THE WORKPLACE

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Technical preconditions for improved occupational health as introduced in parts of automotive industry are discussed.

The traditional assembly line, which uses short cycle times and work stations along a single flow of products negatively affects the working conditions on the shop floor, since it stipulates a repetitive, monotonous, machine paced work. By contrast, long cycle time assembly performed by autonomous work groups located along parallel flows of products allows working conditions to be improved.

The chapter discusses the economical viability on the untraditional production design and summarises early design hypotheses and their later revisions as well as a description of work structuring principles used in long cycle time assembly. The merits of this design are illustrated by data from the Volvo automobile assembly plant in Uddevalla, Sweden, including performance characteristics, assembly competence and psychosocial work environment factors.

1. INTRODUCTION

Work organisation and job design are major determinants of occupational health as well as production performance. This chapter is mainly concerned with a new form of work organisation in the automotive industry. This non-traditional work organisation simultaneously improves the work environment and production performance and incorporates unpaced assembly work with extremely long cycle times (in the case reported below 90 minutes and upwards) instead of paced short cycle time work (usually 1–3 minutes) as practised in all major American, European and Japanese final assembly plants. Thus, the preconditions for the human work on the shop floor is drastically reformed in terms of ergonomics, occupational health etc. At the same time, it is possible to improve the efficiency and flexibility of the production system.

It should be noted that large-scale automobile plants usually include stamping, welding, painting and final assembly facilities. In most plants, the first three functions are now highly automated, whereas final assembly is still a labour-intensive process. For example, Fujimoto (1997) reports automation ratios of 94, 91, 51 and 10 % respectively for the most advanced stamping, welding, painting and final assembly processes in 9 Japanese auto assembly companies. However, this chapter is concerned with manual final assembly, where the majority of the workers in automobile companies are found, while work in automated systems is considered in other chapters.

Tables 1 and 2 below show some statistics about occupational accidents and occupational disease in the Swedish manufacturing industry in general and in the Swedish automotive and automotive component industries, respectively.

The incidence of occupational accidents and occupational disease in the automotive and automotive component industries were similar to those in the general manufacturing industry. In both cases, occupational accidents were more frequent than incidents of occupational disease, but occupational disease accounted for several times as many workdays lost. As shown in Table 1, more than one million workdays were lost in the Swedish manufacturing industry due to occupational disease in 1992.

Table 1
Occupational accidents, incidents of occupational disease and work-days lost in the Swedish manufacturing industry in 1992 (SCB, 1992)

	Occupational accidents	Incidents of occupational disease
Number of cases reported	13,855	9,931
Number of cases reported per 1,000 employees	18.1	12.9
Mean number of workdays lost for each case (approx.)	24	104
Total number of workdays lost (approx.)	332,000	1,033,000

Table 2
Occupational accidents, incidents of occupational disease and work-days lost in the Swedish automotive and automotive component industries in 1992 (SCB, 1992)

	Occupational accidents	Incidents of occupational disease
Number of cases reported	1,400	989
Number of cases reported per 1,000 employees	18.6	13.1
Mean number of work-days lost for each case	18	90
Total number of workdays lost	25,000	89,000

The main cause of occupational disease in the Swedish automotive and automotive component industries was poor ergonomics, resulting in musculoskeletal disorder. This accounted for 751 out of 989 cases, or 75.9 % (SCB, 1993). Similar problems plague foreign automotive industries (see e.g. Nomura, 1993; Confederation of Japan Automobile Workers' Unions, 1992).

Work-related musculoskeletal disorders are a significant problem in modern industrial societies. In the Nordic countries, the total costs associated with musculoskeletal disorders are estimated to amount to 3–5 % of the Gross National Product (Hansen 1993; Hansen and

Jensen, 1993). According to some estimates, 30–40 % of musculoskeletal problems are work-related (Hansen, 1993). These problems are related not only to the physical work load but also to psychosocial factors (Kadefors et al., 1994). Despite much research in this area, the causes of work-related musculoskeletal problems are still not well understood.

