Fred Emery

The Assembly Line

Its Logic and Our Future[1]

Nowhere do the issues involved in the democratization of work comes so sharply into focus as in discussion of the future of the assembly line.

The principles of the assembly line seem to be the basis on which Western affluence is built, and yet it creates a multitude of inhumane, degrading jobs; jobs that increasingly have to be filled by second-class citizens. The challenge is to achieve the low cost of mass-produced goods without creating the human cost. Two facts have led me to choose the automobile assembly line as an example within which to spell out the general principles.

First, Henry Ford's introduction of the continuous flow conveyor to the assembly of automobiles was the apogee of a modern mode of human management, a mode that started to emerge with Frederick Taylor and Gilbreth in the late nineteenth century. General Motors' much publicized fiasco with their Lordstown plant in 1972 seemed to mark the end of that era. Volvo's announcement, within the following months, of the radically new concept for their Kalmar

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[1] Excerpted from Futures We Are In. Leiden: Martinus Nijhoff, 1977.

assembly plant seemed to herald the beginning of a new era of human management.

Second, the logic of human management that was enshrined by the car makers became the logic that was worshipped by practically all other large-scale manufacturers. It came to be seen by the 1940s and 1950s as the only <u>sure</u> way of manufacturing increasingly complex products at a cost that could serve a mass market. As the real cost of labor has increased through the 20th-century, it has been seen as the <u>only possible</u> way of creating mass markets, or of meeting the demands these mass markets make for industrial inputs. So it was not too surprising to find a process industry like ICI (UK) as the leading proponent in Britain, in the postwar years, of the philosophy of Henry Ford.

What I am suggesting is that the logic of the car assembly line is a keystone--probably <u>the</u> keystone--to prevailing 20th-century concepts of human management. The logic of production by a continuous flow line was well understood in the early phases of industrialization. Both Charles Babbage and Karl Marx spelled out this logic. The logic was an "if <u>X</u> then <u>Y</u>" logic. If a complex production task was broken down into a set of constituent tasks, then the level of craft skills required was lowered and hence the cost of labor was lowered. At the extreme, a class of unskilled labor emerged to perform the very elementary tasks that practically always remain after a complex task has been broken down to its minimum skill requirements. Such unskilled laborers would have no part to play in craft production. There is another valuable side of this coin that was not obvious until a much later date: if one lowers the level of craft skill needed for a product, it becomes much easier to switch to production of major variations of that product, e.g., from swords to ploughshares. Massive reskilling of craftsmen is not needed.

Once the partition of a task had been successful in reducing the necessary level of craft skills, it was only natural that further partitions leading to even broader and cheaper labor markets should be sought. World War II gave a further great stimulus to this approach. The military demanded large-scale production of very complex machines when often the only available labor force was that conscripted from outside the traditional industrial work force, e.g., women, pensioners and peasants. The know-how flowed over from blue collar work to the organization of offices. Insurance offices, taxation offices, etc., organized for mass flow production of documents.

However, to realize the economic advantages of task segmentation it was necessary to cope with several sources of cost <u>inherent</u> in the method:

- transfer costs,
- standardization,
- "balancing that line,"
- external supervision and "pacing".

Transfer Costs

Individual craft production requires a minimum movement of the object under production. Partitioning of production requires transport of the object between each of the work stations at which someone is performing a different subtask. The costs are those of sheer physical movement, of repositioning so that the next operation can proceed and "waiting time" when valuable semi-products are, as it were, simply in storage. Henry Ford's introduction of conveyor belts to car assembly seemed to be the natural outcome of the attempt to reduce these transport costs. Conveyor chains had already transformed the Chicago slaughterhouses. Palletization and fork-lift trucks continue to reduce these costs in assembly areas where continuous belts or chains are not justifiable.

