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Towards a New Organization in the Automobile Industry?

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Kalmar, Uddevalla and Beyond: Volvo's Factories of the Future

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ABSTRACT:

This paper reports on experiences concerning development of assembly systems within the Volvo Corporation. We discuss systems that represent three system designs, viz. "elastic serial flow", "rigid parallel flow" and "flexible parallel flow". The first two designs correspond to two actual plants, namely the closed down Volvo Kalmar and Volvo Uddevalla final assembly plants, while the third design exists only in the form of blueprints for a proposed system, intended for the Volvo Torslanda plant.

The paper includes a discussion of some basic design principles for assembly systems, a presentation of the three assembly systems reviewed and data about psychosocial work factors in Uddevalla and Kalmar as well as assembly performance in Uddevalla.

While the Kalmar plant represented a bold attempt at "humanisation" of assembly work, the step from Kalmar to Uddevalla represents a far more radical innovation from the engineering point of view, as explained in the paper. We also suggest improvements to the Uddevalla system as it worked in practice, implying that there is a potential trajectory "beyond Uddevalla".

1 INTRODUCTION

This paper reports on experiences concerning development of assembly systems within the Volvo Corporation. The paper is based on two decades of research and development work within the Swedish automotive industry carried out by the authors.

While the machine-paced assembly line is often regarded as a symbol of modern industrial production, work at the assembly line has also been criticized for being monotonous, repetitive and lacking autonomy. Various ways to reform line assembly have been proposed, and such initiatives have often attracted considerable attention from both researchers and practitioners. Even though final assembly of vehicles only represents a marginal part of the total cost required to manufacture a motor vehicle, traditional line assembly systems as well as innovative assembly systems in the automotive industry have been widely regarded as models to learn from in the rest of the manufacturing industry.

The design of assembly systems is based on more or less well-articulated and well-substantiated design principles. When the Swedish automotive industry initiated full scale experiments with non-traditional assembly systems some twenty years ago, it relied on rather vague design principles. As a result of experience gained from these experiments as well as theoretical reflection over this experience, it is today possible to base assembly system design on a fairly precise, coherent and empirically substantiated theory, however. In order to illustrate this body of knowledge, we have chosen to discuss three representative final assembly system designs.

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The first two designs correspond to two actual plants, namely the closed down Volvo Kalmar and Volvo Uddevalla final assembly plants. The third design exists only in the form of blueprints for an assembly system proposed for the main Volvo plant at Torslanda in Gothenburg. This system represented an improvement of the production principles applied and refined in Uddevalla, but was never implemented at full scale.

2 SOME BASIC DESIGN PRINCIPLES

Traditionally, production engineers use mean operation times based on time-and-motion studies when determining work cycle times, thereby neglecting the effects of individual variation, i.e. the fact that workers have an inherent variation in pace and efficiency in the performance of repetitive work. Such variation occurs both as inter-operator variation and as intra-operator variation, i.e. variation between operators on the same assembly line as well as variation between successive work cycles for a particular operator.

Suppose, for example, that work tasks are allocated along a machine-paced assembly line with individual work stations. To simplify the discussion we assume at the moment that work stations are identical and that there is one worker at each work station. Since the product is moved along the line at a constant speed, it is available for work during equal time periods at the work stations.

If the time the product is available at a work station is equal to the mean time needed to complete the work tasks assigned to that work station, meaning that inter-operator and intra-operator variation is neglected, some unfinished work will inevitably result. If, on the other hand, the time the product is available at a work station is longer than the mean time needed to complete the work tasks assigned to that work station, waiting times (or slower work) will inevitably occur. Assembly systems that fail to accommodate inter-operator and intra-operator variation thus produce idle operator time or need for re-work. In both cases, extra man-power is needed (Wild 1975).

Furthermore, the amount of work to be performed at each work-station will vary between work-cycles and work-stations due to different product variants. Often, the allocation of work tasks to work-stations is based on the product variant requiring most work, i.e. the most time consuming product variant will pace the flow. There will also be process variation due to tools and mechanized equipment etc.

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One way of avoiding the time losses described above is to introduce group work in parallel flow assembly systems. An assembly system may be designed to encourage workers to help each other, meaning that no strict division of labour exists. This facilitates improvement of work methods and the creation of technical autonomy through so-called "working-up", i.e. working ahead of schedule. "Working-up" is promoted considerably if the work group has responsibility for quality requirements, since it is less time consuming to adjust the components fitted directly (Engström and Karlsson 1981, Karlsson 1979).

Usually, production engineers do not have sufficient information to be able to divide the assembly work perfectly between the workers. Also, time-and-motion studies do not take account of the "working-up" option. The workers themselves, who spend eight hours a day in the assembly system, have a better opportunity than the time-and-motion engineer to design an efficient intra-group work pattern, where each worker is in the right working position along the product being assembled at the right time.

Integrated non-assembly work such as cleaning, maintenance, materials handling, etc. is important from a engineering point of view, since these non-assembly tasks can absorb idle time if they are independent of the production output, i.e. possible to perform at any time. Non-assembly tasks may thus be resorted to for example if a working position along the product is temporary occupied by co-workers, if the materials to be fitted is not of sufficient quality, etc.

