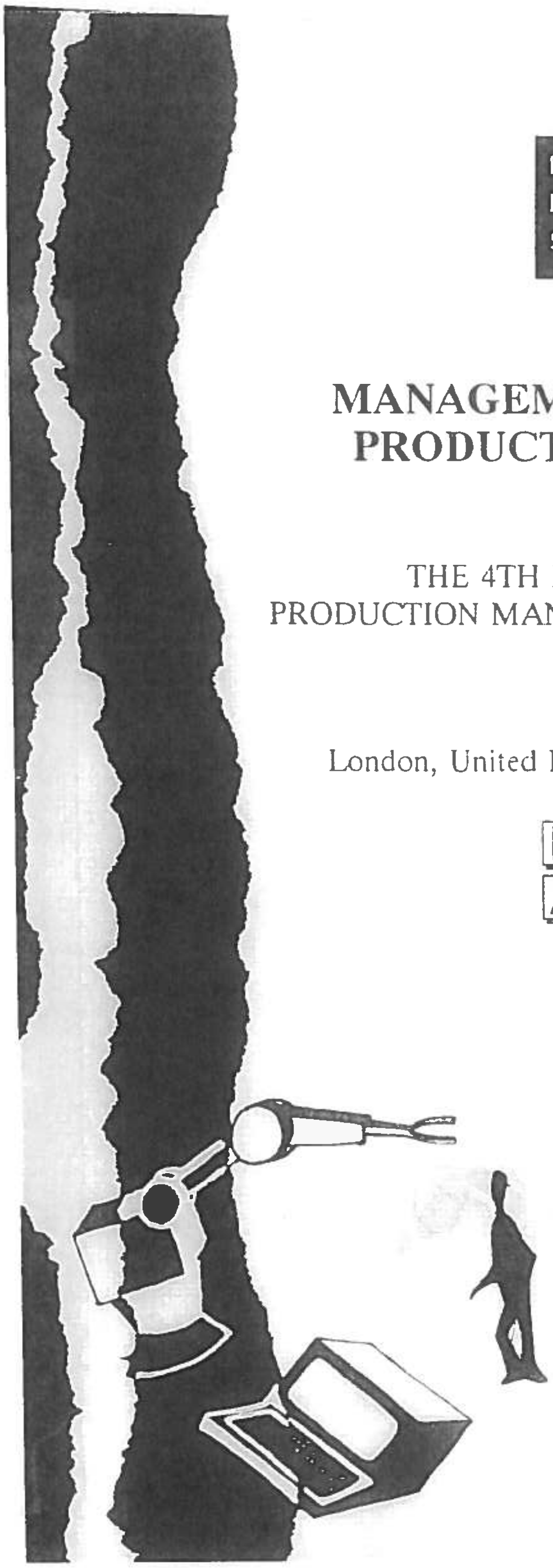

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INTRA-GROUP WORK PATTERNS IN FINAL ASSEMBLY OF MOTOR VEHICLES

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This paper explains why, in long cycle-time assembly work, work groups containing few members function more smoothly than ones containing many.

Also, factors influencing the performance of collective work are discussed and illustrated by empirical data from the shop floor, mainly intra-group work patterns, a design tool practised for the design of the Volvo Uddevalla final assembly plant.

The paper reports how, according to our experience, one ought to reform the prevailing design assumptions used in the Uddevalla plant concerning the effects of parallellization and long cycle-time work, in terms of balance loss, quality cost, the number of tools required and space requirement for the assembly work.

Introduction

In collective working, as may be practised in for example the final assembly of motor vehicles, several operators work on one or more products at a work station designed for group work. The product is released from this work station when all operators have completed their work. It will then be replaced by another product. Note that essential improvements of productivity, quality and morale were obtained through segmentation of an assembly line and installing buffers between the segments [1].

Correctly designed, such a method of working provides the opportunity to reduce time losses caused by variations in work pace, imbalances in the division of labour and product variant differences [2, 3], provided that certain preconditions are fulfilled.

In order to extend work-cycle time and to increase efficiency and flexibility, it is vital that elementary work tasks are first grouped logically into product invariable work modules according to, for example, the components fitted and the tools used.

These work modules form the basis for the intra-group work pattern, i.e. the way in which the work modules are distributed and shifted between the operators and the products.

Work group cohesion will be facilitated by the proximity and interdependence between the members, by their common goal, and by the need to share tools and other facilities.