Standardization

Partitioning of a production process was simply not an economic proposition unless there was a fair probability that the separately produced parts could be reconstituted to yield a workable version of the final product. It would not have to be as good as the craft-produced product if its cost was sufficiently lower. This was obvious enough with the 18th-century flow-line production of pully blocks at the Woolwich Naval Arsenal and the early 19th-century production of Whitney's muskets. Reduction of this inherent cost has a long history. From Maudslay's slide rest onward there has been a continuous evolution in specialized tools, machine, jigs and fixtures to enable relatively unskilled labor continuously to replicate relatively skilled operations to a higher degree of standardization. The aim throughout was that expressed by Whitney:

> To form the tools so that the tools themselves shall fashion the work and give to every part its just proportion--which when once accomplished, will give expedition, uniformity and exactness to the whole.

The most radical developments emerged in the second quarter of this century with metrology, the sophisticated concept of tolerance levels, expressed in statistical quality control and national standards authorities. The difficult emergence of this latter revolution in Australian industry is well documented in chapter 7 of Mellor's (1958) volume of the history of World War II.

"Balancing the Line"

This is a problem that does not arise with the individual craftsman. Whatever the problems with a given phase of production on a particular lot of raw materials, one can proceed immediately to the next phase as soon as one is satisfied with what has been done. One does not have to wait to catch up with oneself. When the task is partitioned that is not possible. Each set of workers are skilled or, rather, semiskilled in only their own subtask. They are not skilled to help clear any bottleneck or make up any shortfall in other parts of the line. They can simply stand idle and wait. Theoretically, there is in a flow line an *iron law of proportionality* such as Marx writes about. Theoretically, it should be like the recipe for a cake: so many hours of this kind of labor, so many of that kind of labor, etc., and, presto, the final product. Unfortunately for the application of the theory, it is not as simple as making cakes.

Balancing the line to reduce downtime was an on-the-line art of observation until Taylor and Gilbreth came on the scene. Their contribution was Methods, Time, Management (MTM). At last the balancing of a line seemed to be a science. Controlled observation and measurements seemed to offer a way of not just balancing the labor requirements of the major segments of a line, but of scientifically planning the work load and skill level of each and every individual work station. Planning and measuring costs money, but there has seemed no other way to reduce the downtime losses inherent in the original fractionation of production.

Let us now look briefly at the fourth major source of costs inherent in line assembly. Then we can ask what all this means.

External Supervision and "Pacing"

So long as the individual craftsman produced the whole product, control and coordination of work on the various subtasks was no problem. The workers managed that themselves. With the fractionation of production a special class of work emerged, the work of supervision. Each person on the assembly line has to attend to his or her own piece of the work, and hence someone else must coordinate what is happening at the different work stations, reallocate work when the line becomes unbalanced and re-enforce work standards when individual performance drifts away from them. A major headache has been the near universal tendency of workers on fractionated tasks to depart from planned work times. The self-pacing that enables the craftsman/producer to vary the work pace and yet maintain good targets for overall production times appears to be absent from small fractionated tasks that are repeated endlessly. Tighter supervision and incentive payment schemes seemed appropriate forms of the carrot and stick procedure to replace this element of self-pacing.

The moving line emerged as the major innovation. Once properly manned for a given speed, it seemed that this speed had only to be maintained by the supervisors to ensure that planned work times would be maintained. Dawdling at any work station would quickly reveal itself in persons moving off station to try to finish their parts. However, it is not quite as simple as that. It is possible on some work stations to let unfinished work go down the line with a chance of its not being detected until the product is in the consumer's hands. The main point was readily learned. The conveyor was a means not just of lowering transfer costs but also of reducing supervisory costs. At certain tempos the line even gave operators a satisfactory sense of work rhythm, a feeling of being drawn along by the work. Davis's (1966) study even suggests that the contribution to control may often be the main justification of the conveyor.

What I have spelled out is old hat to any production engineer. Nevertheless, it prepares the ground for the point of what follows.

We have heard a great deal lately about the demise of the automobile assembly line. The new Volvo plant at Kalmar does not even have conveyor belts. The European Economic Community pronounced in 1973 that the assembly line would have to be abolished in the European car industry.