If, on the other hand, many task are machine-paced due to handling of tools, fixtures, heavy components, etc., the "working-up" potential is small. If the work pace is dependent on co-workers as well as machine-paced work tasks, the "working-up" potential is decreased even further. Restrictions delimiting autonomy due to dependence on co-workers is usually perceived to be more painful than lack of autonomy due to machine-pacing, particularly so in small groups, where workers feel "entitled" to influence each others' work pace (Karlsson 1979, pp 247; cf. Fredholm, 1989).

These facts imply the need for an assembly system design that promotes group work, as well as "working-up". This is facilitated by rather small groups, where the co-workers work close to each other. In the Uddevalla plant, pairs of workers and groups with five members seemed to function best. In the five-member groups, four workers performed assembly on the automobile body, while one worker performed subassembly and non-assembly work. Similar experiences concerning work group size have been reported from the NUMMI plant (Adler 1991).

Work groups will tend to develop their own norm systems with regard to quantity and quality goals, how to handle sick-leaves etc. Such norm systems, once established, change only slowly and often survive even if some group members are replaced. Therefore, it is important to keep track of competence development in different groups and internal turnover patterns to ensure suitable norm structures. In the Volvo bus plant in Borås, for example, all the most trained workers initially chose to work in one of the four parallel work groups in this plant, while all new employees were concentrated in the other groups. While this situation existed, it proved be impossible to achieve the collective competence required to reach full work pace (Engström and Karlsson 1981).

The considerations above highlight the need for a careful design of the worker/work-station relations, intra-group work patterns, tools etc. to be able to combine worker needs and priorities with management requirements for efficiency, quality and flexibility.

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Let us summarise some principles suggested according to our experience of assembly systems involving group work:

- Small work groups of at most 5 – 6 members that control their own production and materials flow are preferable to larger groups. These groups should be supported with engineering knowledge and incorporate non-assembly tasks.

- A certain amount of "slack" in the form of extra products available, extra worker positions along the product, integrated sub-assembly stations, responsibility for non-assembly work, etc. must be available to the work group to provide the required flexibility of the intra-group work pattern.

- Technical autonomy is an important incentive, and the technical and administrative setting for the assembly work must be designed so as to facilitate technical autonomy, which is at the same time a prerequisite for administrative autonomy.

- The technical autonomy possible to achieve at the group level through co-operation must be greater than the individuals' possibilities of working-up in order to create true group work. It is important, though, that the work group is not too big.

Parallel flow assembly systems satisfy these principles far better than the machine-paced assembly line. Thus the design of non-traditional assembly systems incorporates an important engineering dimension, even though the human aspects have frequently been underlined and contrasted to technical efficiency.

On the contrary, parallel flow systems require less man-hours than the assembly line, due to technical superiority, and in addition working conditions are improved due to, e.g., increased technical autonomy. It shoud be noted, though, that the design of such parallel flow systems is intricate, since they require an advanced materials feeding technique (the components to be fitted can not be supplied en masse in materials containers), holistic learning to facilitate the learning of long cycle time assembly work, etc (Engström 1983, Johansson and Johansson 1990, Brynzér 1995).

Incidentally, parallel flow assembly systems have another interesting advantage compared with the serial flow systems. Since the work groups are performing identical work at parallel work stations, it is far easier to analyse, e.g., the performance and quality attained, since the influence of the product design is controlled.

3 THE KALMAR PLANT 1974 – 1994

The Kalmar plant gained an international reputation. The design was heavily influenced by a top manager, who personally intervened in the design process. His involvement inspired the entire Volvo Corporation to look for new production principles and a new work organisation.

The Kalmar plant was extensively used by Volvo for public relations purposes, but in most respects it did not fully match the image that the company promoted publicly. To overstate the case slightly, the design of the Kalmar plant enabled the assembly workers to "stand by the window and perform traditional assembly work" using an expensive AGV system (automatically guided vehicles) to carry the automobile bodies. The AGV system was originally intended to enable the workers to vary their work-pace, but in practice this did not happen.

During the first few years, there was some difficulty in reaching the same productivity as on the conventional assembly lines. After an extensive reformation of basic production techniques, production data and the salary system, as well as a decrease in the number of employees, the man-hour costs in this plant were however reduced to 25% below those in the Volvo Torslanda plant with its traditional assembly system (Agurén et al. 1984).

The assembly system in the Kalmar plant was manned by 27 work groups, separated by buffers. The intermediate buffers were initially not intended to be used for assembly work, but were in practice used in this way (Agurén et al. 1976).

Originally, an internally parallelized production flow was an option in some work groups. This working method was, however, abandoned due to the materials feeding techniques used and the lack of technical autonomy implied by the fact that the first-in first-out rule applied to the automobiles entering and leaving a work group.

In 1987, assembly of the new Volvo 760 model started in the Kalmar plant. This model had a substantially longer total assembly time than the previous model assembled. To accommodate this new model, the plant was enlarged and the intermediate buffers were largely eliminated, since most AGVs in the buffers had to be converted to work-station use. Space restrictions due to the building design and the size of the AGVs meant that the number of AGVs in the plant could not be expanded. Thus, the longer assembly time required by the new product and the restriction with respect to the number of AGVs forced buffer volumes to be reduced.