It is important that the work group is not so large as to prevent consensus or effective communication, in a small group interpersonal relations are likely to be important and the internal turnover may substantially affect the performance of the group.

If the work groups are too large, one cannot take advantage of group pressure as a positive design factor. If the number of group members is less than approximately ten, group pressure will lead to a common work pace [4].

Note that the interdependence between operators increases the more people are involved. One consequence of interdependence between operators may be that unpredictable adjustment work leads to group pressure forcing the release of a product before adjustments have been completed.

This is one of the reasons why, in long cycle-time assembly of automobiles in for example the Volvo Uddevalla final assembly plant and the Volvo Truck factory at Tuve, the function of small work groups have proved smoother than that of large groups.

Another explanation has to do with less complex internal work patterns and the decrease in the number of work tasks needed to shift work modules between operators and products, due to for example different product variants, absenteeism, quality variation of the components fitted, etc.

Usually, the design of work modules and intra-group work patterns aims at grouping together similar short-cycle elementary tasks so that they can be performed repetitively. This design objective is based on the assumptions that repetitive work tasks can be performed faster and that they require less training than corresponding heterogeneous tasks.

In long cycle-time work, however, it is just as important to create interdependence between the operators. This interdependence should ensure that the competence sets of the group members are complementary, to be able to benefit from the skills of other group members. The important communication with more qualified operators is facilitated by the physical proximity of the group members if the products are close to each other and if the group is small.

It is vital that the design of the incentive structure is not only focused on payment, but on an exchange process, where operators exchange collective improvements (work method improvements, selection of internal and external leaders and representatives, training of new members, redesign of tools, etc.) for successively increasing autonomy.

The group is increased autonomy may mean that the members will be able to organize their own overtime working, decide their own breaks, lunch hours, etc. and even determine their own work hours within certain constraints. Resulting in a far more extensive possibility for the work group to increase their efficiency.

<u>Flow parameters in two Swedish final assembly plants</u>

In an extreme application of collective working in final assembly, as found in the Volvo final assembly plant in Uddevalla, each one of six parallel work shops contains eight parallel work groups, and each work group manufactures complete automobiles and also builds the related subassemblies, using internal buffers in the form of automobiles and subassembly volumes in excess of those needed to keep all operators in the group occupied, as well as a "invisible buffer" consisting of the difference between planned and real production output.

In a less extreme application, the now defunct Saab-Automobile's final assembly plant in Malmö, eight sequential work shops, each one containing sequential serial or parallel work groups, manufactured one eighth of the automobile each. The subassemblies were produced in separate workshops.

Thus the work groups did not have the autonomy and potential for efficiency present in Uddevalla, since (1) they were not isolated from subsequent workshops by buffer stocks (this would have required too much space) and (2) each automobile assembled had to be supplied with the unique matching subassemblies (this would have called for a non-traditional way to codify products and plan the production sequences not readily available and obvious during the design and running in period).

The Uddevalla and Malmö plants clearly illustrate that a higher degree of parallellization implies a longer cycle time and high technical autonomy. They also illustrate the importance of distinguishing between internal buffer volumes where the products are "assembly active" and external buffer volumes where it is not possible to work on the products.

<u>Collective working in the Volvo Uddevalla final assembly plant</u>

The Volvo Uddevalla plant has six parallel assembly workshops. These are grouped around two test workshops where media are added and the automobiles are tested. The materials preparation stores and supplies prestructured material to individual automobiles. The larger components with their obvious positions in the automobile are brought to the place of assembly in kitting fixtures. On the kitting fixtures there are also a number of plastic boxes containing medium-sized components as well as plastic bags containing small components.

These plastic bags contain the small components needed for every automobile and they have been grouped in a structured way in the plastic bags. There are a large number of these small components and they represent the greatest share of the assembly time. Through grouping and structuring them, a considerable reduction in material-handling time is achieved. Moreover, this way of displaying the material does in itself function as a work instruction.

In the extreme case of the Volvo Uddevalla facility, work groups of two to twelve operators assemble a complete automobile at one work station more efficiently than in traditional line assembly.

In some cases in Uddevalla, operators have single-handedly manufactured complete automobiles at almost net assembly times, accomplishing more than twice the productivity of the traditional assembly line with its serial flow.

On the basis of our research during the last two decades, we find this level of performance not at all unexpected

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, who perform assembly work on more than one automobile at the same time. These pairs should be supported by one or two alternating individuals co-ordinating several sub-groups, building subassemblies in close proximity and performing general services, such as checking material, cleaning, etc.