I suggest that the new Kalmar plant does not represent any departure from the basic principles of mass flow-line production. In the first place, decision makers there are still seeking the maximum economic advantages to be gained from fractionation of the overall task. In the second place, the plant and its organization have been designed to reduce the same inherent costs of mass flow production, i.e., costs of transfer, standardization, balancing, coordination and pacing. Kalmar is designed as a mass-production flow-line to produce an economically competitive product. There is no radical departure from the principles of flow-line production, only from its practice.

Note, however, that I previously stressed that their aim was "maximum economic advantage from fractionation," <u>not</u> maximum fractionation. What they have done is to recognize that the costs we have discussed are inherent in production based on fractionated tasks. The further one pushes fractionation, the greater these costs become, particularly the costs other than transfer because they are more related to human responsiveness. *The objective of gaining* *maximum economic advantage from fractionation cannot be the objective of maximum fractionation.* There is some optimal level to be sought at a point before the gains are whittled away by rising costs.

Why has this logic been so obvious to the Kalmar designers and yet has appeared to escape other car plant designers? I do not think it is just because MTM, quality control, production supervision, designers, etc., operate in separate boxes with their own departmental goals. After all, at the plant design phase there are usually opportunities for the various specialties to come together. I think the reason lies deeper. If we look at the traditional practices in designing a mass flow line, we find that a critical assumption has slipped in and been reinforced by the widespread reliance on MTM, as a planning tool and as a control tool. This assumption is that it must be possible for each individual worker to be held responsible by an external supervisor for individual performance. On this assumption MTM goes beyond being a planning tool to determine or redetermine the probable labor requirements of sections of the line. It becomes part of the detailed day-to-day supervisory control over production. Under this impetus fractionation heads down to the lowest common denominator (lcd) of the labor on the line.

The same assumption that a line must be built up from the individually supervised one worker/one shift unit has gone into the design of algorithms to determine line balance. Ingall (1965) has reviewed 10 or so of the major algorithms. They all embody the same assumption. They go further along with MTM to assert that this is a firm building block by assuming that, on average, different operators work at the same pace; on average, an individual operator works at the same pace throughout a shift; on average, cycle time of the operation is irrelevant; on average, learning on the job can be ignored; on average, variations in parts and equipment can be ignored.

An average is just that, an average. It represents the mean value of a set of different observed states of a system parameter. It does not even tell us whether the exact average state has ever occurred. One thing is pretty sure: at any one time on a line it is most improbable that all aspects are operating at their average value. Typically, something is always non-average--wrong--and when one thing is wrong so are half a dozen other things.

The practical problems of balancing a line simply cannot be solved by abstracting this aspect from the total system of potential gains and inherent costs of flow production. As Ingall (1965) concludes in his review of assembly line balancing:

> Knowing whether these problems occur together is important because analysing them separately is not sufficient if they do. Using the "sum" of the results obtained by analysing each problem separately as the procedure for the combined problem can be a dangerous pastime (1965:4).

The practical significance of the balancing problem may be gauged from the finding of Kilbridge and Wester (1963) that the U.S. automobile industry wasted about 25 percent of assembly-line workers' time through uneven work assignment. No doubt this figure had been reduced at Lordstown in 1972.

I have wandered a little afield because I wished to stress how far this assumption about the individual building block has unquestionably grown into the professional ways of looking at the assembly line. It is this, I suggest, which has prevented others from seeing the obvious logic of the line as did the Kalmar designers. This hidden assumption has, I think, had a further distorting effect on thinking about the line.

Some people in the car industry during the 1950s and 1960s became sensitive to the fact that pursuit of maximum fractionation was self-defeating. They realized it was not at all like the engineering problem of pursuing maximum aircraft speed by reducing friction and drag. They realized it was not a problem to be solved by the grease of yet higher relative pay, by "feather-bedding" or by any of those things that Walter Reuther of the US Automobile Workers' Union bitterly referred to as "gold-plating the sweat-shop."

