Enriching Production

Perspectives on Volvo's Uddevalla plant as an alternative to lean production

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Production system design – a brief summary of some Swedish design efforts

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1. Introduction

Production system design traditionally includes aspects connected to the materials flow patterns inside the factory. Therefore, the design process of the production system includes, for example, problem areas such as work place design, layout planning, materials flow analysis, etc.

For example, concerning the manufacturing of components using expensive production equipment, the design process will focus, among other things, on the utilization of the individual machines, as well as, introducing methods such as group technology, mechanization of the materials handling between the machines, etc. If, on the other hand, components are assembled into complete products, as is the case in the final assembly of vehicles, it becomes important to better utilize the human being in order to reduce the required manpower. The design process will, therefore, focus on: balancing methods, 'just-in-time techniques', etc.

The system design of production systems for final assembly, has in many cases, consisted of a process of refining the existing production systems, i.e. the traditional assembly line, rather than implementing non-traditional production principles. This is due to the risks involved as well as intellectual barriers to some extent (Granath, 1991).

We argue that today there exists an empirically tested coherent theory of how to design non-traditional production systems for final assembly of large products, such as yachts, trucks, buses and automobiles. However, this theory has not been fully recognized and communicated at an international level. In most cases, this is probably due to the fact that Swedish efforts are generally considered and presented as social experiments, assumed to be isolated from important technical dimensions, like materials flow pattern, materials feeding techniques, etc.

2. A brief history

At the beginning of the 1970's, the most radical changes in assembly work took place within the manufacturing of trucks. A very similar production system was used at Volvo in Sweden in the small Volvo Arendal work shop and at British Leyland in the United Kingdom (Blackler and Brown, 1978). In British Leyland's production system, a group of 12 workers assembled complete trucks.

The Arendal workshop proved to have a superior productivity and product quality. At that time there was no valid theoretical explanation for this phenomenon. A general theoretical analysis had been performed in the Volvo Car Corporation (Rosengren, 1981), but these were not generally recognized. This production system was in many aspects identical to the one introduced by the Volvo Truck Corporation several years later, that of a parallel flow with integrated sub-assembly, characterized by unpaced high-autonomy, collective work. The parallelized flow means that the flow of products is parallel instead of in a series, as is the case with the traditional assembly line, thus increasing the cycle time (the amount of time required to complete one work task in repetitive work).

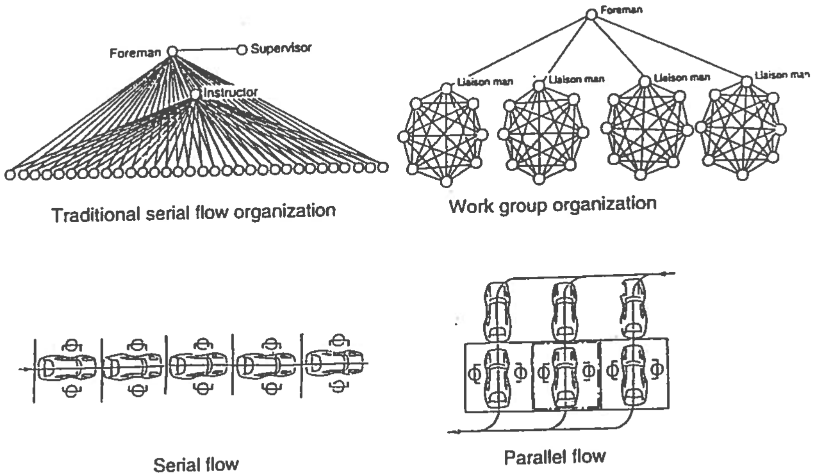


Figure 1. The Saab-Scania body shop in Trollhättan was changed from serial flow to parallel flow, thus increasing the productivity and the technical autonomy. Paradoxically, it became possible to simultaneously combine efficiency and humanized work (Karlsson, 1979). The organization was reformed to suit the technical preconditions determined by the changed technical dimensions.