In the figure 4 we have illustrated the intra-group work pattern used in work shops 4 – 6. 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, in 1 – 3 it is moved once. There are also other dissimilarities with regard to the location of the subassembly stations, assembly tools, etc. However the same basic work modules are used in all work shops.

Two different layouts were used because the work shops were 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.

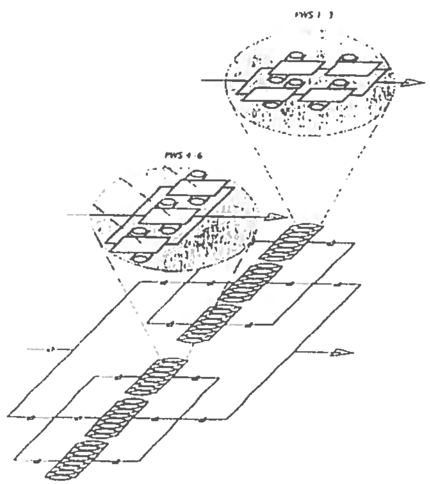


Figure 1. Schematization of the flow pattern in Volvo's final assembly plant in Uddevalla.

The original intra-group work pattern – the initial base for a holistic work design

The experiences gained from the pre-full-scale production training work shop in Uddevalla used for the design of the assembly work shops. These experiences showed that the operator concentration (i.e. the maximum number of operators who can work on the product at the same time without disturbing each other, using the correct work method) varied greatly. When the total assembly work required for an automobile was divided into four final assembly phases, each assembled by one of four sequential work groups, the operator concentration varied from 1.8 to 3.2 persons within each phase.

In this case it is assumed, as was the case during the early design process of the Uddevalla plant, that the automobile and its variants are to be manufactured using maximum operator concentration and a minimum of automobiles, in order to increase the internal buffer volumes. It is then necessary to continually trying to rebalance the work to maintain equally great work loads in order to sustain an even production flow.

This procedure proved to border on the absurd, since it generated a great deal unnecessary production engineering work. It leds to prolonged, uneconomical learning times because on non-coherent work modules, and it reduced the efficiency because of productivity losses, even if the continual relocation of small fragmented work tasks were performed correctly (such unnecessary work in fact makes up most of the job performed by the production engineers in traditional short cycle-time assembly).

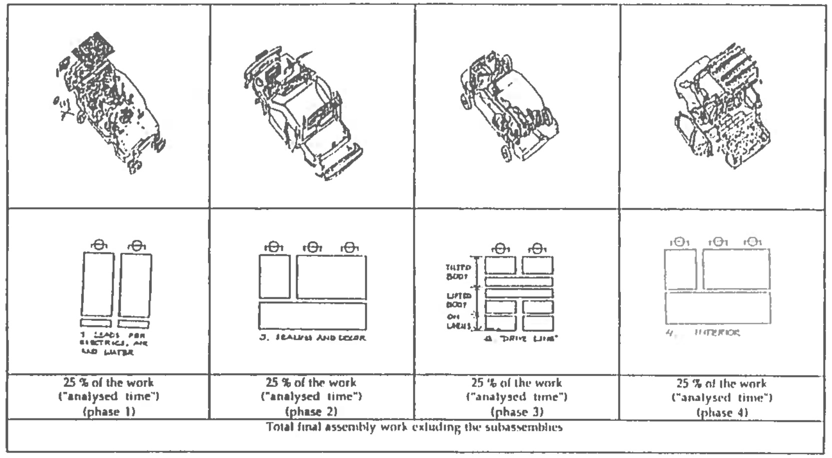


Figure 2. The difference in maximum operator concentration for the 740 Volvo and the original intra-group work pattern practised in the Uddevalla training workshop during 1987. In this case the automobile was assembled in four final assembly phases. This experience was the base for the decision to let one work group assemble complete vehicles at four work stations and to have two final assembly phases in work shops number 1 – 3.

If, for example, a number of different product variants are assembled in a work group performing assembly on an assembly line, an unpredictable alternating dependence is created. This applies, for example, to truck assembly on an unpaced line in one in the Volvo Tuve plant. It sometimes forces the operators, for no obvious reasons, to speed up the work and sometimes there is no assembly work available. The result is that one prefers to work at a constant pace irrespective of variant mix, because of the complex and constantly shifting work preconditions in the form of queues or waiting times for people, materials and tools.