The response of these people to these critical insights was to look again at the building block, the one-worker/one-shift unit, to see what could be done about that. They did not question whether the individual was the appropriate block for building on.

One proposal to arise from this was to employ on the line only people who were at, or very close to, the lcd used by the MTM and the planners, i.e., donkeys for donkey work. This proposal does not look so good now as the international pool of cheap migrant labor dries up. In any case, there was little future in this proposal. Provided the line designers pursued the same twisted logic of maximum fractionation, they would inevitably design around an even lower, cheaper common denominator and the other costs would rise again.

The other proposal was to discard the concept of an lcd and accept job enlargement or enrichment up to a point which would come closest to the optimal fractionation for a majority of the people on the line. Imposing such enrichment on the minority whose optimum was below this level was an immediately obvious practical flaw. A more deep-seated flaw was that this job-enrichment approach argued from consideration of only one aspect of the system: task fractionation. It did not simultaneously confront the other parameters of the system: balancing, pacing, etc.

These parameters constitute a <u>system</u> of production. If some people on the line are responsible for only one parameter and someone else has the problem of looking after the other parameters, inefficiency and trouble have been designed in (Ackoff and Emery, 1972:222-27). No designers in their right senses would design a purely technical system in that way unless there were a very considerable lag time between changes on that parameter and changes on the other system parameters. I think I am safe in saying that no such protective lag time exists for the parameter of degree of task fractionation in a mass flow line. If something goes wrong with, for instance, the line balance or pace, the operator can very quickly become frustrated by a stoppage and consequent break in the rhythm of work or be temporarily slotted into some other station on the line.

An organization like this is basically unstable and is rendered even more so when the other party (or parties) looking after the other parameters live in the more powerful world of management, i.e., when communications are subject to the constant distortion of messages going between "them" and "us." Inevitably, the supervisors, MTM, work programmers, etc., respond to the predictable system problems by pushing for more fractionation and tighter controls.

The instability I am referring to is not that of the technical system of mass flow production. The instability is that of a superimposed organization which has very different roots in history. This organizational instability has very serious practical consequences. First, it makes it pretty well impossible to enrich individual jobs, either by a formal program or informally by supervisors who have taken to heart their exposure to courses on human relations in industry. As the pressures build up, the screws are back on again. Second, it is not just on the line that the pressures are experienced. As the instabilities accumulate to their recurrent crises on the line, all levels of staff are sucked down to coping with deficiencies in performance of the levels below them. Even the plant manager lives by the hour-to-hour performance of the line. Third, the almost universal experience of these phenomena of instability has created a sustained history of, almost an addiction to, technical solutions that would design people out of the system, or at least "fool-proof" technologies.

It is in looking at the mass flow production line as a <u>socio-technical system</u> that we come to what is really radical about the Kalmar design. The designers approached their task with an awareness that the problems of flow-line production could be theoretically approached in different organizational designs. At one extreme they literally examined the old cottage industry. More seriously, they compared the Norwegian experiences (Thorsrud and Emery, 1969; Emery and Thorsrud, Vol. II, "The Norskhydro Fertilizer Plant") with the semiautonomous work group as the building unit, as against the traditional individual/shift/work station unit.

The most striking outcome was the discovery that in an appropriately skilled and sized work group, all of the key parameters of mass flow production could come together and be controlled vis-a-vis each other at that level. Picturesquely, this was labeled "a lot of little factories within a factory." In terms of how we picture a factory, this the groups are not. Walk around Kalmar and you see nothing that even looks like a lot of little workshops producing their own cars. In system terms, however, it is a very apt description; a very valid design criterion.

This becomes more apparent if we look at the production groups formed at Kalmar. The first effects are rather like those some farmers have gained from cooperation.

Individually, their resources gave them little or no freedom of movement, and they had to ride with a market that was basically out of their control. Collectively, they have found new degrees of freedom and have started to shape their markets to allow even more freedom.