The most prominent example of an alternative production system was implemented during the mid-1970s in the Saab-Scania body shop in Trollhättan. Note that in a body shop the work consists of grinding and welding on the naked automobile body. Thus, one does not need to supply a large number of components, as is the case in final assembly. Therefore, the most crucial research task was to develop methods for supplying materials to parallelized flow production systems.

In theory and in a number of case studies, it later proved to be both practical and economically viable to supply materials to large products in parallelized flow. This was achieved by using kitting of the materials and a combination of decentralized and centralized materials stores (Engström and Karlsson, 1982; Engström, 1983).

Although this possibility existed, the traditional materials feeding techniques (methods used to supply the components needed for the assembly work) and the need to use both the traditional assembly line and the alternatives simultaneously in the same plant, led to the development and implementation of the so-called 'mini-lines' at Saab Scania in Trollhättan.

This was a serial flow production system with intermediate buffers, integrated sub-assembly stations and the possibility to continuously regulate the pace of the line. Thus, it was possible to use traditional materials feeding techniques. These 'mini-lines' appear to be similar to those implemented in the Japanese factories at Kyushu and Tahara almost ten years later.

The Volvo Uddevalla final assembly plant wich ran between 1987–93, was the latest full-scale example of a practical application of the design theories of non-traditional production systems. In fact, the Uddevalla plant provided the last key elements needed to complete the theory and its application.

While the 'mini-lines' were a compromise, concerning the materials feeding techniques, among other things, the Uddevalla plant, on the other hand, was an example of an inverted design process. By turning the design process the other way around, i.e., starting the design process from scratch, some of the generally accepted traditional design criteria were transformed into methods. For example, long cycle time and parallelization were methods used for achieving high productivity and quality, as well as flexibility. Long cycle time was not considered as a goal in itself.

The original phrasing of the research area during the 1970's, as a materials feeding restriction against parallelization, originated in dialogues with representatives from the automotive industry. This was somewhat misleading but relevant during the early period. The components needed for a single product were perceived to be far too many, thus requiring far too much space provided the materials were to be exposed on a work station using traditional materials feeding techniques.

It was therefore assumed to be impossible to supply the components needed for complete automobile assembly on a work station. This was partly due to the fact that the all-embracing information system in the Volvo corporation deformed the product perception emanating from the designers' product structure. This also implied an enormous amount of product variants. (The product structure is the way information on the product is organized in the information system by using numerical, alphabetical and verbal codes in a hierarchy).

During the design of the Uddevalla plant these assumptions proved to be false. Although extensive analyses of the real product and its traditional representations in the information system had been carried out, further analyses as described below was required.

Another critical restriction towards parallelization during the 1970s was learning. How could it be possible to learn the tasks in an extended cycle without prolonged training? The generally accepted assumption, according to traditional learning theory (Argote, 1990; Wright, 1936), was that the shorter the cycle time, the shorter the learning process and the more efficient the work.

3. The design method used for the Volvo Uddevalla final assembly plant

During the 1970s and 1980s, automobiles and trucks were assumed to be difficult to understand from an assembly point of view. In retrospect, this assumption was incorrect. It is now clear that the product structure used today by most Swedish automotive manufacturers, leads both researchers and practitioners to erroneous conclusions.

This explains why the efforts of researchers, despite comprehensive empirical and theoretical analyses, did not achieve penetration in the largest industrial systems during the 1970s. It did not matter if one knew how to do it – it had to be proven and explained using the nomenclatures familiar to the practitioners. Hence, methods such as disassembly of complete products, the use of prototypes of materials handling equipment, prototypes of information systems using computer print-outs, etc., were used. In fact, it proved necessary to use a large experimental work shop for the six-year period between 1985–91.

The shop was filled with automobiles and trucks in various stages of disassembly, as well as equipment for the manufacturing of prototypes of materials handling equipment. The facilities also included full computerized support connected to the centralized data banks at the Volvo Truck and Car Corporations.

