Reflective Production

in the Final Assembly of Motor Vehicles

An Emerging Swedish Challenge

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ABSTRACT

Recently, Jones et al. (1)* have directed attention at how efficiency can be increased in line production. They attempt to prove that the assembly line has a greater potential than is exploited in traditional mass production. The form of production practised by Japanese car manufacturers is seen as an ideal. An alternative production form tried in some Swedish plants is dismissed as inefficient. This conclusion is not adequately supported by theoretical analysis or empirical evidence, however.

There is an obvious need, then, to present some theoretical principles and empirical evidence relating to the new Swedish production systems for final assembly of motor vehicles. It is our contention that in these production systems it is possible to simultaneously enhance efficiency and quality of working life.

In Section 1 we briefly sketch three production forms as they apply to the final assembly of automobiles, viz. Traditional Mass Production, Lean Production and Reflective Production. We also discuss the societal environments in which these different forms of production have evolved.

Volvo's Swedish Uddevalla Plant represents one of the main examples so far of a reflective production system for final assembly of automobiles. Section 2 contains some notes on the design, planning, implementation, and running-in of the Uddevalla plant.

In Section 3 we amplify the analysis of different production flow patterns for final assembly and in particular addresses the issue of semi-parallel mechanistic production flow and parallel organic production flow as alternatives to serial flow on a conventional line assembly. This is an empirically based comparison.

In Section 4 we spell out some conclusions and summarize.

1. THREE PRODUCTION FORMS

1.1. Production forms and socio-economic conditions

In this paper, three different approaches to automobile assembly will be discussed; Traditional Mass Production, Lean Production, and Reflective Production. Each of these forms of production has its roots in a particular country; Traditional Mass Production in the United States, Lean Production in Japan, and Reflective Production in Sweden. Also, each form of production mirrors certain socio-economic conditions in the country where it originated.

North American society has a particular historical relation to the automobile industry; Ford's assembly line was the cradle of Mass Production. Japanese society is of interest to the automobile industry of today; both management and the assembly line have been made more efficient, and efficiency has also been improved in the relations within the automobile manufacturer as well as with suppliers and markets, i.e. Lean Production. The Swedish automobile industry has for some 15 years been trying out alternatives to the traditional assembly line, and may be said to have introduced a new form of production - Reflective Production - with the inauguration of the Volvo

* Les chiffres entre parenthèses renvoient à la bibliographie en fin de texte
Car Corp. final assembly plant in Uddevalla.

The fact that the recent innovations in automobile production originated in Japan and Sweden rather than in the United States and also the differences between the Swedish and Japanese initiatives may be partly explained by differences between these countries with regard to product markets, labour markets, industrial relations and other socio-economic conditions.

The North American automobile industry has always been oriented towards its huge domestic market. In contrast, both the Japanese and the Swedish industries are strongly export-oriented. Japanese automobile manufacturers have, mainly for reasons of market restrictions, established a number of plants in foreign countries. In this connection they have taken with them their own production form and created "copies" of Japanese production facilities outside Japan, so-called Transplants. The Swedish automobile industry, as opposed to the Japanese, is oriented towards low volume production of luxury cars. When Swedish plants have been established abroad, alternatives to line assembly have been used in plants with small production volumes, e.g. in South East Asia, and some practical knowledge of alternative forms of production has thus been gained, albeit on a small scale.

For a long time, the North American automobile industry enjoyed technological superiority over its foreign competitors, and it totally dominated its domestic market, the largest in the world. From the American perspective, the automobile industry appeared to be a mature industry, and economies of scale - not new forms of production per se - was seen as the key to success.

Meanwhile, the Japanese faced the task of rebuilding their industry after the war, and in Sweden Volvo and Saab somewhat later faced the challenge of surviving as independent low volume manufacturers. It was clear that neither the Japanese nor the Swedes could succeed by following in American footsteps. This situation favoured the introduction of new forms of production.

It may also be that industrial relations in Japan and Sweden are more productive and pose less of an obstacle to the introduction of new production forms than those in the United States. An important factor in this connection is that the relations on the North American labour market continue to build on the classical conflict between labour and capital. Industrial relations in the motor vehicle industry have tended to be antagonistic rather than cooperative. As a consequence, phenomena connected with local problem solving based on mutual understanding have had no great effect in North America.