The principle to prefer in collective working is to under-load certain products and use them as internal buffers, i.e. to ensure that certain operator positions around the product are not always blocked by operators.

Despite the resulting space increase, because of the under-utilisation of operator positions around the product, more efficient work is achieved, viewed as a whole. If the flow is parallellized, the space is increased because the larger work stations are more than compensated by the reduction of the buffer volumes needed for technical reasons between work stations placed in sequence.

In parallellized flow assembly, this principle could be further developed by using labour-intensive pre-assemblies, foe example principally doors, engine and instrument panel are integrated in the work group, as is the case in the Volvo Uddevalla plant. The aim is to increase the internal assembly-active buffer, e.g. the amount of work time available but not always used.

Our analytical calculations as well as practice have shown that this allows a variant-resistant intra-group work pattern on group level, i.e. it is possible to use the same intra-group work pattern independent of product variants.

Even with a certain degree of absence in the group, balancing losses can be avoided. The work group can themselves easily redistribute the work modules, i.e. the less skilled operator can still achieve full pace by exchanging difficult work tasks. It has proved worthwhile to use the subassembly of the doors on the automobile as the first to learn and as an internal buffer. This is because the work on one door is similar to the work on the other three.

Transforming the original intra-group work pattern taking experiences gained into account

In Uddevalla, the assembly work had been tried over a period of time in the four work groups and in four final assembly phases originally containing a total of 18 work modules, as illustrated in figure 2. These phases were combined on the premise that half-automobiles were to be built to delimit the amount of equipment needed to move the body in order to facilitate assembly and to achieve maximum utilization of the space in the workshops. The phases were combined based on a number of factors:

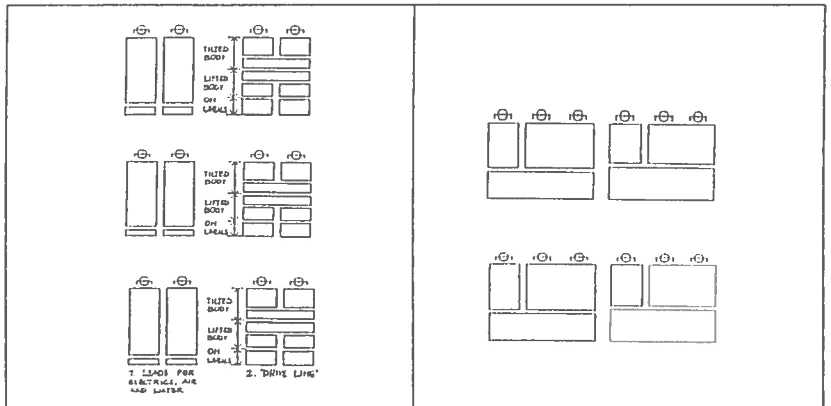
1 Work tasks that required specific quality demands, mainly "fit the components to a specific torque". This led to the conclusion that the "Leads for electric equipment, air and water" and "Drive line" were combined at two internal work stations where also tilting of the automobile body was required in order to achieve satisfactory ergonomics.

2 Work tasks which demanded precision and cosmetic fitting of high quality. This led to the conclusion that "Sealing and decor" and "Interior" required a lifting table to be ergonomically satisfactory.

3 Work tasks where the operator dirtied his hands led to the same conclusion as in 2 above

4 The total work ought to be in balance, i.e. the first half of the automotive assembly ought to equal the second half.

This combination into two final assembly phases, as is shown in figure 3, represents in a difference relative to machine paced work due to the number of torque wrenches required to fit single components in the first phase, restricting the possibility to work up. Another restricting factor is the limitation to temporarily increase operator concentration (maximum being two operators according to figure 2).



50 % of the work and 12 operators ("analysed time") (phase 1 + 3, according to figure 2) | 50 % of the work and 12 operators ("analysed time") (phase 1 + 3, according to figure 2)

Total final assembly work exluding the subassemblies

Figure 3. Schematic function of our analysis used to design the Volvo Uddevalla plant's first three workshops where one group assembles complete automobiles. The automobiles are manufactured in two phases, with a sideways transfer within the work group. This analysis was based on the original intra-group work pattern practised in the training workshop according to figure 2.

Work in the second phase is more difficult to learn, since this phase contains a greater amount of adjustment of many interrelated components at the same time. On the other hand, one is perfectly able to temporarily increase the number of operators' (maximum being three operators according to figure 2). Thus the trained individual or group is easily able to increase the production output, due to superior work methods or higher work pace.