Industrial designers have been criticised for failing to design ergonomically acceptable workplaces and for lack of insight about how design objects affect the work environment as a whole. Statistical data indicate that workplaces in Sweden were not improved from the point of view of stress level on the lower back between 1968 and 1985. While many heavy jobs have been replaced by lighter jobs, 25 % of the workers still lift heavy weights daily (SBU, 1991). Moreover, the new jobs may still be monotonous and repetitive.

Several attempts to improve occupational health in particular workplaces have also proved unsuccessful. For example, a production system for assembly work was recently redesigned with the explicit goal of decreasing the frequency of musculoskeletal symptoms (Johansson et al., 1993). However, such symptoms proved to be equally frequent in the new system. While disorders common in the old system became more infrequent, other types of symptoms emerged in the new system. Similar experiences have been reported by (Bao et al., 1995).

These observations underline the need for a deeper understanding of the shop floor work from an interdisciplinary point of view. The physical and psychosocial work environment as well as the production system must be taken into account. Furthermore, attention must be given to work environment factors as well as production performance when designing and evaluating production systems.

During recent years, there has been an extensive international and national debate promoting Japanese productions systems, often described as lean production (Womack et al., 1990), as an alternative to traditional mass production as supposedly practised by, e.g., American auto manufacturers.

This chapter is linked to this debate since it reports on research and development work within Sweden concerning final assembly of motor vehicles using a production form that constitutes an alternative to lean and mass production. The most prominent full-scale production plant so far has been the defunct Volvo Uddevalla final assembly plant. Some of the present authors were involved in the design of this plant.

To provide a background, there is a report on the pre-Uddevalla history and also an explanation of how earlier research implied a method to combine efficiency and humanisation through using technical autonomy (Section 2).

During the late 1970s, the research and development work focused on development of material feeding techniques, while during the late 1980s, it focused on development of learning aids for shop floor work, as well as on a refinement of the material feeding techniques, thereby improving the work environment, as well as creating a far more efficient manufacturing process due to the reduction of the so-called losses of the assembly line (Sections 3 and 4).

These facts are illustrated by describing the Uddevalla plant and its pyschosocial preconditions as well as some performance figures (Section 5).

The experiences and theoretical frames of references reported in this chapter implicate a revitalisation of Scandinavian sociotechnical design theory as formulated e.g. by Thorsrud and Emery, (1969) and Emery and Trist, (1960), as well as indicate the emergence of a typical Swedish production model not yet fully explicitly formulated or internationally accepted.

EARLY RESEARCH AND DEVELOPMENT WORK

An early hypothesis underlying the design of the Volvo Kalmar final assembly plant in 1974, which was built two decades before the Uddevalla plant, was that a long cycle time represented a desirable aspect in itself. The assumption was that by making work more attractive in this way, the extended learning due to the increased work cycle was "financed" by a reduction in absenteeism and labour turnover.

During this early period, the benefits in form of increased efficiency, higher flexibility and product quality, less space requirement, etc. as a result of parallelised flow were not recognised at all within the Swedish automotive industry. The commonly accepted argument was a vague line of reasoning of humanisation caused by the increased work content as mentioned above, or by integrating non-assembly tasks in work groups.

Until about 15 years ago, development and research work concerning assembly work in Sweden, as well as in other countries, focused on optimisation of the maximum cycle time along the assembly lines in view of learning restrictions since it was regarded as an axiom that the time required to complete a work task, e.g. to assemble an object, decreased with the number of times the task had previously been performed. Learning curves that describe this effect may be specified in different ways (Wright 1936; Argote, 1990). From a practical point of view, the salient question therefore often was how long it would take an assembly worker to become "sufficiently skilled" at performing a task. The most significant measure of the rate of learning would then be the time needed to acquire such proficiency.