The situation in Japan and Sweden is different. Beginning in the 1960's, industrial relations in the Japanese automobile industry have been transformed from a confrontational to a cooperative mode. Japanese trade unions today have been described as "an indispensible partner to management" (2). Swedish trade unions are among the strongest in the world, but there is also a tradition from the 1930's onwards of cooperation and mutual understanding between employers and trade unions. Solving problems in an atmosphere of critical, unbiased, mutual understanding is regarded both as being able to bridge immediate conflicts and as being conducive to results that exceed those that would otherwise have been possible.

A further similarity between Japan and Sweden is that unemployment rates are very low in both countries, whereas wide-spread unemployment exists in the United States.

There are also some significant differences between socio-economic conditions in Japan and Sweden, however. In particular, large wage differentials and individualized wages are less acceptable to Swedish trade unions than to those in Japan. Unlike the situation in Japan, it has
therefore not been possible for Swedish motor vehicle manufacturers to recruit and retain a high-quality workforce by means of high relative wages, or to use seniority-based individual wages to reduce employee turnover. This may be a decisive factor behind the Swedish motor vehicle manufacturers' attempts to attract employees by creating intrinsically more satisfying jobs without compromising productivity.

1.2. From Traditional Mass Production to Lean Production

Traditional Mass Production, as found in the motor vehicle industry, is based on a rigid and extensive division of labour and a serial production flow, usually implemented by means of a paced assembly line. Line assembly appears rational in that material flows are well-defined, a familiar material feeding technique is available etc. During the last decade, the traditional assembly line production has been strongly criticized, however.

To a greater extent than is generally recognized, considerable productivity losses are inherent in line assembly. This is mainly due to the natural human variation in working pace, the sensitivity to disruptions, the difficulty of balancing the work operations, and the need for extensive inspection and adjustment of the objects assembled (4, 5, 6 and 7).

In addition, many products have become more complex and the number of product variants has increased. This has greatly increased the number of different components that have to be displayed along the assembly line. When a line with conventional materials feeding techniques is used, this leads to consequences such as space shortages along the line and material handling problems

In traditional line assembly work, the individual's working pace is controlled by the movement of the assembly line, and the work is fragmented - the main reason for the latter being, of course, the line itself, but also in some cases the way of describing the product and organizing the pre-production work (8). These working conditions have led to high levels of employee turnover and absenteeism, and have undermined the sense of responsibility for product quality.

Internationally, the pre-dominating trend has been to refine line assembly to address these problems. Some common methods for improving line assembly are quality circles, team work, just-in-time principles, extended subassembly, product standardization, etc. The expression "Lean Production" originally coined by Krafcik (9) was used by Jones et al. (1) to refer to a production form incorporating such improvements on Traditional Mass Production.

The notion of Lean Production as presented in Ref. 1 covers a broad range of activities including product design, purchase of parts, manufacturing processes, and marketing of products. Manufacturing processes in the case of automobiles include stamping, welding and painting of bodies, as well as final assembly. In this paper we focus on Lean Production as it applies to the final assembly of automobiles.

Lean Production, we read in "The Machine that Changed the World":

"... is "lean" because it uses less of everything compared with mass production - half the human effort in the factory, half the manufacturing space, half the investment in tools, half the engineering hours to develop a new product in half the time. Also, it requires keeping far less than half the needed inventory on site, results in many fewer defects, and produces a greater and ever growing variety of products.” (11).

This and similar statements in Ref. 1 seem to imply that the main objectives of Lean Production are
high productivity, high capital turnover and high product quality. That is, Lean Production is by definition oriented towards the three objectives just mentioned. Note, however, that these objectives are nowadays shared by virtually all motor vehicle manufacturers, regardless of their forms of production.

Secondly, it is maintained that Lean Production is characterized by a high degree of goal attainment with respect to the three objectives mentioned (10 and 11), but it is not clear whether this is part of the definition or an empirical hypothesis. We prefer to regard this statement as an hypothesis, since otherwise Lean Production would be superior by definition, and in scientific research one should avoid value-loaded concepts.

The third element in the characterization of Lean Production is concerned with the means used to attain the goals mentioned above (rather than the selection or attainment of goals). Lean Production has been presented as a revolutionary new production form, but in our view it is more adequately described as a refinement or perfection of Traditional Mass Production.