Formation of semiautonomous groups on the Kalmar assembly line has given workers a cycle time and buffers that would be negligible if split up for individual work stations. Split up in this way, no one could take an untimed coffee break; grouped together, everyone can, without increasing overall downtime. On individual work stations, everyone has to meet the standard work on that particular job, minute by minute; in the group setting, variations in individual levels of optimal performance can be met hour by hour. Those who prefer repetitious tasks can get them; those that need to be told what to do will be told by others in the group. Within the range of their task, the group can balance their work without outside assistance. If quality control is among the group's responsibilities and they are given time allowance for this, it can be within their capabilities.

Now we come to the fundamental matter of coordination, control and pacing.[2] If a semiautonomous work group is not willing to exercise control and coordination over its members, then the design flow lines must go back to the traditional model. At this point, I must rely on experience, not theory. The experience, over more than 20 years with a wide range of technologies and societies, is simply this: *if reasonably sized groups have accepted a set of production targets and have the resources to pursue them at reasonable reward to themselves, they will better achieve those targets than they would if each person was under external supervisory control*. If a theory is required, then I think it need be no more than that spelled out

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[2] Volvo engineers came up with an ingenious technical solution to the transfer problems: the individual self-propelled carriage. This allows the groups to vary the times put into each car while maintaining average flow on to the next groups.

in the six psychological requirements defined in 1964 (Thorsrud and Emery). In groups that have sufficient autonomy and are sufficiently small to allow face-to-face learning, these criteria can be maximally realized. It has been the realization of these individual human requirements that has enabled semiautonomous group working of mass flow lines to do what could not be done by MTM and algorithms for balancing the lines. There is also no economic way in which the individual psychological requirements could be maximally recognized by psychological testing procedures to fit individuals to the individual/shift slots of MTM.

I have suggested that the revolution at Kalmar has not been that of throwing out the assembly line. The revolutionary change began with the eradication of an organizational principle of one worker/one shift/one station; a principle that had no intrinsic relation to the design of assembly lines. Further, I have suggested that the payoff in the change began with selecting as the building block, a socio-technical unit--an appropriately skilled and sized semiautonomous group--that had the potential of simultaneously controlling, from their own immediate experience, the basic set of parameters of gain and cost in the total system.

It might be excusable to expand a little on this last point. Just as in scientific fields one of the most critical strategic breakthroughs is discovery of the appropriate "unit of analysis," so in production systems it is discovery of the basic "unit of design." Identifying "unit operations" was a classic breakthrough in the tremendously complex problems of chemical engineering. With this in mind, the British Social Science Research Council funded an international, interdisciplinary team "to devise a conceptual scheme for the analysis of men-machine-equipment relations with the more common unit operations" (Emery, 1966). The conclusion of this study was that *the basic unit for design of socio-technical systems must itself* *be a socio-technical unit and have the characteristics of an open system.*

In design terms, this represents the lowest level at which it is possible to optimize jointly the human and technical with respect to environmental requirements (the overall system inputs and outputs). Failure to recognize this may lead to design decisions being made solely on technical and economic cost criteria with consequent inefficiencies due to

- excess operating costs,
- maintenance difficulties,
- lack of growth in system performance,
- high overheads for control and supervision,
- lack of adaptability to market shifts (Emery, 1966)

Now, after nearly 10 years of living with this conclusion, I think I am prepared to argue even more strongly for a further conclusion unanimously arrived at by the study team: the best designs will be those that make the most use of the highest human potentials one could expect to find in any average group of eight to 10 human beings. My argument is this: first, there is a basic fact about systems that is simply ducked by the current plethora of so-called systems theoreticians, i.e., that "it is not simply the fact of linkages but rather the principle according to which all linkages fall together in *one controlling order* which makes an organization" (Feibleman and Friend, 1969). "Every system has one and only one construction principle ... *unitas multiplex*" (Angyal, 1941). The overriding principle of the mass flow production lines we are talking about is "economically productive." Any designer who creates a section which was itself unconcerned about being an economically productive part of the total system has created a "tool," not a genuine part of the system. As a tool it may be good or bad, sharp or blunt, but it is still a dull, nonadapting thing; it does not respond to changes in circumstances, it does not learn, it simply wears in and wears out. A genuine part of a system embodies in its own *modus operandi* the same governing principle as the overall system. In adapting it draws closer to the principle of the system.

