic assembly principles. A working group of industrial engineers, architects, and sociologists was formed to generate and analyze design proposals. From the beginning it was agreed that conventional solutions had to be abandoned and with them, reliance on established assembly technology. Because of the smaller run quantities demanded in Volvo production, intensive mechanization along the lines used by Chevrolet at Lordstown, Ohio was not economically feasible. Moreover, given the labor upheavals which occurred in the Lordstown plant, viewed by many as a response to its mechanized and fast-paced conditions, this would not have been an attractive alternative to Volvo planners on social grounds.

The design team was therefore confronted with the need to approach the problems of interdependence, fractionization, size of labor unit and level of mechanization in a novel way, one which would, in the words of Volvo's President:

> "...create a manufacturing facility which, without any sacrifice of efficiency or profitability, will give employees the opportunity to work in groups, to communicate freely with each other, to shift between jobs, to feel a genuine identification with the product and a responsibility for quality, and to influence their working environment."(17)

The result was Kalmar. Final approval for construction was given in the spring of 1972 and the plant began operating in early 1974. It has a planned capacity of 30,000 vehicles per year. The labor force numbers 650, approximately 580 of whom are production workers. Female workers account for 30 percent of the labor force. Let us now examine in more detail the special features of this factory.

The layout of the Kalmar plant resulted in a uniquely-shaped building with two levels and a basement section, covering a total floor area of 40,000 squre meters. Despite this relatively large size, the hexagonally-shaped sides of the building allow the internal spaces to be scaled down to sections which have the atmosphere of small workshops. All storage facilities for components are located in the center of the building and are therefore quickly accessable to the circular production flow. Assembly of components into finished cars is assigned to a number of teams, each responsible for a special sub-system of the vehicle, such as brakes, steering, the electrical system, etc. Each team consists of between 15-20 workers, who decide among themselves how their efforts are divided and scheduled. The workplaces have large picture windows in the outer walls which face onto the countryside. Each group has its own work entrace, changing room and carpeted coffee and rest area.

The workflow of the plant is arranged as follows (See

Exhibit 1): Painted auto bodies enter the plant by rail (Point 4) and after passing through a washing section (Point 17) are placed onto individual wagons (Point 5). They are then lifted to the second level where the interiors are fitted step by step along a roughly-circular path. Meanwhile, on the ground level, the chassis, engine, transmission and axles are assembled following a circular flow similar to the upper level. The two lines meet at a point where the body can be placed onto the completed chassis and transferred back to the lower floor (Point 7). From this point, assembly continues as each vehicle moves from section to section (Points 8-16) on separate wagons. Special tests and inspections are conducted during a final phase before the vehicle leaves the plant (Point 18).

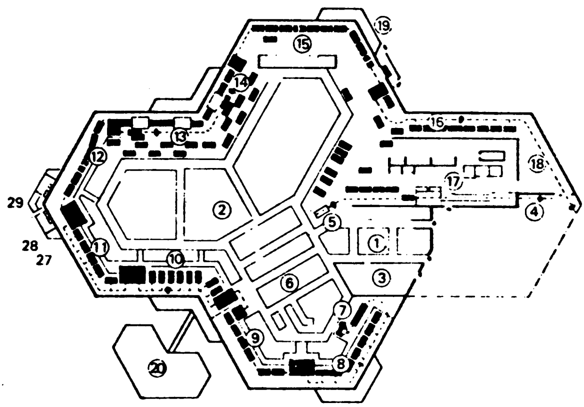

Exhibit 1 Ground-floor plan (18)

The key innovation which enabled the fixed-speed assembly line to be abandoned was the deployment of battery-powered, self-propelling assembly wagons. These are moving platforms which transport the body or chassis from one assembly section to another. The wagons are normally used in an automated mode, guided by electronic tracking devices buried in the floor. They can also be semi-automatically or manually controlled to fit particular queing circumstances. Normally, the wagons move automatically between sections where they are parked in special buffer areas to await call by each successive work group. There are two types of wagons, each designed to suit the special needs of chassis and body assembly. Both are equipped with devices which tip the entire vehicle 90 degrees to the side. In addition, the wagon for chassis assembly can be raised and lowered to enable easier access for the engine, transmission, axle and exhaust system assembly. The invention of the wagons at Kalmar was a unique solution to the interdependence of operations problem. It enabled a system of flexible buffering to operate which freed workers from constant line speeds.