Lean Production thus retains the assembly line, short work cycles, standardized work methods, hierarchical organization, and firm discipline, but it does also have some distinctive characteristics:

- Production is "lean" in the specific sense that the number of employees is kept at a minimum (so that over-time work is frequently required), inventory stocks are reduced, buffers are eliminated or reduced, less floor space is allocated to final adjustment, etc. An additional benefit of this "lean" approach is that production bottlenecks can more easily be identified.

- On the other hand, lean automobile assembly as practised by Japanese companies requires that the production system is provided with first-rate production resources. These include a highly paid and carefully selected work-force, a well-designed automobile to assemble, and dependable just-in-time supply of materials.

- Workers belong to "teams", usually consisting of 5 to 10 members (as noted in (2), these teams are not autonomous work groups in the Scandinavian sense, however). Mutual help and information sharing within and between teams are encouraged. Job rotation and the transfer of workers to new jobs are wide-spread practices. Both formal and on-the-job training is extensive, and the acquisition of multiple skills is rewarded.

Important values in Lean Production are thoroughness, consistency and steady, incremental improvement with perfection as the ultimate goal. The problem-solving approach is to identify and eliminate the cause of the problem rather than to rely on a quick fix.

1.3. The evolution of Reflective Production

In order to nuance the debate around Lean Production we here introduce Reflective Production as a new production form. Such Reflective Production has today been realized in the final assembly work as well as its preconditions, in material feeding techniques, and in the design of information systems. In the future, Reflective Production principles will influence the central activities of design and pre-production.

The main examples of Reflective Production in the motor vehicle industry so far are Volvo Car Corporation's facility for final assembly of automobiles in Uddevalla and Volvo Truck Corporation's Tuve facility for final assembly of trucks.
Technically, a reflective production system for final assembly is based on the idea of highly parallelized material flows that enable autonomous work teams to assemble objects independently. As a concomitant of this parallelization, the work tasks assigned to teams and individuals will comprise a larger number of work operations. This means longer work cycles in the final assembly, requiring extended competence. On the other hand, new types of competences are also generated by the extended work content. The work teams are given responsibilities so that they can meet demands on, e.g., quantity and quality.

The introduction of parallelized final assembly with extremely long work cycles changes the work content from being controlled from outside the work process, towards team controlled flows connected to more complicated tasks, wherein the worker makes important decisions together with his coworkers on, e.g., variation in work pace and the sequence in which work tasks are performed. To make this possible, it is necessary to introduce a radical change of various technical and administrative subsystems. The assembly has to be totally reorganized on the basis of formalized knowledge derived from the shop floor. Final assembly with considerably longer work cycles can then be achieved. Note that today's information technology allows completely new possibilities in this respect.

It should be emphasized that Reflective Production does not endorse humanization of work at the expense of economic and technical efficiency quite on the contrary! High productivity, high capital turnover and high product quality are important goals for Reflective Production as well as for Lean Production. Reflective Production is also concerned with other goals, however. As noted in Ref. 12, there is no systematic discussion in Ref. 1 of quality of work and related issues. To remedy this imbalance, Reflective Production does also take goals based on employee concerns into account, specifically adequate ergonomics, high autonomy, and meaningful work content.

It is argued in this paper that Reflective Production for final assembly is as efficient as Lean Production and in addition more "socially efficient".

As noted above, Reflective Production has been realized in Volvo's final assembly plant in Uddevalla. Some implications are listed below:

- The assembly work has to be viewed in a wider context on the shop floor. It must include not only the assembly itself, but also the preceding phases, i.e. controlling the materials, structuring the materials and tools, and the subsequent phases, i.e. final inspection, and if necessary, adjustment and further inspection (13 and 14). The vertical division of labour is also affected in that assembly workers take over certain administrative tasks. This new concept of assembly work calls for the workers' own reflections.

- In Reflective Production, the assembly work itself becomes intellectualized and thereby meaningful. The work teams are able to rebalance their own work. In non-reflective production forms, on the other hand, assembly work is planned in advance down to component level by people other than the workers. The work design is thereby divorced from the workers' practical knowledge. Humanization in the non-reflective sense then becomes a question of replacing assembly with other activities.