The second aspect of systems design goes one significant step further to note that "systems are specific forms of the distribution of members in a dimensional domain ... In aggregates it is significant that the parts are added; in a system it is significant that the parts are arranged" (Angyal, 1941).

The usual design of an assembly line does nothing to create system properties in any section of the line. It simply adds more of this or that quanta of labor to the section. In practice, it sets up an inexorable demand for labor once the designed line comes into operation. When reality inevitably departs from theory there is a buildup of pressure on some individual work stations. Everyone else insists that their work station is a full house and hence additional work stations have to be squeezed in to cope with the peak points. That is, the original design predicates a creep to overmanning. Adaptive rearrangement, which would be the first response of a system design, comes a very poor second in these designs.

It is easy to fob off responsibility for this trend to trade union pressures. It is not primarily due to this. It is primarily the result of the original engineering design. There is sufficient evidence that unions would agree to different designs that offer real advantages to their members. If what the unions are offered are aggregative designs from which the employers hope to maximize their economic gains through maximizing fractionation, then the unions must exploit this game to the maximum of their ability. Until recently, the unions have not had the alternative possibility of sending the employers back to the drawing board. They have not had this possibility because they have not had the knowledge of alternatives that enabled Gyllenhamer of Volvo to send his designers back and back again to the drawing boards until they got a really new concept for the Kalmar plant. The Kalmar design finished up as a genuine systems design. By the first criterion, the groups were enabled to confront, and take responsibility for, the basic parameters that determined whether they were an economically productive section. By the second criterion, the groups were enabled and encouraged to meet variance in their circumstances by rearrangement of their own efforts. Adding further permanent members was very much a last resort, to be used only after making-do by rearranging themselves or temporarily borrowing labor from neighboring groups. As we had seen from the earliest coal-mining studies, there was a marked reluctance of groups to accept any change of group membership until they had done their best to cope with their work problem on their own.

There is a third and last step in systems thinking that is, I believe, important to the design of productive systems. In the statement of the first two principles I may have appeared to play down the characteristics of the human beings that are the indispensable elements of socio-technical systems.

I have spoken simply of "overriding principles" and the priority of "positions of parts and the arrangement and rearrangement of the parts." The third principle is, however, that"the more the inherent properties of parts are utilized as codeterminants of positional values ... the greater the organisation of the whole" (Angyal, 1941:27) It states that higher levels of organization can be achieved only by the fuller use of the inherent properties of parts as codeterminants of positional values. "The human organism, for example, is highly economical in this respect: it carries a minimal load of irrelevant properties of parts; most of the properties are 'utilized,' that is, are co-determinants of the positional value of the part" (Angyal, 1941). This principle means, quite simply, that the best design for any productive system will be that which not only allows that the goals of any subsystem, any part, embody in some manner the overall system goals (Principle I) but allows any such part to be self-managing to the point that it will seek to cope with external variances in the first instance by rearranging its own use of resources (Principle II). The best design will be that which also recruits or develops its constituent parts so that they have the intrinsic properties suited to the demands on the position they occupy. At the simplest level, the third principle would indicate designing-in a degree of multiskilling that would meet the probable rearrangements of the section about its tasks. At a more sophisticated level of design, account would be taken of the human potentialities for reasoning, creativity and leadership that might be expected in any group of 8 or 10 human beings. This would mean designing the social system of the small group so that it becomes an instrument for its members--something they largely manage themselves--not vice versa. Then it becomes <u>variety increasing</u> for them, and they are enabled to pursue not only production goals but also purposes and even ideals that pertain to themselves.

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