For the work groups this meant that it was more difficult to achieve full pace in the last phase of the running-in period, while the possibility to work up was smaller on the first phase. This is why some operators who learnt quickly and had a "cosmetic talent" preferred to work in the second phase, while the untrained ones preferred the first phase.

This fact also explains why the assembly time calculated by the production engineers sometimes proved to be or was assumed to be incorrect.

Although a tough from a production technique point of view, the intra-group work pattern might seem correct. For example, the combination of untrained operators performing assembly in the first final assembly phase, and untrained ones in the second, meant queues.

The running-in experiences from Uddevalla pointed to the importance of a constant need for redistributing the work modules to correspond to the qualification profiles of the groups. This is an exchange process, which ought to substitute collective improvement for successively increasing autonomy.

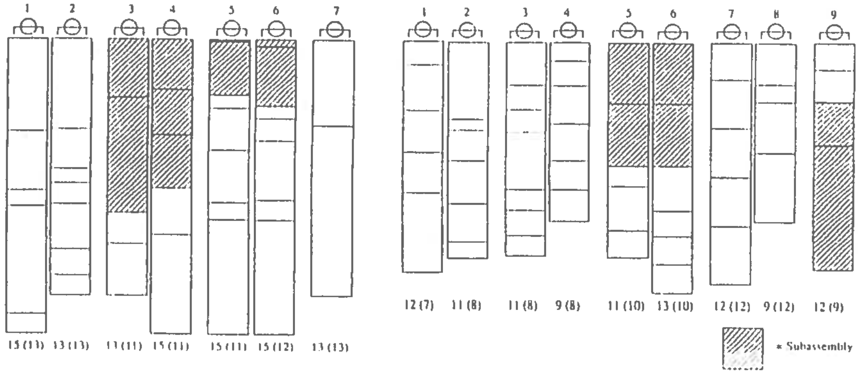


Figure 4. The intra-group work pattern practised today in work shop 1 – 3 (to left) and work shop 4 – 6 (to right), including the subassemblies. This work pattern is derived from combining of the work pattern in figure 3. The observed time required (whitin parenthesis) and the time studies calculated time required, so-called "analysed time" (without parenthesis). In the table we have normalized the assembly work for complete automobiles to 100 % as the "analysed time". We note that performance of the work groups are exceeding those calculated by the production engineers by 14 % respective 16 %, note also the inherent unbalance which in practice implies collective working and the need for internal redistribution of the work according to the mix of variants.

Reformation of the initial generally accepted design assumptions

One of the initial, generally accepted design assumptions, within the Volvo Corporation [4], in respect of the Uddevalla plant was that there is an optimum between the costs for quality and balance loss, which tend to increase on an assembly line, and the costs for equipment and learning, which increase in a parallel flow (see figure 6).

We were able to modify these assumptions based on our analysis and experience, as is illustrated in figure 6, for the following reasons:

- If the cycle time is large enough, if the automobile is standing still during the assembly and if the materials are arranged according to certain principles [5], the learning time is reduced according to schematization in figure 5. This is of course provided that the internal or external turnover is not is extreme.

- The balance loss on the assembly line has proved to be marginal compared to other losses [6].

- The quality cost is even more important when it comes to expensive automobiles, like the Volvo, which is why the curve for quality cost ought to be steeper than that the cost for imbalance.

- The cost for tools proved to be the other way round. This paradoxical since, contrary to general assumptions, it has become clear that one does not need to increase the number of tools in parallellized assembly [5].

	Serial flow	Parallel flow
Space requirement [m^2/(automobile/year)]	0.6	0.4
Number of hand tools and mechanized equipment per assembly minutes	1.6	0.6

Figure 5. Comparison of the space requirement and the number of tools required in two fully run in production systems for final assembly, using a normalized product.

The same experiences concerning the reduction in the requirement of tools in the Volvo Arendal work shop for the final assembly of trucks had been made in the early 1970s, when the employees were asked to specify what kind of tools they wanted [7].

The need for expensive tools compared to traditional line assembly is reduced for several reasons. (1) The degree of mechanization is lowered on account of greater work content and more but less complicated tools. (2) Fewer tools with a fixture function are required, as the operators in the work group command the whole tolerance chain and are capable of fixing the component, adjusting its position and finally fitting it to the required torque. (3) Expensive production equipment is utilised jointly by several work groups. As an example the yearly product change including investments, indirect cost and preproduction work has prowed to be about 50 % lower in Uddevalla compared to traditional Volvo plants.