- Established empirical knowledge of grouping and restructuring work tasks is also a basic precondition for the realization of efficient and humane production systems. Such a total reorganisation leads to other conclusions regarding industrial work than those drawn today. Work content, factory layout and investment in equipment will be chosen differently. In addition, manual, intellectual and machine resources will be exploited more effectively than today.
Production thereby becomes reflective in the performance itself.

- In long cycle work in highly parallelized reflective production systems, where the work has been designed according to the principles for naturally grouped assembly work, it is possible to assemble a product with a lower degree of design than today's Swedish automobiles (Ref. 5). If the existing variations of products are viewed as natural and as a precondition, then variants are an "asset" in long cycle assembly work (8).

Reflective and non-reflective production forms require different sets of competence. This in turn closely relates to the underlying principles of learning. There are two essentially different ways of learning; the dominating additive method and the functional method. These methods include the organization of ideas and purely technical dimensions, such as material flows and assembly instructions. Let us take a closer look at some important dimensions in each.

The additive learning method rests on the assumption that the final result is the sum total of all elements. Demands for standardization in combination with rationalization have in some Swedish cases led to the replacement of meaningful names by codes adapted to machines. The components are thus assigned numerical codes suited to computer systems for product description and material feeding. For this reason, and through there being so many model variants, the number of parts seems enormous and impossible to overview. This is one reason why in the eyes of traditionalists it is impossible for one and the same person to assemble a whole car himself.

The functional method of learning (15), on the other hand, rests on the assumption that the automobile is an understandable whole consisting of well-known functions. Then, there must be adequate names in use for the components. The workers have to be able to talk to each other in a plain, expressive language about their work and about the components that they assemble. It is not meaningful to communicate about assembly work using a sequence of component numbers, for example.
Figure 1: Schematic comparison between Lean Production and Reflective Production. The comparison is simplified in the sense that differences in the preconditions of operations have not been considered. Swedish products are characterized by a low degree of design (Ref. 5) and by the fact that variant materials that are fitted are often optional. Japanese automobiles in the higher price bracket often include these extra functions.

When transferring this principle to material feeding techniques, the basis thus must be the vehicle itself. This is important for the assembly workers but even more so for the materials handlers, who in their practical role must be professionals at choosing the correct components. The product functions are normally realized through a number of physical parts (components) being related to each other (fitted) with a predetermined quality (precision) and fixed to the car body. Therefore it is possible to describe the automobile in terms of functional material groups which are related to the assembly work. This means that product functions, assembly work, and the position of the material, to give a few examples, can be taken into consideration at the same time.

Reflective Production, we conclude, is based on human preconditions, which dictate the design of technical and administrative preconditions on the shop floor. Reflective Production is based on specifications for both man and product. These preconditions then specify unambiguously future relations to both the market and supplier.

The application of Reflective Production in the automobile industry is radically new. Reflective Production does not mean a return to pre-industrial handicraft. In a reflective production system the principles of learning rests on mans natural way of thinking, to relate things which belong to the same meaningful context.

Lean Production, on the other hand, is the result of a long and conscious refinement of the principles of Traditional Mass Production. This production form, and to a certain extent Lean Production, have produced preconditions for the development of Reflective Production. In its application, Reflective Production is a considerably more advanced concept, compared to Lean Production.

2. NOTES ON THE REALIZATION OF REFLECTIVE PRODUCTION IN A SWEDISH FINAL ASSEMBLY PLANT

2.1. From rectilinear to creative design and planning of production facilities

The design and planning of production facilities in Sweden takes place largely along the lines of a traditional projection paradigm. The prevailing paradigm to factory layouts the assembly line is supported by an institutionalized, rectilinear projection technique. It is thereby assumed that the track from start to finish can be seen as a straight line. Behind this lies the assumption that there is one correct way of solving the design problem, see figure below. This means that the task of reaching the goal does not start until the goal has been fixed and operationalized, in line with the accepted proposal for a solution. This can of course be very effective, presuming that the goal has been correctly understood and formulated from the beginning.

By employing consultants and applying this traditional planning technique, industry paves the way for competence waste. The consultants hired build up a unique competence about the production system and its preconditions, but since they do not belong to the permanent organization take their competence with them when they leave, often exactly at the time when it is needed most.
There has been a paradigm shift in the process of design and planning of production facilities. Creative projection has evolved, which means that guidelines are set for where proposals for solving problems are to be found, based on one's position at the starting point, "now" (see figure below). A possibility is thus created to take advantage of alternative solutions that may appear during the projection process, and which can provide better preconditions for attaining the goals set. Creative projection thus makes use of reflections made by the involved personnel rather than their ability to follow a rigid planning schedule.