This focus on the cycle time also depended on the assumption that the cycle time was assumed to be the main determinant of the meaningfulness of the assembly work and the related assumption that the more meaningful the work is, the less the personnel turnover and absenteeism will be and, as a result, the manufacturing efficiency will be increased. The design of the wage systems as well as worker participation were also considered to be important in this context.

Technical autonomy – an important human factor

Not until the late 1970s did some industries realise the importance of increased technical autonomy as a reward for increased responsibility for a work group, such as production planning, cleaning, liaison duties, etc. The generally accepted concept of humanisation did not only become a question of increasing the cycle time, but also of replacing some assembly tasks by other activities.

During this period, the production technique benefits of the parallelised flow long cycle time manufacturing in terms of productivity, quality, etc. of parallelisation became obvious to a small circle of people, as a result of a successful industrial application in the body shop at Saab Scania in Trollhättan, where the production flow of automobile bodies was parallelised thus increasing the cycle time from 3 minutes to 45 minutes.

This experience were reported by Karlsson (1979), who emphasised technical autonomy as the most vital incentive for accepting increased responsibility and as a precondition for administrative autonomy. Thus, it was possible to identify the important principle of accumulating the working-up (to gain technical autonomy), i.e. workers or work groups could gather the micro-pauses arising during the short cycle repetitive work due to speeding-up of the work or by choosing a more time-saving work method.

The other important fact highlighted and proved by Karlsson was the technical explanation for inefficiencies, e.g. losses inherent in the technical structure of the assembly line. This conclusion was based upon research work performed by Wild (1975).

The work in a body shop consists of grinding and welding and does not require a supply of a large volume of materials. In final assembly, however, a parallel flow leads to material supply restrictions, as the limited space makes it impossible to exploit all the components needed in separate material containers containing numerous identical components, as is the traditional practice along the assembly line. In this specific case, the efficiency improvement was 40 % of the manpower, 25 % less capital bounded in automobile bodies and the personal turnover was sufficiently reduced (Karlsson, 1979).

The question then emerged how to find appropriate material feeding techniques for parallelised flow production in the final assembly. Thus, the question of combining efficiency and humanisation in the final assembly area in many respects became a technical research question. The research work during the late 1970s and early 1980s focused on the material flow and volume along the assembly line. The product design proved to be an important factor affecting space requirements along the assembly line, the total amount of work needed, the increased amount of product variants, etc. (Engström, 1983).

Summary of the early research and development work

To recapitulate, paced line assembly is the most common production system design for assembly in the automotive industry. At first sight, such a design appears to be rational, since material flows are well defined, due to familiar materials feeding techniques etc. However, the monotonous, paced work where the individuals working pace is controlled by the movement of the line leads to high personal turnover, high level of sick-leave and a minimal responsibility for quality.

Or, to put it another way, the most desirable preconditions for line assembly are no or few product variants and small demands for meaningful work on the part of the workers. Even if these criteria are met, losses occur due to the need of extra inspection and adjustment of assembled products due to the inevitable variation of the human operator and product. The assembly line is sensitive to absences, resulting in the need for a sizeable pool of substitutes, since all work stations must be manned for production.

Thus, a production system design which offered technical autonomy in exchange for increased responsibility and minimised production losses was sought for. Empirical experiences and theoretical arguments supported a parallelised flow production system. However, this type of system required new material feeding techniques, as well as certain measures to facilitate learning of the increased cycle time.

3. PRODUCTION LOSSES AND PRODUCT DESIGN

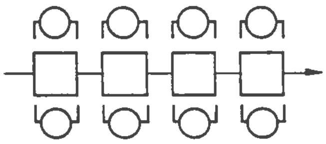
The efficiency of collective working with regard to idle time, amount of work in progress and production output (or conversely space required) has been demonstrated by simulation research (Wild, 1975). Wild originally formulated and proved the theoretical frames of reference for what is sometimes referred to as analysis of production losses.