This modification more or less turned the Kalmar plant into a line assembly system having the special feature of allowing the production sequence to be revised during the course of production to absorb variations in required assembly time. If required, it was possible to temporarily remove an automobile from the production flow without introducing waiting times, because the automobile on each AGV could be individually identified in the central computer system and also because the product specifications for each specific automobile were printed out when an automobile arrived at the work group and used as work instructions.

In 1989, parallel flow assembly was introduced in those work groups where engine and gearbox sub-assembly was performed and these sub-assemblies and the rear axle were fitted to the automobile body. This change was initiated in order to improve the ergonomic situation in these work groups, but a predictable substantial increase in productivity was also achieved. This revitalization of the Kalmar plant is described by Sandberg (1995).

4 THE UDDEVALLA PLANT 1986 – 1993

The plant had six parallel workshops for assembly work. These workshops were grouped around two test workshops, where media (petrol, freon, etc.) were added and the automobiles were test driven. A separate materials workshop prepared kitting fixtures. These fixtures, which contained all the components needed to assemble complete vehicles, were transported to the assembly workshops.

The workshops for assembly work in the Uddevalla plant normally contained eight work groups using two main layouts. In one layout, used in the three product workshops first started, the automobile was assembled in two stages with one sideways transfer within the work group. Each automobile was normally assembled by seven workers, and the normal cycle time was 100 minutes.

In the revised layout used in the remaining three workshops, the automobile was not moved at all during the assembly work within the work group. At the end of the final period of full production, normally nine workers alternated between four automobiles (rather than three, as was originally intended). The normal cycle time was 80 minutes.

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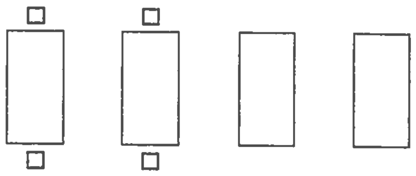
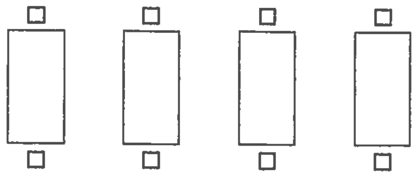
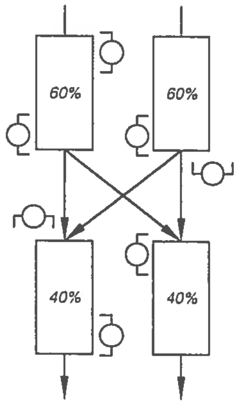
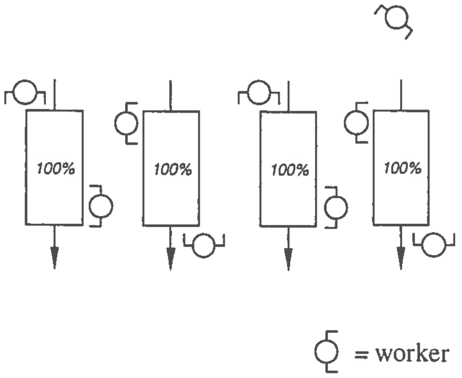
	Workshops 1 – 3:	Workshops 4 – 5:
Layout:		 □ = tilting device
Schematic function:		
Normal work group size:	7	9
Normal cycle time [minutes]:	100	80

Table 1. Layouts and schematic function of work groups in assembly workshops 1 – 3 and 4 – 5, respectively, in the Volvo Uddevalla final assembly plant. In workshops 1 – 3 the automobile was moved once during the assembly (from a tilting device to a lifting table), while in workshops 4 – 5 - the body remained stationary in the same kind of tilting device during the entire assembly. The tilting device allowed the car body to be lifted as well as rotated. For a more detailed description of the intra-group work pattern etc, see Engström and Medbo (1994a).

In both types of workshops, there were buffer volumes within the work group available in the form of extra automobile bodies representing non-occupied working positions along the body as well as non-occupied working positions at the workstations for subassembly, i.e. doors, engine and dashboard. These subassemblies were therefore integrated into the work group. There was a slight but important difference between the workshops in that all workers performed work on bodies as well as subassemblies in the first three workshops, while specific work group members performed engine and dashboard subassemblies in the remaining workshops.

It should be noted that a large variation in work methods and work group sizes existed in the Uddevalla plant. In one extreme case, two female workers regularly assembled complete automobiles by themselves.

produktivitet

Com arbete å ju [illegible] [illegible]

+ [illegible] BAKE

+ BUFFER CAP.

samma som ovan!!

5 AN ALTERNATIVE ASSEMBLY SYSTEM DESIGNED FOR THE VOLVO TORSLANDA PLANT IN GOTHENBURG

During 1988 – 1990, the engineers at Volvo were planning the manufacturing of the new 800 model at the Torslanda final assembly plant, as well as looking for a total design of the plant. The assembly system aimed for ought to be suitable also for the other models manufactured, the 200 model and the 700 model. Certain restrictions in the existing facilities in the form of buildings, ongoing production and large and expensive mechanised equipment (e.g., roller testers and robots for gluing the windscreen) also had to be considered. The design procedure used is described in Engström and Medbo (1994b).