Figure 2: The diagram illustrates how the vision of the production system in Volvo’s Uddevalla plant for final assembly changed in the course of the planning period. The diagram is based on time-geographical principles (16). The development is related to the passage of time and a design dimension on which the extremes are "automated assembly on a large scale" and "craftsman-like assembly on a large scale". The diagram indicates the position at the time of certain important decisions. Different principles for final assembly are entered along the horizontal axis. Such variables as cycle time, total number of employees involved in assembling a particular automobile, the workers' overview of assembly, the worker's personal skill, the development of this knowledge, and control of the production flow (whether determined from outside or by the worker himself) are central elements in this dimension. The diagram thus illustrates in principle, not in detail, how solutions were changing in the direction away from traditional towards reflective final assembly (17).

During the projection of the Volvo final assembly plant in Uddevalla the creative projection model was applied. Conflicting visions of production systems thus existed side by side in the project group for a long time, until the proposal for a way of solving central problems suggested by one of them - reflective production proved to be superior. This put great demands on the ability of the project leaders to handle conflicts that arose during the projection.
It is necessary to realize that the essential fundamentals of the production form chosen must be maintained. Sooner or later one proposal must be chosen, in accordance with one of the visions but the choice must be made when several factors indicate the superiority of just this choice. It is not sufficient for one factor to point in a certain direction (17).

2.2. Some implementation issues

Since our arguments are based on the practical realization of a number of production facilities in Sweden we would like to summarize our experience of the process of change. Here it has been a question of projecting a completely new plant with naturally grouped assembly work, in accordance with the principles we have discussed above, starting with a blank sheet of paper:

- The preconditions for the realization of the visions must be built within the company and it has often been necessary to do this by stages. However, such realization has to be complemented by competence as regards implementation of the new production system.
- The new vision of the production system which is perceived as relevant and desirable to realize involves far-reaching delegation, democratization and variable leadership, as illustrated in the figure below. Levels of competence and leadership styles must be variable, so called situation-conditioned leadership (18).
- The realization is not democratic in the sense that everyone can "hold one another's hand" - the best must still be the leaders. This means that different work organizations are best suited to their particular purpose during the different phases of projection, running in and fully run in production.
- We have noted that it is not always easy to assimilate external knowledge. It is here a question of a process of competence development, in which a lack of previous experience, and inability to assimilate any existing competence must be taken into account. It is not possible to understand on behalf of someone else or, in other terms "to understand is to invent".

In Uddevalla, work teams can consist of from seven to twelve members. Equipment with low loading are common for the whole team and sometimes for several teams. The degree of interdependence between the team members is dependent on the task and varies with the situation. Team members mostly work in sub-groups of two persons, who assemble the same object and are thus most dependent on each other, while one or two individuals serve and co-ordinate several such sub-groups. In practice, small teams have proved to function more smoothly because of a less complex internal work pattern.

Figure 3: A model of the implementation process and competence growth for functions closely connected to the factory floor. A boss, who does not change leadership style, will create problems.

On the factory floor, the division of labour between team members is influenced by the size of the team and must be adapted to the distribution of competence among its members. The design of the team organization can be compared to the development of systems in team sports, i.e. to have mastered a number of strategic action plans in advance, where agreed actions have known but not always unambiguous effects.

3. AN EMPIRICALLY BASED COMPARISON BETWEEN DIFFERENT PRODUCTION SYSTEMS FOR FINAL ASSEMBLY
In this section we intend to compare, in certain aspects, three production systems for final assembly with different flow patterns.

1. A serial flow traditional mass production system. In Sweden, this type of production system can be found in Volvo's Torslanda plant and Saab's Trollhattan plant.

2. A semi-parallel flow hybrid production system. This system is characterized by a "mechanistic" flow pattern with centralized mechanized functions characterized by large differences in the degree of mechanization in the process (assembly and materials handling). Saab Automobile's final assembly plant in Malmo provided an example of such a production system.

3. A parallel flow reflective production system. This system is characterized by an organic flow pattern with successively decreasing mechanization and maintained/expanded sorting capacity from the beginning of the process to the finished automobile. An example of such a system is provided by Volvo's Uddevalla plant (13 and 14).

