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Design Assumptions and Empirical Evidence Concerning Parallellized Long Work-Cycle Assembly

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Abstract

This contribution reports on alternatives to line assembly including different types of work-group based organisation. The paper is based on experiences gained through extended case studies and action-oriented research as well as development work within the Swedish automotive industry during 1974 – 93. In particular, the paper summarises different production systems for the manufacturing of automobiles, buses and trucks, focusing on shop floor assembly work and the utilisation of a wide range of flow patterns, buffer volumes and cycle times. This summary includes theoretical explanations for the achieved performance of the production systems discussed, through the use of buffer volumes. Finally, we draw some general conclusions.

1. BACKGROUND

In traditional line assembly work, the individual's working pace is controlled by the movement of the assembly line, and the work is fragmented. Working conditions in traditional line assembly tend to lead to high employee turnover and absenteeism, and to damage the sense of responsibility for product quality. Internationally, the dominating trend has been to refine and improve the efficiency of the assembly line. In so-called lean production, for example, there is an emphasis on worker participation aiming to successively improve the given production system. These systems have highly formalised and standardised work organisations designed to support effective learning and innovation. At the same time, the workers participate in developing the rules that govern their work [1]. During the last decade, however, some sharp criticism of lean production has occurred even in Japan, focusing among other things on the working conditions and the acceptability of traditional assembly work in a society upgrading the demands for a more humanized work [2]. Against this background, experiences of alternatives to traditional and non-traditional assembly work merit attention.

2. AN EARLY UNEXPECTED EXPERIENCE FROM LONG WORK-CYCLE TRUCK ASSEMBLY

Case #1: The Volvo Arendal truck assembly experience (1974). The experiences gained in the Volvo final assembly workshop for trucks in Arendal were the most radical ones within the company during the 1970s. The setting up of the workshop was initiated by the fact that the production capacity of the ordinary Lundby factory had reached its limit, and there was an urgent need for an additional 400 trucks a year. The Arendal workshop was the answer to Volvo´s capacity problem, but it also became an experiment with new production principles. In order to reduce the investments in the rented facilities, one chose to handle the axles and chassis packages by air cushions, a handling equipment not previously used by Volvo. The vehicles assembled in the Arendal workshop were the most complex and labour-intensive trucks manufactured by Volvo during this period.

In the workshop, a work group of twelve people assembled complete trucks. It was a so-called "two-stage dock", i.e. the chassis was moved once during the assembly with the possibility to buffer one chassis in the aisle between the two docks. The number of workers required was calculated using the data from the manufacturing of similar variants on the assembly line. A work group consisted of nine assembly workers, one worker officially performing adjustment, one worker officially controlling the quality and one worker for materials handling. Thus, in all twelve people were to assemble two trucks per day, a task considered very tough, but which proved possible after some weeks.

After four months, the time needed for the work decreased significantly. The work group finished its work two to three hours before the end of the day, and they used the remaining hours to discuss and prepare for the next day´s work. There was no theoretical explanation for this type of performance during this period. Inside the Volvo company, there was some suspicion that the quality of the product had deteriorated. A representative sample of trucks manufactured at Arendal were sent to quality audit. The audit showed that the quality was better than for trucks manufactured on the assembly line. This type of production ended after the industrial holiday period in the summer in 1977.

3. THEORETICAL REFERENCES AND EXPLANATIONS

The experiences described above have shown that, in contradiction to the general assumption that high-level division of labour implies efficiency, production systems with extended unpaced work cycle assembly in parallellized flow collective work stations are more efficient than a system with paced short work-cycle assembly in serial flows. The term collective working is used to describe production systems in which workers work together on one or more products. Efficient collective working requires that the product is of a sufficient size (or available in a sufficient number) to permit the workers to be employed in a work station system to avoid work blocking.

Simulation research has demonstrated the advantage of collective working in respect of system output (or conversely idle time), amount of work in progress and space required by the system to accommodate work in progress, i.e. the system capacity. This is in accordance with theoretical predictions based on loss analysis [3]. This means that for a given total space requirement, and a given number of workers, the collective working system operates with less idle time than an equivalent flow line. Alternatively, for a given output an assembly line requires more space and will accrue considerably more work in progress than an equivalent collective system.

4. FLOW PATTERNS IN SOME SWEDISH ASSEMBLY PLANTS

Below we present five different alternatives to traditional line production systems with their flow patterns together with some brief comments.