The parallel flow assembly system under development in Uddevalla during that period and the serial flow assembly system which was being introduced at the same time at the Gent plant were both considered as possible alternatives. The former system had during this period not yet proved its merits, while the latter with its serial flow and automated marriage equipment for the large subassemblies carried on palettes was heavy on investments.

The assembly system designed by two of the authors of this article consisted of modules which included six work groups containing two parallel subgroups of eight operators performing assembly. The work groups were located around a materials store shaped as a semi-circle. Between the work groups there was space for kitting fixtures, which included some of the components to be fitted. The subassembly was integrated into the work groups and some subassembly stations were common for the two subgroups. The expensive equipment for marriage of the subassemblies and gluing the windscren to the automobile body was common for several work groups and possible to reserve during a certain amount of time. Thus the materials feeding technique utilised a combination of centralised and decentralised materials stores.

Using these techniques, the materials supply work became an integrated part of the assembly work and not, as was the case in Uddevalla, as separate activity. It was possible to move the border line between the assembly and materials handling work, so that a suitable combination of materials feeding techniques could be sought out during the running-in period. It was also possible to assemble different automobile models with for example varying amount of subassembly work, as well as variation in the amount of subassemblies delivered from the external suppliers. This made it possible to manufacture all three Volvo models, i.e. the 200, 700 and 800 models, using the same assembly system.

Some trademarks of the new assembly system proposed for Torslanda were:

(1) Stationary assembly on one work station using tilting equipment, as was the case in two workshops in the Uddevalla plant. The flow frequency of the body and finished automobiles was extremely low.

(3) The marriage was performed in the tilting equipment. The marriage equipment used to torque down the bolts was mobile and shared between four work-groups.

(4) The number of assembly active automobiles was maximised.

(5) There was a floating borderline between the assembly and the materials handling work, not as was the case in Uddevalla a separate workshop for picking of components and preparing the kitting fixtures. No AGV system was used.

Work-group consisting of two subgroups with eighth operators.	Product workshop consisting of six work work-groups around a centralised materials store.
- total space requirement: 502 m^2, excluding buffers, adjustment but including some of the materials - number of work station for the automobile body: 12 - 16 operators organised in subgroups of eight - cycle time: 1.77 hours - number of subassembly work stations: 10 utilised by both subgroups - production capacity: - 1.12 automobiles/hour, - 8.08 automobiles/day and shift using 7.2 hours working day, - 1 820 automobiles/year and shift using 1 635 hours/years work time	- total space requirement: 7 632 m^2 - space requirement for the centralised materials store: 1 500 m^2 - production capacity of: 21 177 automobiles/years using two shift work - number of operators employed for assembly work: 96 - number of equipment for gluing the glass: 1 - number of equipment for marriage: 3

Table 2. Summary data describing the proposed parallel flow assembly system for the Torslanda plant (Engström and Medbo 1994b).

Due to reorganisations within the Volvo corporation and a decline in sales, the total rebuilding of the Torslanda plant according to the refined Uddevalla production principles was never carried through (see Granath 1991).

6 PSYCHOSOCIAL FACTORS IN KALMAR AND UDDEVALLA

Although it is not the topic of this paper to discuss the psychosocial effects of the Kalmar and Uddevalla plants in detail, it is important to realise that the working conditions improved in comparison to industrial blue-collar work in general, while the Uddevalla plant proved to be superior to the Kalmar plant (Engström et al. 1995).

In connection with the closing down of the Uddevalla plant, we developed a "multi-disciplinary" questionnaire covering psychosocial and technical aspects. This questionnaire was distributed to the subjects during working hours. The subjects were randomly selected and they answered the questionnaire anonymously. The participation rate was approximately 90 per cent. The present study is based on 64 assembly workers.

The workers' attitudes to their job were assessed using a "standardised" questionnaire (Rubenowitz 1994, Johansson et al. 1993). According to Rubenowitz, it is possible to distinguish five important psychosocial factors (based on factor analytical procedures) which should be satisfied at work in order to meet the individual's fundamental psychological needs. The questionnaire measures the factors by mean values. These factors, with Cronbach alpha coefficients in brackets, are:

1 "Influence on and control over work" (alpha = 0.65). The items are: influence on the rate of work, influence on working methods, influence on the allocation of tasks, technical control, and influence on rules and regulations.

2 "Supervisor climate" (alpha = 0.84). The items are: contact with immediate supervisor, if immediate supervisor asks for advice on work-related problems, immediate supervisor considering viewpoints, immediate supervisor providing information, and the communication climate in the organisation.

3 "Stimulus from the work itself" (alpha = 0.85). The items are: if work is stimulating and interesting, if work is varied and diversified, opportunity to use talents and skills, opportunity to learn new things at work, and the general feeling about the work.

4 "Relations with fellow workers" (alpha = 0.82). The items are: relationships and contacts with fellow workers, talking with fellow workers about the job, extent of experiencing a cheerful atmosphere, discussion of work-related problems, and regarding fellow workers as good friends or not.