This analysis is based on the net assembly time of the product considered, i.e. the minimum time required for an operator to assemble the complete product at full pace if tools and materials were materialised in his hands at the precise moment required. This is certainly an idealised case and extra time therefore has to be added due to:

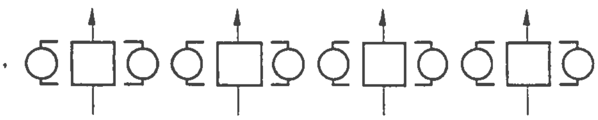
- Difficulties in dividing the work evenly between operators or work-stations in order to maximise time utilisation during the work-cycle, resulting in so-called balance loss;
- The fact that a large part of the work during the work-cycle is used for materials handling due to the need to reach, grasp and move materials and tools, resulting in so-called division of labour loss;
- The fact that equivalent repetitive tasks do not require exactly the same amount of time each time they are performed, resulting in idle time and/or other forms of so-called system loss.

There are two extreme design alternatives:

- Many work-stations in sequence, each one manned by one or two assembly workers performing short-cycle work, as in the assembly line used in traditional Mass production as well as in Lean production. This is referred to as a serial flow pattern;
- Autonomous work groups with extended work-cycles. These groups have to work in parallel if the same output as that of an assembly line is required, i.e. the flow pattern is parallelised.



Serial flow as used in traditional assembly lines



Parallelized flow as used in nontraditional long cycle time asembly

Figure 1. Schematization of production systems with serial and parallel flow. Due to the parallelization of product flows, the cycle time is increased and the division of labour is decreased.

In Table 3, balance losses, division of labour losses and system losses are expressed as percentages of the "necessary work" to perform the assembly. This means the assembly time is considered to be dependent on the product design. "Necessary work" in manual assembly thus means the work time required for an "ideal" operator to carry out all the work, with the components materialising in his hands.

The losses inherent in serial flows imply that parallel flow patterns lead to improved efficiency and a smoother material flow and are a precondition for the autonomy necessary for humanisation of the work. A full-scale example of this type of parallel flow production system was the Volvo Uddevalla final assembly plant.

To summarise, Wild's research indicates that for a given total space allocation and a given number of operators, a production system with autonomous work groups having a sufficient number of products available to work on operates with less production losses than an equivalent assembly-line system.

Table 3
Theoretical and observed "system inefficiency" for two different flow patterns

	Serial flow pattern		Parallel flow pattern	
	Minimum theoretical	Observed	Minimum theoretical	Observed
Balance loss (%)	5	30	1	5
Division of labour loss (%)	6	25	4	15
System loss (%)	25	80	5	20
Total "work inefficiency" (%)	36	135	10	40
Total man-hours required (%)	136	235	110	140

It is obvious that the parallel flow pattern is the most efficient one. The observed data derives from several of our studies of the Swedish motor industry. "Necessary work" corresponds to a man-hour requirement of 100 %.

Table 4
Actual assembly time in manual assembly as determined by "necessary work", which means the work time required for an ideal operator to carry out all the work (Wild, 1975) and production losses

	Total manpower required for		
	(1) Swedish serial flow pattern (hour)	(2) theoretical serial flow pattern (hour)	(3) theoretical parallel flow pattern (hour)
(A) Automobile requiring six hours of "necessary work"	15	8	6.5
(B) Automobile requiring four hours of "necessary work"	10	5.5	4.5

...e that the actual assembly time may be reduced by improving the product design as well as reducing the losses. Note that this type of comparison makes it possible to discuss merits of different production systems independently of product design.

WORK STRUCTURING OF LONG CYCLE TIME ASSEMBLY WORK

One of the basic principles in long cycle time assembly work is that there must be congruence between how the work is carried out, how the materials are displayed and how the work is performed. One consequence of this congruence is that the assembly work is simultaneously supported by the materials as displayed as well as by documentation of the components and the assembly tasks and, thirdly, the "mental maps" that the operator activates during the assembly work (Engström and Medbo, 1990).