Case #2: The Volvo automobile assembly plant in Kalmar (1974). The Kalmar plant gained an international reputation. The design was heavily influenced by a top manager who personally intervened in the design process. This fact inspired the total Volvo corporation to seek new production principles and a new work organisation. It was never a question of waiting for an evaluation or of basing the design of the plant on any theoretical frames of reference. The Kalmar plant was heavily used by Volvo for public relations purposes. It did not, in most aspects, fully match the image that the company promoted publicly.

To put it roughly, the Kalmar plant architecture gives the possibility to "stand by the window and perform traditional assembly work" using an expensive AGV-system for the automobile bodies.

During the first few years, there was some difficullty in reaching the same productivity as on the conventional assembly lines. After an extensive reformation of the basic production technique, production data and salary system, as well as a decrease in the number of employees, this plant proved to be just as efficient as the traditional plants.

The production system contains in this case 27 work station systems in sequence with intermediate buffers. The intermediate buffers were initially not assumed to be used for assembly work (assembly active), but were in practice used in this way [4].

From the beginning there was a possibility for some work groups to have a parallellized flow inside a group, as is illustrated in figure 1. This working method was not practised due to the materials supply system and due to the fact that it became impossible to gain any significant technical autonomy, since the sequence of the automobiles entering a work group must be the same as the sequence leaving the group.

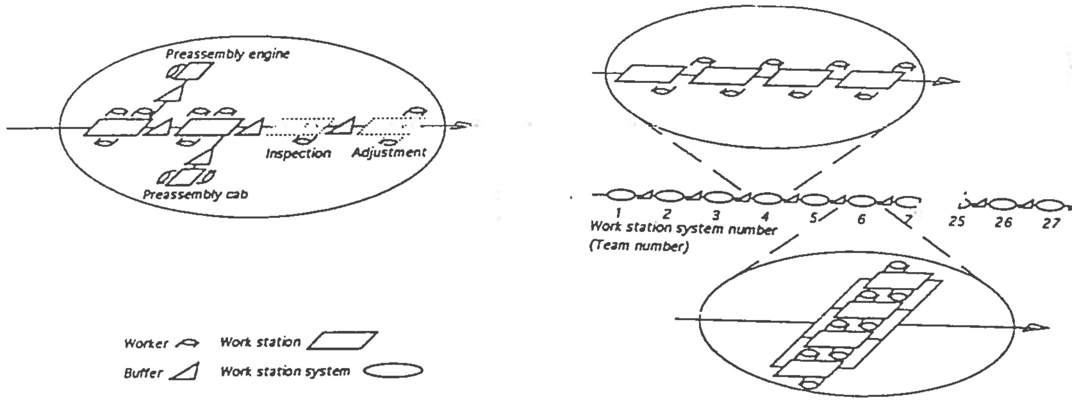

Figure 1. The flow pattern in the Volvo final assembly workshop for trucks in Arendal and in the Volvo final assembly plant for automobiles in Kalmar.

<u>Case #3: The Volvo bus assembly plant in Borås (1978)</u>. After the start of the workshop in Arendal, Volvo needed to establish a bus factory in Borås, and the experiences from Arendal indicated the potential of different production principles and work organisations. Thus the Borås plant was using four parallel so-called "three-stage docks", i.e. the chassis was moved two times during the assembly, but without the possibility to buffer chassis between production stages like in the Arendal workshop.

One important argument for not using an assembly line for buses was the fact that buses are manufactured in smaller series and in a wider range of product variants than is the case with trucks. The pre-production and production engineering work necessary for each product variant on a traditional assembly line would have been far too time-consuming and expensive. In Borås one did have some problems, mainly concerning quality. This was because the training and education of the people involved in the design and running-in period had been neglected. During a period, it was discussed whether to replace the "three-stage docks" with an assembly line. After a three-year period, however, the productivity and quality increased remarkably. This improvement occurred during a short period of time.

The rise in productivity met with suspicion in the Volvo Corporation, but the rumour of superior performance nevertheless influenced the then ongoing design of the truck factory at Tuve. Research aimed at proving the inefficiencies of the plant reported an increase in productivity in contradiction to traditional knowledge [5]. The production principles were later copied by Saab-Scania, who improved the concept by introducing intermediate buffers in the final assembly plant for buses in Katrineholm.

<u>Case #4: The Volvo truck assembly plant in Tuve (1981).</u> The designers of the Volvo truck assembly plant in Tuve did not have any theoretical explanation as to why long cycle-times sometimes proved viable and sometimes not. A cycle time of 40 minutes was chosen, because the Borås plant used two hours cycle time but had some problems with the quality of their trucks during this period, while the Kalmar plant only used 20 minutes.