5 "Psychological work load" (alpha = 0.83). The items are: stress at work, work load, extent of feeling tired and exhausted after work, possibility of relaxing and having a break, and mental strain.

For these five factors, it is possible to make comparisons between the study sample and reference data from the industry (Rubenowitz 1992). The reference data include 2 394 blue-collar workers from seven different research studies made within the metal industry in Sweden (Johansson et al. 1993, Johansson and Nonås 1994). It is also possible to make comparisons with a random sample of assembly workers (n = 33) from the Volvo Kalmar plant (Johansson and Rubenowitz 1994); these data were collected before the closing-down of the Kalmar plant.

The profiles from the measurements of psychosocial job factors among assembly workers, compared with reference data from blue-collar workers in the engineering industry, are shown in Figure 1.

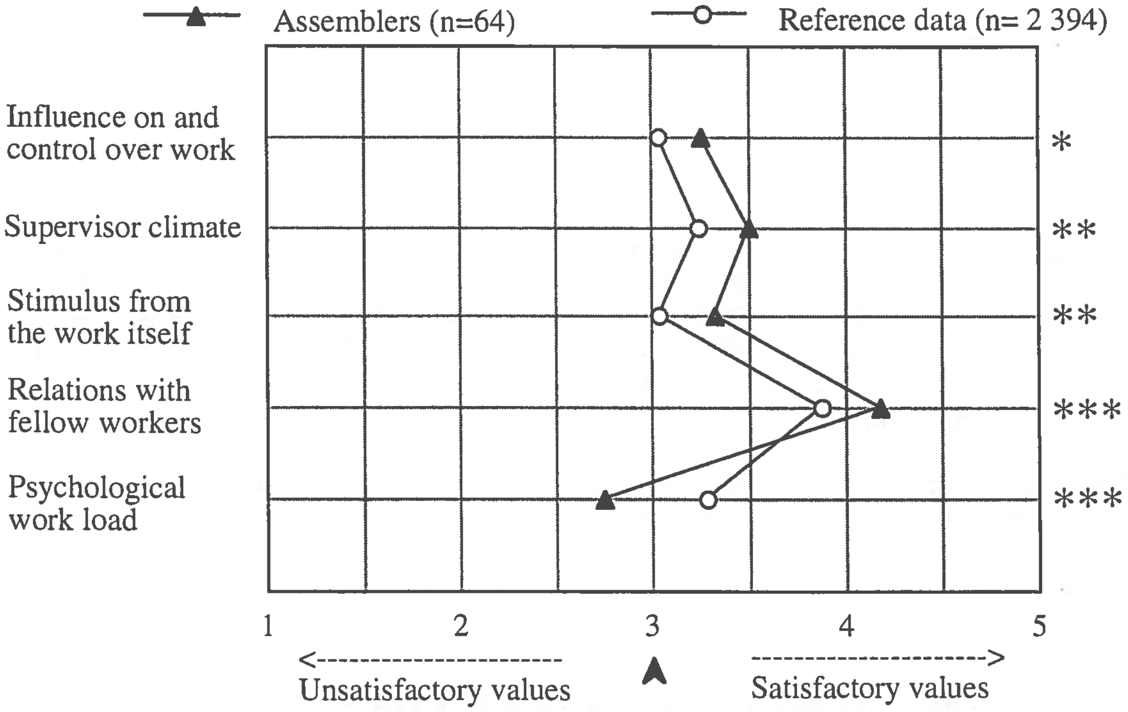


Figure 1. Psychosocial job factors in the Volvo Uddevalla plant compared with industrial blue-collar workers in general. Profile of attitudes to work, showing psychosocial job factors by mean values. Note: Significant differences (according to a two-tailed t-test) between the assembly workers in the Uddevalla plant and reference data (industrial blue-collar workers) are marked with asterisks (*p<0.05; ** p<0.01; *** p<0.001, Engström et al. 1995)).

Figure 1 shows that there were more satisfactory values in the study sample with regard to the factors "influence on and control over work" (t = 2.28, df = 63, p<0.05), "supervisor climate" (t = 2.67, df = 63, p<0.01), "stimulus from the work itself" (t = 2.74, df = 63, p<0.01) and "relations with fellow workers" (t = 4.59, df = 63, p<0.001). In contrast, "psychological work load" was rated as less satisfactory in the study sample (t = - 4.82, df = 63, p<0.001).

The profiles from the measurements of psychosocial job factors in Uddevalla as compared to Kalmar are shown in Figure 2.