It was necessary to disassemble products, since we needed to understand the real products as well as the corresponding computerized formalization

and different documents published by the design department or the central process engineering department. This was a time-consuming and mentally trying process, because of the inconsistent and often poor quality data.

We were able to translate the product structure and information received from the design and manufacturing engineering departments into a final assembly-oriented product structure. The method used was to compare computer print-outs and actual components, and to modify the structure in accordance with the disassembly and assembly work.

The guiding principle for long cycle-time assembly work, is that there must be conformity between the work perception on the shop floor itself, the materials display on the work station and the description of the work. This implies that in long cycle-time assembly work, the description of the product and the work needs to be based on a final assemblyoriented product structure.

The final assembly-oriented product structure used in the Volvo Uddevalla assembly plant comprised five main so-called 'final assembly functional groups'. These were simultaneously verbal and visual 'maps'. They described the product and the assembly work in a way that maintained stable relations between the description of a specific automobile and all possible individual product variants.

The distinguishable functional groups were: 0. Doors; 1. Leads for electricity, air and water; 2. Drive line; 3. Sealing and decor; and 4. Interior. This division was designed to categorize the components so that the groups of materials, both individually and in interrelation, formed contexts and were distinguishable from each other. For example, that a component was to be used in the assembly of the interior, was clear not only from a single component but also from the other components being related to a group of materials assigned a descriptive name, which also belonged to a multi-level verbal, visual and spatial assembly-oriented product structure.

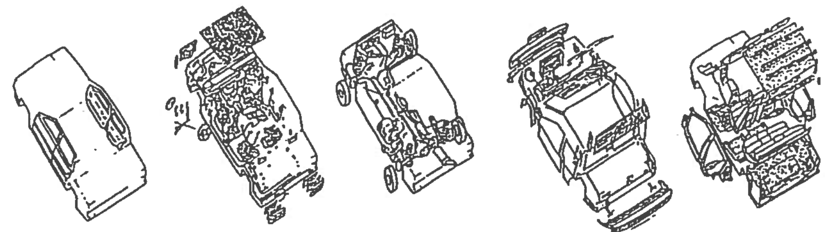
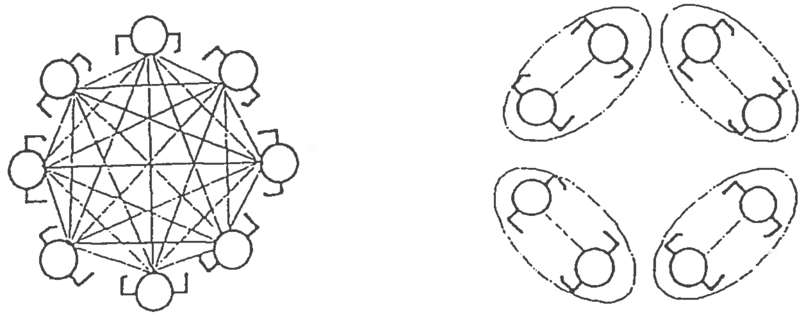


Figure 2. The final assembly-oriented product structure on an aggregated level where each distinguishable functional group corresponds to 1/4 of an assembly work on an automobile.

Although some workers in Uddevalla did assemble complete automobiles single-handedly, the most practical way was to organize the work in pairs of workers, using a cycle time of 100 minutes or more. This was dependent upon the specific competence and choice of intra-group work patterns.



Number of relationships between workers in a group of eight having complementary competence.

Number of relationships in a work group consisting of eight, all having the competence to assemble a complete product.

Figure 3. Schematization of the difference in complexity between different intra-group work patterns. The experiences from Uddevalla indicate that efficient work groups performing long cycle-time automobile assembly ought to contain five to nine operators and consist of sub-groups of two operators. These operators should be supported by one or two alternating individuals co-ordinating several subgroups, building subassemblies in close proximity and performing general services, such as checking material, cleaning, etc.

The base for the technical concept of the now defunct Volvo Uddevalla plant was the increased efficiency demonstrated as a result of parallelization and the result of the elimination of inefficiencies, as illustrated in figure 3 (Wild, 1975; Engström, Lundberg and Medbo, 1993).