The Borås plant had proved that intermediate buffers were necessary and this was the reason for using a great deal of space for buffers in the Tuve plant. Here the transportation of chassis used auto carriers and air cushions for the large subassemblies.

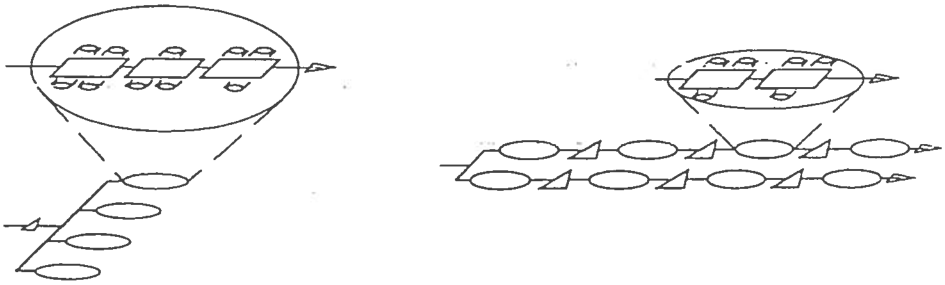

Figure 2. Flow pattern in the Volvo final assembly plant for buses in Borås and the truck plant in Tuve (1981).

Case #5: The Volvo automobile assembly plant in Uddevalla (1989). The non-traditional design and running-in of the Uddevalla plant represented the most advanced production system for final assembly of vehicles on an industrial scale at that time. Originally, the project group responsible for the design aimed at a plant less advanced than the Kalmar plant, while top management called for something far more advanced, a development of the Kalmar plant.

After heated discussions and lobbying, a far more advanced direction was approved by the management, and the final design probably proved to be far more non-traditional than was originally intended. It was a design and running-in period which successively discarded several layouts in the product workshops [6]. The plant had six parallel assembly shops, so-called product workshops. These product workshops were grouped around two test workshops, where media were added and the automobiles were test driven. The materials workshop prepared and supplied kitting fixtures to the final assembly. In Uddevalla one had two different layouts in the product workshops. In one layout, the automobile was assembled in two stages, with a sideways transfer within the work group, while in another layout, the automobile was standing still all the time.

In both cases assembly active buffers were used, i.e. one did not have maximum worker concentrations around the automobile body, and subassemblies (doors, engine, instrument panel, etc.) were integrated into the work group and used as internal buffers.

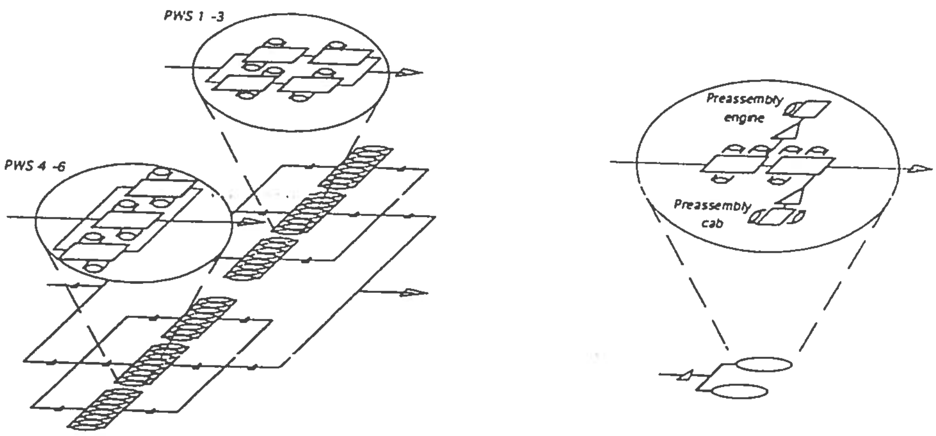

Figure 3. Flow pattern in the Volvo final assembly plant for automobiles in Uddevalla (1989) and in the truck assembly workshop in Tuve (1992). Note that the Tuve workshop is in many respects similar to the Arendal workshop started 18 years later.

Case #6: The Volvo truck assembly workshop in Tuve (1992). This is a two-step dock similar to the one used 18 years earlier in Arendal. The possibility to have an assembly active intermediate buffer, as in Arendal, is however missing. The Tuve workshops have proved more efficient than the series flow showed in figure 2 and have produced the highest quality. This was exactly what happened 18 years earlier. It is consistent with the theory formulated by Wild (1975). The production system contains collective work station systems with integrated subassembly. The truckt is assembled in two stages by six workers in each stage. The collective work does not include an accessible main assembly buffer but accessible subassembly buffers.