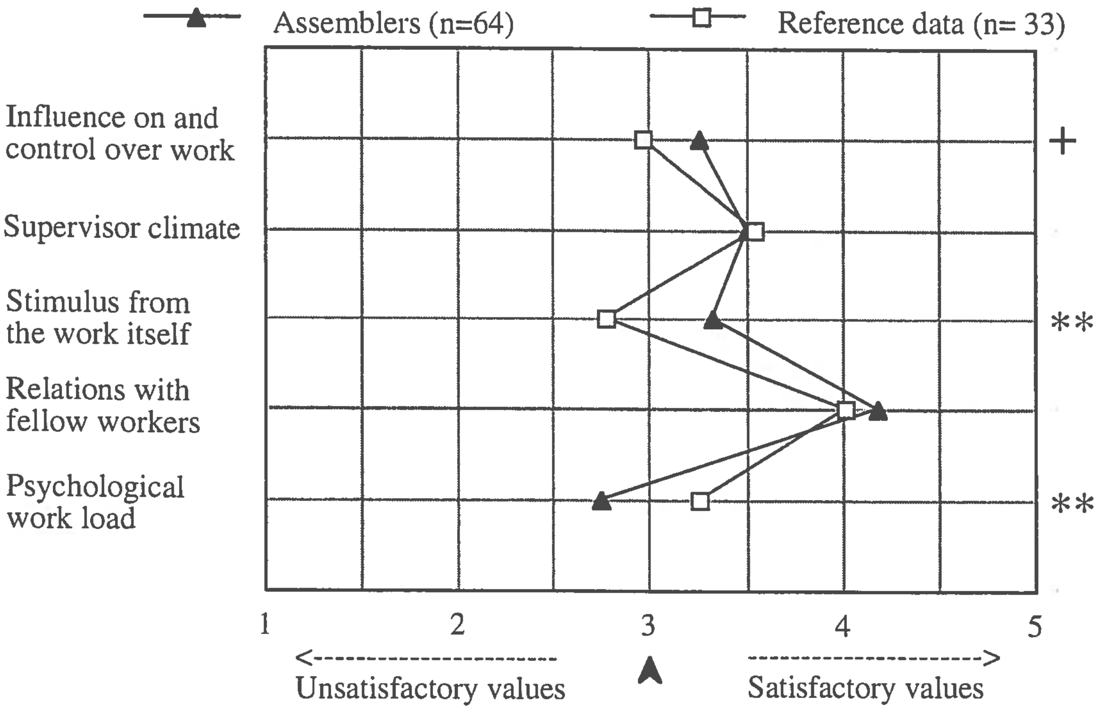


Figure 2. Psychosocial job factors in the Volvo Uddevalla plant compared with the Volvo Kalmar plant. Profile of attitudes to work, showing psychosocial job factors by mean values. Note: Significant differences (according to a two-tailed t-test) between the assembly workers in the Uddevalla plant (n = 64) and reference data (a random sample of assembly workers in the Volvo Kalmar plant) are marked with asterisks (+ p = 0.06; ** p<0.01, Engström et al. 1995).

Figure 2 shows that there were more satisfactory values in the study sample with regard to the factors "influence on and control over work" (t = 1.89, df = 95, p = 0.06) and "stimulus from the work itself" (t = 3.09, df = 95, p<0.01). In contrast, the study sample value with regard to the factor "psychological work load" was less satisfactory (t = - 2.92, df = 95, p<0.01).

7 ASSEMBLY PERFORMANCE IN UDDEVALLA

In order to analyze the assembly work at the Uddevalla plant in detail, an integrated video/computer system specially developed for this purpose was used (Engström and Medbo 1994c). This development work was necessary because of, among other things, the extensive amount of recording we did at Uddevalla during the closing down period.

The equipment used time-codes each picture frame on the recorded tape. This makes it possible for the computer controlling the video recorder to identify each individual frame.

Thus it is possible for the software to relate video-recorded activity sequences to the time dimension, i.e. to define the activity types and activity times for a recorded video sequence. Similar equipment has been developed by others (Bengtsson et al. 1983, Bengtsson et al. 1986, Oba et al. 1993) but for quite different purposes, i.e. time-and-motion studies of construction work and to provide a discrete visual simulation system with digital input.

The recordings on which the results are reported here are based included practically all assembly work work on nine specific automobiles. Each video camera followed an individual worker during the working day. Thus it was possible to gain authentic data from the shop floor. These data may then be compared to time-and-motion studies carried out by Volvo at the central process engineering department and locally at Uddevalla; studies used to support production scheduling and to provide a basis for the wage system. The video recordings were backed up by two hours of structured interviews of the workers recorded. The working pace and methods were not judged to be inflicted by the closing down decision.

The analysis included a categorisation of the work (or the time used) into; (1) the assembly work itself, i.e. the so-called net assembly time (2) materials handling, i.e. handling of kitting fixtures and (3) idle time. The data reported below concern only the net assembly time.

In Figure 3, normalized observed assembly times for nine vehicles, as obtained from analysis of the video recordings, have been plotted against normalized normed assembly times, obtained from time-and-motion studies. For example, the vehicle with the longest normed assembly time (100%) actually required only 90% of this time to assemble. Normed assembly times varied between 100% and 84%, while actual assembly times varied between 90% and 67%.

In all cases, actual assembly times were shorter than normed assembly times, corresponding to a mean work pace of 118% of that assumed in time-and-motion studies. The work pace distribution for the nine aumobiles video-recorded is shown in Figure 3.