In a serial flow system, i.e. in line assembly, specific work tasks will move between work stations for reasons, among others, of balancing. Components that are identical or have a connection with characteristics in the vehicle will not always be assembled at the same stations for each individual vehicle. This means that the assembly work is characterized by a number of additive sequences without any apparent logical connection.

In a fully parallellized flow, i.e. the organic flow pattern, on the other hand, the automobile stands still while a team assembles the complete vehicle. and the work teams control the production flow. The product's inner logic becomes obvious, necessary adjustments can be made, and the worker can correct faults - if there are any - directly (8).

An organic flow pattern meets the demands for efficient exploitation of space, flexibility, less sensitivity to disruption in the materials flow and worker control of the flow to a greater extent than a mechanistic flow pattern. The organic pattern does not preclude adaptation of the degree of mechanization. Manual work is concentrated to the periphery.

The three systems characterized in the following text, are not replicas of real life systems. Instead, each of them represent an ideal type of system with input from several assembly plants, mainly within Sweden. The performance figures presented in the figure below are partly taken from published research, but some of the figures are given without reference because of their being confidential. However, the data has been collected by the research team over a long period of time and from several assembly plants.

3.1. The serial flow case

The serial flow system consists of 250 work stations (two workers at each station) in series, divided into foreman areas with approximately 20 workers each. Within such an area, there is job rotation to some extent, and the the workers are on average able to perform the tasks on four work stations. The movement of the automobile is achieved by means of an underfloor chain conveyor and the cycle time is 2 min.

In addition to the assembly workers in the foreman area, one worker handles quality control and another takes care of some of the mechanical adjustment. There is also one instructor. Absence is mainly handled within the foreman area (more workers hired), but workers can also be borrowed
The materials are fed to the work stations in pallets and plastic boxes and displayed on racks along the line. The containers are exchanged independently of each other and the ordering and transportation of materials (by means of fork lift trucks and wagons) are carried out by workers belonging to the materials department. All part numbers necessary for production of every product in the product mix on the line are displayed at the line at all times. For materials in boxes, the two-bin system is used. For palletized materials, a buffer pallet not accessible to the worker is stored at a higher level on the storage rack. A few components are fed to the line in so-called sequence delivery flows.

3.2. The semi-parallel mechanistic flow case

This system consists of eight production steps in series. Each step contains between one and six (parallel) channels. This means that some parts of the system function in the same way as the serial flow system described above. The production steps are separated by intermediate dual-purpose buffers. First, the buffers compensate for variances in working pace in the steps and for variations due to different assembly objects having different assembly times. Second, they sort the assembly objects, so that the sequence of objects is maintained throughout the system even if the objects overtake each other in production steps with parallel channels. This is necessary because of requirements from the materials feeding system.

Because of the serial flow, even if parallelized in some production steps, there is a requirement of balancing the work between and within steps. The parallel teams within a production step also have to be balanced to minimize the risk of overtaking between objects in the system. Because of this, absence has to be handled effectively in the system.

Because of the varying number of parallel channels, the cycle time varies between 3 and 20 min. (80 min. is possible in some production steps). In the parallel areas, the work organization is a team with six workers in each. Quality control and mechanical adjustment are performed both by the work teams in the production steps and in a separate adjustment area at the end of the production flow.

Materials feeding is performed through a combination of four methods. So-called variant materials are picked in kits from the local storage by the assembly teams, basic materials (the same for each automobile) are delivered in batches for 12 automobiles to the work stations, small materials are fetched by the assemblers when needed, and some materials are fed by the materials feeding organization to the assembly stations in sequence deliverles.