In selecting groups as the appropriate labor unit, further flexibility was built into the production system. The new materials handling method permitted workers within each section to decide among themselves how to divide their labor. They may use a straight assembly method, where individuals are assigned to stations (usually 6) arranged serially and surrounded by buffers, of two cars. Two or three persons work at each station, with individual time cycles lasting about five minutes. Another method of straight assembly popular at Kalmar is for individuals to learn the job at all six of the stations. By following a wagon through the six stations, the worker can expand the cycle time up to between 20-30 minutes.

The other assembly option is known as dock assembly. With this method, the wagon is shunted into a dock area within the section and kept there until the entire assembly operation is completed. Three workers are assigned to each dock and have individual work cycles of between 20-30 minutes. Within each subgroup, workers also have the option of exchanging jobs. Dock assembly has the advantage of keeping the auto stationary while it is being worked-on. The disadvantage is that space limitations often preclude adequate storage of all materials necessary for 20-30 minutes of assembly. Only about 25 percent of the sections in the plant have thus far been able to use dock assembly methods satisfactorily. In contrast to most auto assembly plants, where cycle times range from .5-3 minutes, both of the Kalmar assembly options provide individual cycle times of 20-30 minutes with few exceptions. In the dock assembly method, workers may choose a cycle time which could last as much as 60 minutes. In all cases, workers in each section are responsible for quality control. Follow-up information on quality is processed by a central computer and relayed back to the section where remedial action is required. The computer is also used to keep track of the location of each wagon and its assembly status, and to relay information to stations where variations in design require special components.

Variations in design require special components. In summary, creative engineering permitted the basic parameters of assembly to be set in a novel way. By introducing the Kalmar wagon in conjunction with the formation of semi-autonomous groups, workers could choose the extent to which their jobs were fractionated.

Performance and cost data on Kalmar have not been released to the public. Results which have been made available by Volvo, based on comparisons with orthodox assembly operations at their other Volvo plant, suggest that Kalmar has been competitive. The Company was successful in recruiting a full complement of labor and in meeting their first year's start-up targets. If detailed cost data were available, we might expect them to be not dissimilar to the comparative data in the Philips case. In an important sense, straight cost comparisons might not be instructive in the Kalmar case. An over-riding concern of the Company were the dark prospects for labor recruitment which, if not resolved, would have put the future domestic production of any Volvos at risk. In such a case, costs have to be viewed in a more global perspective.

Returning to the American scene, Volvo will be opening an auto assembly plant in Chesapeake, Virginia. While details remain confidential, it is generally clear that the designers will adapt assembly innovations pioneered at Kalmar to fit their American environment. The wagon and buffer area concept will be an essential feature of the new design. Group working will not be used, but individual workers will have extended task cycles. We shall await the start-up of this plant with much interest.

Conclusion

In the Philips and Volvo cases, each development represents a continuing, organization-wide attempt to create alternative ways of producing which satisfy both economic objectives as well as the changing expectations of their workers. It has not been our intention to advocate the total abolition of the assembly line, nor to argue for importing remedies which are not appropriate to the problems existing in American workplaces. There are parallels to Sweden and Holland, however, which should not be ignored. Worthy of note are the rising educational level of the U.S. workforce and the changing values of its younger members. By 1980, the total labor force will have averaged 12 years of schooling.

It has been our intention to suggest that the design of every production system provides an opportunity to explore options concerning the relationship between people, technology and economic costs. Manufacturing engineers are as much the designers of social systems as technical systems, and this point cannot be overstated. The cases described above illustrate that alternatives to the assembly line can be economically viable. We therefore recommend that a fresh look be taken at the way manufacturing operations are organized, knowing full well that unique solutions need to be evolved which are appropriate to the circumstances of each situation.

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