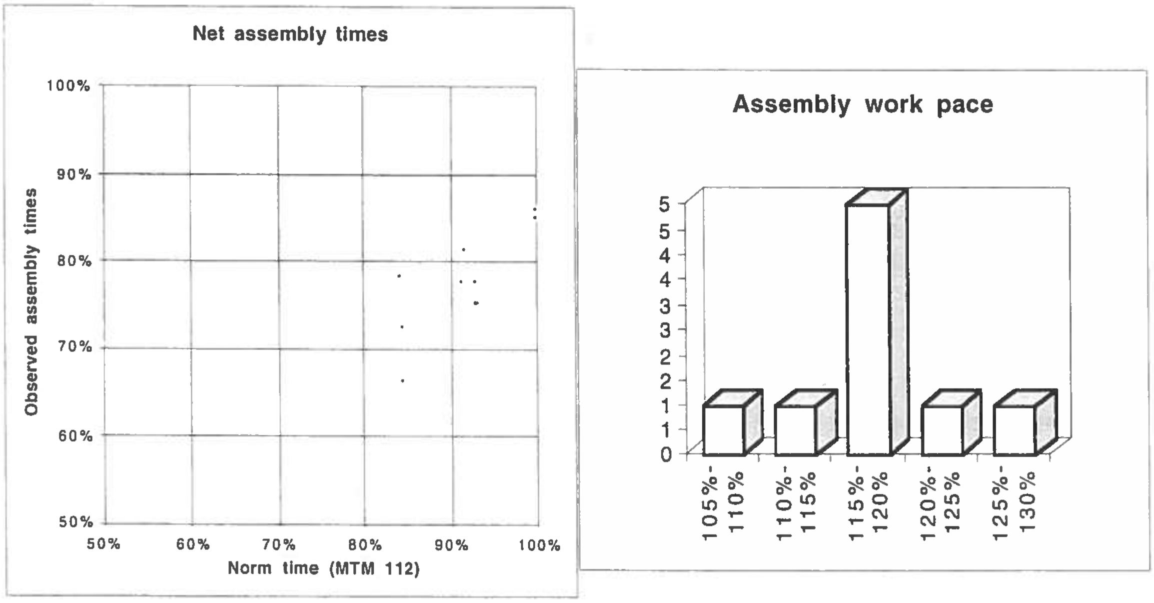


Figure 3. Observed assembly times compared to norm times.

Som et [illegible]

Assembly workers thus proved to be able to perform very long cycle (80 – 100 minutes) assembly work at a high work pace, and the work pace did not drop significantly even for extremely long work cycles. Two cars analyzed were assembled entirely by two female workers, resulting in mean work cycle times in excess of 300 minutes. As shown in Figure 4, their work pace did not differ significantly from that of workers with mean work cycles of 80 – 100 minutes.

It should be stressed that the norm time corrsponds to a work pace of 112 according to the MTM standard, i.e. the normal work pace at assembly line work in Sweden.

It may be noted that the work pace observed did not differ perceptably according to the option content of the car assembled, implying that the actual assembly time was roughly proportional to (but shorter than) the normed assembly time; se Figure 4.

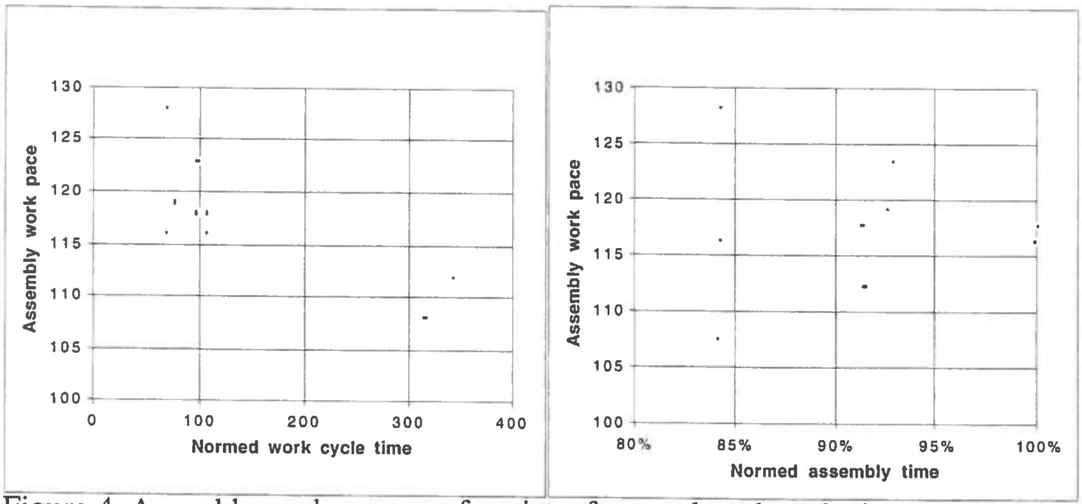


Figure 4. Assembly work pace as a function of normed work cycle time and normed assembly time for the entire automobile, respectively. Suma [illegible]

The data reported indicate that the assembly work itself was performed faster than expected according to time-and-motion studies. Idle time and materials handling time must however be added to tne net assembly time.

Unfortunately, the materials handling within the work groups impaired the performance somewhat. Since two principally different layouts were used in the assembly workshops, the kitting fixtures were not designed to optimize materials handling times since, among other things, the same fixtures was used for the different layouts. An improvement of the internal materials handling system using smaller materials containers to bring more components available at the worker position along the automobile body was planned but never implemented.