According to our observations, interviews and video recordings, the assembly performance of fully run-in work groups assembling complete automobiles in Uddevalla was 14–16 percent better (equal 10–12 hours) than the time calculated by the industrial engineers, using time and motion studies. These performance results should not, however, be mixed up with or compared to Volvo's official data wich reported an assembly time of 32 hours in November of 1992, since this figure refers to all blue-collar workers in the plant, including materials handling, maintenance, etc.

	Serial flow		*Parallel flow*	
	Theoretical	*Observed*	*Theoretical*	*Observed*
Balance loss (%)	5	30	1	5
Division of labour loss (%)	6	25	4	15
System loss (%)	25	80	5	20
'Work inefficiency' (%)	35	135	10	40
Total need of manpower (%)	136	236	110	140

Figure 4. Theoretical and observed inefficiencies for serial and parallel flows. The figures show that the parallel flow is obviously the most efficient one. The observed data are derived from several of our studies of Swedish automotive manufacturers, while the theoretical losses have been calculated. The losses are expressed in relation to the so-called 'necessary work' time equivalent to 100%, which is the work time required for one operator to carry out all the work under ideal conditions. The 'necessary work' needed is defined by the product design. Only the time from the point when the worker has the component in position for assembly until the component has been fitted, is included. The figures in the table above clearly show the superior performance of the parallel flow production system (140% contra 236% total need of manpower). These figures are more correct than the official assembly times published by Volvo, proclaiming the productivity of different Swedish production systems to be equal.

One design criterion behind this production system was that human capabilities and needs, as well as market demands should be the starting point for the design of technical and administrative preconditions, the common denominator being the product itself.

The parallel flow and the extended cycle time used, called for pre-structuring the information and materials needed to facilitate the assembly work. This pre-structuring demanded non-traditional materials feeding techniques. Therefore, the materials were supplied as kits in kitting fixtures containing materials for the individual product, combined with advanced information systems. The systems were contingent on a precise verbal network complementary to, for example, the part numbers traditionally used by automotive manufacturers. This means, among other things, that every component is designated a name indicating its function, assembly position on the vehicle, etc. In fact, the information system in Uddevalla even included locally defined nick-names of certain characteristic components.

The complete product constituted a whole that formed the basis for the structuring of the assembly and materials handling work. This was made possible by the product being described in detail by the design department.