Obviously the original design assumptions do not include space reduction due to parallellization. Increased parallelization and greater work content mean that it is not necessary to disengage objects by placing them in a buffer. Instead time differences can instead be accumulated by changing sequences. We are here referring to the fact that a buffer can have a greater or lesser sequencing capacity [8].

One other important insight is that the highly parallelized flow-assembly plants of tomorrow will not demand AGV-systems between material kitting and assembly, as is the case in Uddevalla [8].

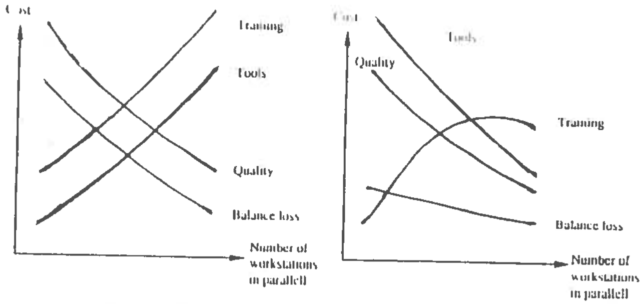


Figure 6. To the left, schematization of the initial design assumptions of optimal parallellizing according to the accepted design assumptions made in 1986 [2]. To the right, the reformation of the design assumptions taking into account our experiences gained during the design processes of several final assembly production systems, mainly within the Volvo Corporation. Some production systems were built, some only planned, or planned and put into practice as training work shops.

Final comments

It is our opinion that the social aspects and consequences of the production principles adopted in Uddevalla have been overemphasised in many presentations and discussions about the Uddevalla plant – especially those directed towards a wider a audience.

According to Volvo a total of 32.8 hours was on average needed in the Uddevalla plant in November 1992 to manufacture an automobile of top quality, including the materials handling and feeding work [9]. The traditional Volvo assembly line plants need a few hours more.

Note that the performance of some individuals and work groups exceeds the figures. For example, individuals report an actual direct assembly time of 10 – 15 hours [10, 11].

It is worth noting that this level of performance has been reached in a plant where the running in has taken place in parallel with the extensive development of new and unique production principles, principles which include other vital, but not generally known, effects.

Principles based on extensive practical and analytical work, such as mapping the intra-group work patterns and experiences from the design and running-in period.

REFERENCES:

[1] Van Beck H G (1964). **"The Influence of Assembly Line Organization, Output, Quality and Morale"**. Occupational Psychology No, 38.

[2] Wild R (1975). **"On the selection of Mass Production Systems"**. International JournalProduction Research. No. 5.

[3] Rosengren L G (1981). **"Potential Performance of Dock Versus Line Assembly"**. International Journal of Production Research Vol. 19, No.

[4] Karlsson U (1979). **"Alternativa produktionssystem till lineproduktion"**. Sociologiska Institutionen. Göteborgs Universitet. Göteborg *(Ph.D. thesis)*.

[4] Ahlquist G (1986). Föredragning på Forum Konferens and non official published documents from Volvo.

[5] Engström T, Medbo L (1992). **"Pre-conditions for Long Cycle Time Assembly and Its Management – Some Findings"**. International Journal of Operation & Production Management. MCB University Press.

[6] Ellegård K, Engström T, Johansson B, Johansson M I, Jonsson D, Medbo L (1992). **"Reflective Production in the Final Assembly of Motor Vehicles – An Emerging Swedish Challenge"**. International Journal of Operation & Production Management. MCB University Press.

[7] Gyllenhammar P G (1977). **"People at Work"**. Addisson Wesley.

[8] Engström T (1991). **"Reorganisation of Material Flow for Naturally Grouped Assembly Work – Some Principles and Results from Action Research"**. Achieving Competitive Edge – Getting Ahead through Technology and People. Sixth International Conference. Operations Management Association UK. Birmingham. Springer-Verlag Limited. London.

[9] Tidningarnas Telegrambyrå (1992). **"Rekordresultat för nedläggningsbeslut"**. TTs Nyhetstelegram. Nummer 004, 16 December *(nyhetstelegram)*.

[10] Gatu H (1993). **"En besviken elitarbetare"**. Metallarbetaren. Nummer 1 *(newspaper)*.

[11] Nilsson A (1991). **"Kraftprovet – Tjejen som växte till helbilsbyggare"**. Volvo Nu. 10 Maj *(newspaper)*.