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<th>Serial flow</th>
<th>Semi-parallel</th>
<th>Parallel organic flow</th>
<th>Handling loss (%)</th>
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1. The time taken for the workers to fetch and handle tools and materials.
2. Inspection and adjustment during and after the assembly process.
3. The losses are in relation to the required assembly time, which is the same in all three cases and is equivalent to 100 %. In the case of the line, the reported total time used is thus 235 %. The assembly time needed is dependent on product design. Only time from the point when the worker has the component in position for assembly until the component has been fitted is included.
4. Two different limiting factors are the limits imposed by the system, and the fact that the worker himself can not over-achieve more than to a certain extent; at least 20 % should be allowed (Ref. 4).
5. On a line working-up always takes place at the expense of ergonomics, more materials handling etc. Working up of time is here, in fact, not permitted. In practice, however, it is permitted within foreman areas.
252015 System loss (%) $2.803020$  Total loss (%) $3.1356540$  Throughput time base (object (h))

6 16

7 Possible working-up at collective and individual level (min.)

0 0-15 5 20-60 20-60 unlimited

15-100 Space requirement $(m^2/(automobile/year))$

0.6 0.6

0.4 Size of repair area $(m^2/(automobile/year))$

0.2 0.2

0.1 No. of hand tools and mechanized equipment per assembly min.

1.6 (Ref.20)

1.6

0.6 No. of material supply units per automobile displayed for the workers

5000

1800

1500

Figure 4: Comparison between three different fully run in production systems for final assembly. Uppermost in the table is shown a loss analysis. Then follow representative key factors. For example, the space requirement in the mechanistic flow case is dependent on the demand for autonomy (20-60 min. working up) and on maintaining the sequence which means large buffer areas between the eight production steps. The results here are consistent with the results from earlier studies (Refs. 3, 4, 5, 6, and 7). Note the differences between the three cases with regard to

6. In parallel systems with administrative autonomy the possibility to work up is regarded as unlimited at the group level since the group plans for itself (a group controls/perform the assembly of complete automobiles). How much working up is possible at the level of the individual is dependent on how the group distributes work/free time.

7. Measured from layouts of three typical systems and includes both assembly and storage areas. Normalization has been made with regard to the stipulated autonomy and other preconditions in each case.

8. Measured from layouts of three typical production systems for final assembly and includes both mechanical and paint repair.
productivity (as a consequence of different productivity losses) and space requirements. Additional benefits of a parallel organic flow system include improved mix flexibility and volume flexibility as well as cars becoming more easy to assemble as a result of improved conditions for effective communication between the employees that assemble automobiles and those who design them.
3.3. The parallel organic flow case

This is a system consisting of 50 parallel assembly teams, each responsible for the assembly of complete automobiles. The teams are grouped in several product work shops. Each team has about eight members, performing not only the actual assembly but also inspection, mechanical adjustment, instruction, production planning, cleaning, production engineering tasks, etc. The number of produced automobiles demanded of each team is related to the number of workers present and the assembly time required for each automobile. Substitutes when members are ill are therefore not needed, which differs very much from the two systems presented earlier The cycle time is normally approx. 100 min., but can vary depending on how the team allocates the work tasks and of course it depends on the competence level of the members in the teams. In the extreme case a complete automobile is assembled by two workers. Each team zone has four automobiles standing still and accessible for assembly. Assembly adjustment - if needed - is done directly by the worker in the course of assembly. There is a spokesman position in each team, a position that rotates among the team members.

The work force differs from the two other systems, where the majority of workers were young men. In this system, the age of the workers are more varied and more women are employed. This has been a strategic choice in the recruitment since the early planning of the system.

The materials are delivered in kits from a centralized picking store (this is true for all materials except for some few components having a very unpredictable consumption per automobile). A number of minor subassemblies, as well as some that require heavy equipment, are included in the kits. The main subassemblies, however, are built by the teams in the team zones.

4. CONCLUSIONS

It is argued in this paper that a reflective production system for final assembly with parallel organic flow may be as economically efficient as a lean production system, in addition to offering a superior work environment. In figures 5 and 6 below, we have summarized our conclusions with regard to the final assembly of motor vehicles.

In this connection, we want to emphasize that the work of final assembly on the factory floor itself represents only a small part of the total cost of the production of the automobile. The debate about the design of industrial work focuses all too easily on man-time in assembly, which is a considerable simplification. In the production of luxury automobiles, the quality of the finished product is considerably more important than the time needed for final assembly, and it is necessary therefore to design production systems that can produce excellent quality.

Figure 5 (p.125): Comparison between different production forms with regard to economic and human goals achieved in final assembly of automobiles having the degree of design of Swedish automobiles. Note that the comparison is simplified and automobile manufacturers with low production volumes cannot easily achieve the high degree of design of Lean Production in its most extreme application. High volume manufacturers have better pre-conditions for exploiting suppliers' competence in respect of design and development work, for example.