To put it very briefly, the design of the materials supply system in Uddevalla was affected by some severe restrictions due to early decisions to:

(1) utilise an existing building for the materials workshop and

(2) to use automated guided vehicles (manufactured by a Volvo subsidiary) to supply automobile bodies and materials fixtures.

These decisions introduced a separation between the materials handling work and the the assembly work. In this connection, it is also worth underlining that the automated guided vehicles were not essential for the implementation of the new production principles in

Uddevalla. The AGV system would not have been needed if materials handling and assembly work had been spatially and technically integrated, as described above.

The general shape of the building in Uddevalla, as well as the space allocated for the assembly workshops and the interfaces between the assembly work and the AGVs were also defined early before the assembly principles finally was decided. In particular, the number of and positioning of the stands for fetching and leaving materials and automobiles were specified early in the planning process. These stands had to be identical in all product shops, because the AGV system was common for all six workshops.

A revision of the production scheduling system according to assembly charateristics was also planned. The basic idea is that different instances of the same "assembly variant" are interchangeable for production scheduling purposes. The characteristics of products are grouped into four levels with respect to criteria such as competence requirements, assembly time, and tool and equipment needs (Engström and Medbo 1992, Medbo 1995):

> Level (1). Characteristics requiring similar assembly work for different products or components, e.g. interior panels of different colours are fitted in the same way).
>
> Level (2). Characteristics requiring marginally different assembly work for different products or components, where differences with regard to assembly are obvious, e.g. if the interior light has an integrated reading light only some extra electrical leads need to be fitted).
>
> Level (3). Characteristics requiring different assembly work for different products or components, but where all workers have the knowledge and equipment required to manage these differences, e.g. types of doors, if this work is integrated into the final assembly work.
>
> Level (4). Characteristics requiring different assembly work for different products or components, due to different competences, assembly times or equipments. It is characteristics on this level that generate significant differences from an assembly point of view and thereby define the majority of the different "assembly variants", e.g. low frequency variants on this level must in practice be planned separately.

+ Ref [illegible] [illegible] [illegible]

A production scheduling system taking into account the distinction between these four levels of characteristics would have improved the assembly performance, since technical autonomy would have served as an incentive and the waiting time due to materials fixtures, automobile bodies, etc. would have been almost eliminated.

8 CONCLUSIONS

The Kalmar plant represents an "elastic serial flow" concept, since it allowed the pace of the product passing through the system to vary. On occasion workers moved into other groups and to revise the production sequence.

The Uddevalla plant as it actually operated represents a "rigid parallel flows" concept, since even though it was fully parallelized and used a long cycle time the production scheduling system used did not allow the planned production sequence for each work group to be changed. Thus it was impossible to accumulate the working-up between cars manufactured. Since the production schedule was planned minute by minute weeks before the manufacturing moment, the human flexibility was not fully utilized. The assembly workers had no scope for working faster than planned and the material handling workers were constantly subordinated by the assemblers requiring kitting fixtures.

The proposed assembly system for Torslanda represents a "flexible parallel flows" concept. One reason for this is the flexible border-line between assembly and materials handling discussed above, another reason is the proposed use of so-called "assembly variants" (Engström and Medbo 1992).

It is interesting to note that a decisive argument in the design of the Uddevalla plant was the more efficient use of space allowed by applying parellel flow assembly. Space requirement considerations, or conversely production capacity for a given plant size, were vital also in the Torslanda case.

In the existing Torslanda plant, 1.6 automobiles per square meter per shift per year could be assembled (assuming a certain net assembly time per automobile etc). The corresponding figure for Uddevalla was 2.0 automobiles, and in the proposed new Torslanda plant it would have been 2.9 automobiles. ([illegible]

[illegible]

"Elastic serial flow"	"Rigid parallel flows"	"Flexible parallel flows"
Short work cycles	Long work cycles	Long work cycles
Work groups in sequence	Parallel work groups	Parallel work groups
Traditional materials feeding techniques	Non-traditional materials feeding tecniques required	Non-traditional materials feeding tecniques rerquired
Restricted technical autonomy	Technical autonmy delimited between products	Full technical autonomy
AGVs used to carry automobile bodies	AGVs used to carry materials	AGVs not used
(Not relevant)	Production scheduling not based on "assembly variants"	Production scheduling based on "assembly variants"

Table 3. Some vital characteristics of the three assembly system designs. Note that the "elastic serial flow" and the "rigid parallel flows" systems were designed for one type of automobile, while the "flexible parallel flows" system was originally designed for three types of automobiles.

In conclusion, it may be noted the design of assembly systems in the Swedish automotive industry has only to a little extent been based on solid systematic experience and formalised scientific knowledge. For researchers involved for a long time in designing and evaluating assembly systems and the very few practitioners with a similar long involvement the pattern of a successively emanating coherent theory is quite clear. The busy managers caught in particular circumstances and the never-ending chain of specific short-time industrial projects might not discern any pattern at all, however. The last years' trend toward decentralisation and cutting down of centralised departments have harmed the transfer of knowledge within Volvo, and this may explain why in some cases the public statements emanating from the Volvo Corporation might seem confusing for the uninitiated external reader.

[illegible]
+ Bill [illegible].

Ref [illegible]

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