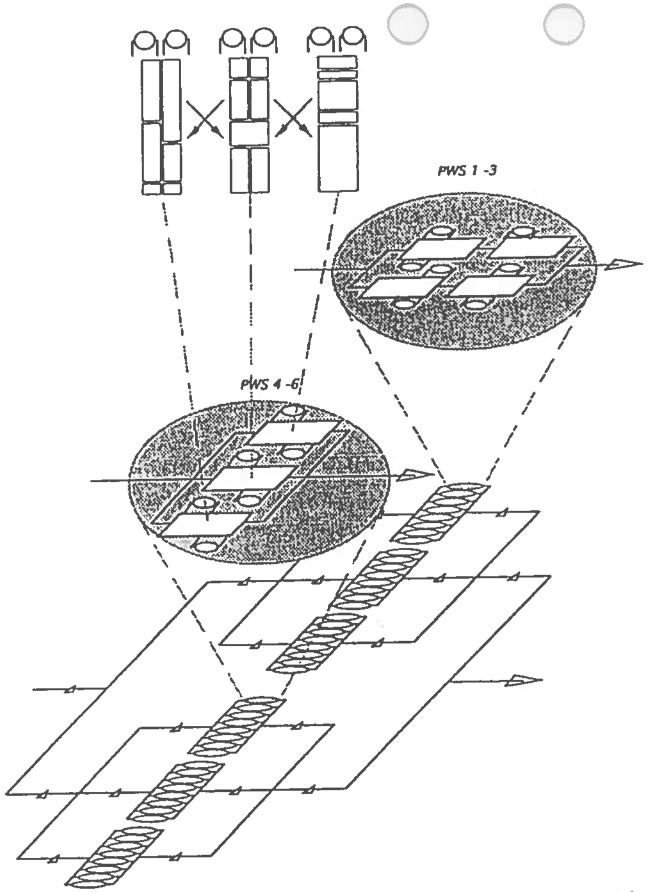


Figure 5. Schematization of the flow pattern in Volvo's final assembly plant in Uddevalla. We have illustrated the intra-group work pattern used in work shops 4–6 (the blocks in the upper part of the figure). Note that these work shops are not identical to work shops 1–3. In 4–6 the body is standing still at one internal work station during the whole assembly, while in 1–3 it is moved once. There are also other dissimilarities with regard to the location of the subassembly stations, assembly tools, etc. The labour-intensive subassemblies, such as doors, engine and instrument panel, were integrated into the work groups. The aim was to increase the internal assembly-active buffer, e.g., the amount of work time available but not always used. The difference in layout was due to the work shops being put into operation successively (thus avoiding the difficulty of co-ordinating and training the whole work force at the same time). The experiences gained from the work shops in operation could be applied to the design of work shops completed later.

The long cycle time assembly work can, in itself, be said to verify the pre-structuring of information and materials performed in advance. This method ensures that the products assembled are in accordance with the product design specification, which has proved not to be the case in traditional production systems.

This type of work and information structuring is possible, through the fact that the components included in an automobile are related to each other and to the symmetries that exist or arise in the vehicle during the assembly process. The components are related to each other due to the causal connections, assembly sequence, as well as the variations in the total flora of product variants, forming long chains with a varying degree of self-explanation during the assembly. This becomes evident if one compares different product variants to each other, or if one understands the functions of the subsystems in the vehicles.

When the automobile stands still during the assembly process, as was the case in Uddevalla, these relations become obvious. Using specially designed materials feeding techniques it is, for example, possible to achieve a relationship between the components fitted and the one to be fitted. It is also possible to exploit the vehicle's organic as well as generic characteristics, thus constituting 'holistic learning' as opposed to 'atomistic learning'. In 'atomistic learning', the starting point is fragmented work tasks. In 'holistic learning', on the other hand, the individual focuses on the message or idea being communicated. Such an individual is said to have a 'holistic approach'. For example when viewing the learning aids as a whole, in which the parts are seen in relation to this whole (Marton, 1986; Marton Hounsell and Entwistle, 1986)

When a traditional assembly line is used, it is obvious that the movement of the automobile body through the plant determines the nature of the work. In the Uddevalla plant, however, the work was characterized by the intra-group work pattern. To the untrained eye, this work does not seem efficient since nothing appears to happen. On the assembly line, on the other hand, the work pace is more obvious. The nature of the design of the technical and administrative preconditions in the production systems advocated here, ought to be such that the individual and the work groups have to become increasingly skilled. Increased knowledge has to pay off in the form of extended technical and administrative autonomy, both at individual and group levels.

Such extended autonomy was not fully achieved in the Uddevalla plant. Among other things, the development of a 'bureaucratic' production planning and scheduling system was not suited to the shop floor characteristics. However, a new concept for planning and scheduling was developed before the shutdown, but not in time to be implemented.

4. The Uddevalla production principles

The inverted design process of the Volvo Uddevalla plant generated five new production principles, methods for achieving high productivity, quality, as well as, flexibility:

1. Parallel flow pattern and autonomous group work. In fact this was an organic flow pattern characterized by successively decreased mechanization, increased parallelization and maintained or expanded sorting capacity from the beginning of the process to the finished product. The work group members carried out assembly work on several products simultaneously. It seldom occurred though that more than two workers were working on the same product at a time. Thus it was possible to vary method and pace, depending on how the work proceeded. This was also independent of the work status and variation of other work groups.
2. Prestructured materials feeding to individual products. The larger components with their obvious positions in the product were brought to the place of assembly in kitting fixtures. On the kitting fixtures were also a number of plastic boxes containing medium-sized components as well as plastic bags containing small components (Johansson, 1989; Johansson and Johansson, 1990). These plastic bags contained the small components needed for every automobile. There was a large number of these small components and they represented the greatest share of the assembly time. Through this arrangement, a considerable reduction in materials-handling time was achieved. Moreover, this way of feeding materials served in itself as a learning aid and work instruction.
3. Naturally grouped assembly work. This presupposes that the traditional disintegration is broken and professional skills are created (the characteristics of a skill are: natural rhythm, holistic view, functional grouping and result orientation). The skills involve a number of tasks being combined in work functions (Nilsson, 1981; Ellegård, Engström and Nilsson, 1991). In practice, this means that the natural relationships between materials display, administrative work description and the method of working are preserved. This in turn has led to the development on the shop floor of a professional terminology and concepts which draw on the design work to a greater extent than usual.
4. A final assembly-oriented product structure. This leads to more efficient information handling, where the product and the work derive from an assembly-oriented product structure and where they are described using a number of predefined interrelated 'charts'. The naturally grouped assembly work was supported and formalized by an information system which is capable of breaking down the product into its smallest components and relating this information to the long cycle-time assembly work.

5. Materials and production control based on the principle that products that are similar for assembly purposes are also principally similar. This is so when it comes to materials handling and product descriptions including work instructions, so-called assembly variants. This meant less need for replanning and also a materials consumption sequence, which was more consistent with the planned sequence. It also led to reduced buffer volumes, better just-in-time efficiency and a reduced number of variants in the final assembly. However, as previously indicated, this type of production control was never introduced, due to the decision to close down the factory.

The application of these production principles had the following nonobvious, or initially accepted effects:

- Reduced space requirements including buffer volumes compared to traditional line assembly. This was due to few products being placed in intermediate buffers between different production phases and to reduced need for transport areas. This was the case as most automobiles in the product workshops were 'assembly active', i.e., subjected to assembly work. Despite the resulting space increase due to the underutilization of operator positions around the product, more efficient work was achieved as a whole. Or put another way, if the flow is parallelized, the space is increased because the larger work stations are more than compensated for by the reduction of the buffer volumes needed for technical reasons between work groups placed in a series (Engström, 1993).
- Reduced need for expensive tools compared to traditional line assembly for several reasons: (1) the degree of mechanization was lowered on account of greater work content and less complicated tools; (2) fewer tools with a fixture function were required, as the assembly workers in the work group commanded the whole tolerance chain and were capable of fixing the component, adjusting its position and finally fitting it to the required torque; (3) expensive production equipment was utilized jointly by several work-groups, and (4) glued components were fitted using small fixtures with low pressure allowed to be applied for a longer period. This was in contrast to short cycle work and products that move from work station to work station, implying that glueing requires high pressure and a short application period.
- The efficient information handling led to a speeding up of the time and resources needed to implement a change of model and to effect change orders. In this respect, the Uddevalla plant also proved superior to Volvo's other automobile plants.
- Successively reduced need for technical production support (production engineering and supervisory functions) to the work groups.

- Flexible work scheduling, which led to shorter lead-times than in traditional production systems. It has in practice only become possible to manufacture automobiles which have already been sold to the customer.
- The difficult, time-consuming or complex product variants could be manufactured at the same time as more common variants, without generating disturbances in the production system. It was possible to start building certain product variants, try-outs, as the introduction of new variants did not require extensive work by the worker or the industrial engineers.

5. Conclusion

Finally, we conclude with one important fact concerning the Volvo Uddevalla plant, namely, that the unique production principles used led to superior performance due to reduced inefficiencies. This has confirmed the relevance and validity of the theoretical and empirical frames of reference, as well as of the extensive research and development background only touched upon in this article. The technical dimension formed the vital preconditions for advanced work organization on the shop floor, as well as for flexible manufacturing, including the organization of white-collar work. This potential was unfortunately not fully realized during the plant's short lifespan.

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