5. COMPARISON OF DIFFERENT SWEDISH PRODUCTION SYSTEMS

The most important design parameters characterising the six production systems described above are summarised in figures 4 and 5.

	Number of workers per work-station system	Number of products per work-station system	Sub-assembly integrated in work-station system	Maximum stipulated cycle time (minutes)
#1 Arendal	12	3	yes	240
#3 Kalmar	8	4	no	20
#4 Borås	9	3	no	180
#5 Tuve 1981	6	2	no	40
#6 Uddevalla	9 to 2	4 to 2	yes	480
#7 Tuve 1992	12	2	yes	240

Figure 4. Intra work-station system parameters for some Swedish final assembly plants.

	Number of work-station systems in series	Number of work-station systems in parallel	Buffers between work-station systems (capacity / type)	Assembly-active buffers between work-station systems
#1 Arendal	1	1	0	-
#2 Kalmar	27	1	4 objects / serial	Yes
#3 Borås	1	4	0	–
#4 Tuve 1981	4	1	2 objects / serial	No
#5 Uddevalla	1	48	0	–
#6 Tuve 1992	1	2	0	–

Figure 5. Inter work-station system flow pattern parameters for some Swedish final assembly plants.

Each one of the cases 1, 2, 3, 4, 5 and 6 provides an empirical basis for a comparison of performance between production systems with extended unpaced work-cycle assembly in collective work stations, on the one hand, and systems with short work-cycle assembly in paced serial flows, on the other.

Systems with extended work cycle assembly in unpaced parallellized flows have consistently yielded superior productivity in accordance with theoretical predictions based on loss analysis.

One might believe that the new production systems with extended work-cycle assembly in unpaced parallellized flows were introduced for this reason, i.e. their superior productivity due to reduced losses. Ironically, this was not the main reason for the change in any of the cases considered. On the contrary, management saw unpaced work as a threat to productivity. In addition, extended work-cycle assembly was believed to be inherently less productive than short work-cycle assembly due to the difficulty of learning the work in the former case.

While the Swedish initiatives were thus not based on a loss analysis, they involved social considerations. The Swedish initiative to change the assembly work in the motor vehicle industry during the 1970s focused on work participation, job enrichment, questions of scale economy and environmental issues. The approach to the work tasks not possible to automate was job enrichment and improving the physical working environment

[7]. At the beginning of the 1970s, the most radical changes of the assembly work took place within the production of trucks. There were similar achievements in Volvo and in British Leyland in Great Britain, as reported by Blackler and Brown [8]. These authors underline the importance of the by law prescribed, traditional co-operation between management and unions in Sweden, emphasizing a spirit of a common purpose of improving conditions and society. They point out that the socio-political climate in Sweden was more in favour of redistribution of power and privileges. The new work organisation was rather an initiative from the management than from the union or the shop floor, primarily depending on a lack of labour and related problems. There was a belief that (1) the Swedish labour force would return to the automotive industry if the work was interesting enough, (2) an interesting work would increase quality and reduce the turnover and (3) a more complex and therefore more demanding work suited the well-educated younger workers better. In addition, there also existed a need for a flexible work organisation, since the assembly lines were assumed to decrease the flexibility.

6. SOME CONCLUSIONS ABOUT FLOW PARAMETERS AND COLLECTIVE WORK-STATION SYSTEMS

Although the negative social effects of assembly-line work were discovered early, the production techniques demanded by the highly parallellized flow had not been developed until the Uddevalla plant was designed and run in. The traditions of participation in Sweden focused on how to obtain social effects through social change. In the 1970s and 1980s, the reconstruction of the assembly work meant social changes within the framework of existing technology and/or with obvious technical restrictions such as existing materials feeding techniques. Formal knowledge and experiences are not regarded as important resources in the design process. This process is of a participating character instead of based on empirical evidence or theoretical frames of reference [9]. This is a fact despite the long tradition of close co-operation between management and labour in Sweden. In its extreme, Wild's theory, mentioned earlier, implies that the most efficient assembly is non-traditional, highly parallellized work groups. This is of course from the management's point of view risky, implying loss of their traditional way of controlling the work process. Because of the extended cycle time, the product has to stand still, and it is the workers' competence, the content of the tasks, the position of the tools and the movement of the material that describe the assembly process. This explains why long-cycle assembly may look inefficient from a conventional production technique point of view. From the managerial point of view it certainly is difficult to control by traditional methods, since the management will have problems in recognising what is actually occurring.

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