This congruence makes it possible for the operator performing assembly work to decide whether the wrong materials have been supplied, or whether the administrative support, in the form of, for example, work instructions, is inaccurate or whether the operator himself is uncertain about how to carry out the work. It is not necessary to test-fit components in order to be sure which one of these three problems occurred. The consequential risk of being forced to dismantle test-fitted components is then eliminated, reducing the need for extra personnel to inspect and adjust products.

The aim is to create technical and administrative preconditions which allow the operators to perform inspection and adjustments themselves in order to thereby maintain product quality and the quantitative planning of production volume. The knowledge developed must then be transferred into routines and documents which facilitate expanded assembly work which includes other types of work than just the pure assembly work.

The general principle is that an extended cycle time implies the need to prestructure the information and materials to facilitate the assembly work. This prestructuring calls for non-traditional materials feeding techniques where the materials are supplied in the form of kits forming a work instruction in itself combined with advanced information systems (relying on precise verbal networks to complement traditional part numbers and variant codification).

The complete product constitutes a whole that should form the basis for work structuring. The product is described in detail in the design phase and the long cycle time assembly work itself may be said to verify the prestructuring of information and materials. This prestructuring constitutes an advantage that is unfortunately seldom exploited.

In traditional line assembly, the importance of maximising productivity through securing that the operators do not have any slack during the cycle time is emphasised. This method leads to the erroneous conclusion that the learning of assembly work should aim at the internalisation of the single best assembly sequence.

Note that to simply describe the assembly work on the basis of the assembly sequence creates no overview and moreover demands an infinite number of work descriptions, since different product variants require different assembly sequences and assembly sequences must also be adapted to production scheduling of the automobiles.

Correct work structuring produces a cascade of interrelated methods for different individuals, naturally having quite different qualifications and serves as a starting point for the untrained operator to gain a holistic perception.

Long cycle time assembly work is guided by a chain of associations, where the fitting of one component successively generates the choice of the next. The individual operator's assembly sequence forms a track of work tasks through the automobile and the work group's collective work pattern.

For the untrained operator, performing long cycle time assembly work, the larger components "call for" the small ones. For the more trained operator, in contrast, the small components claim the larger ones. The most trained operators gain a dual-perception capability, being able to instantaneously switch between different perceptions.

This is analogous to the so-called "figure-ground" effect explored in Gestalt psychology. Briefly, one region of the perceptual field tends to stand out as "figure", while the complementary region is perceived as "ground". The roles of "figure" and "ground" can however be reversed (see Figure 2).

For the untrained operator, the larger components constitute the "figure" in virtue of their conspiciousness, while the smaller components constitute the "ground". For the more experienced operator, by contrast, the smaller components constitute the "figure" in virtue of the large amount of information about the assembly work that they represent, while the larger components now constitute the "ground". The most advanced operators, finally, are able to switch between these perceptions at will.

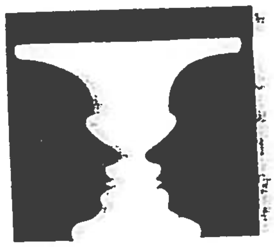


Figure 2. The "figure-ground effect" is illustrated by using the Peter-Paul goblet (Berelson and Steiner, 1964).

Note that the existing product structures generally used by the Swedish motor vehicle industry to describe the vehicle and its components do not provide adequate support for long cycle time assembly work (Engström and Medbo, 1993). Before the Volvo Uddevalla plant, no assembly-oriented product structures relevant for long cycle time assembly existed either for complete vehicles or parts thereof.

It is important to note that the existing product structures used by the Swedish motor vehicle industry lead to erroneous conclusions in connection with long cycle time assembly, due to inadequate perceptions of the products and the work. The product descriptions used create an apparent obstacle to the development of parallel flow, long cycle time assembly, since the product is perceived to be far too complex and to contain too many components for any adequate material feeding technique to be used.

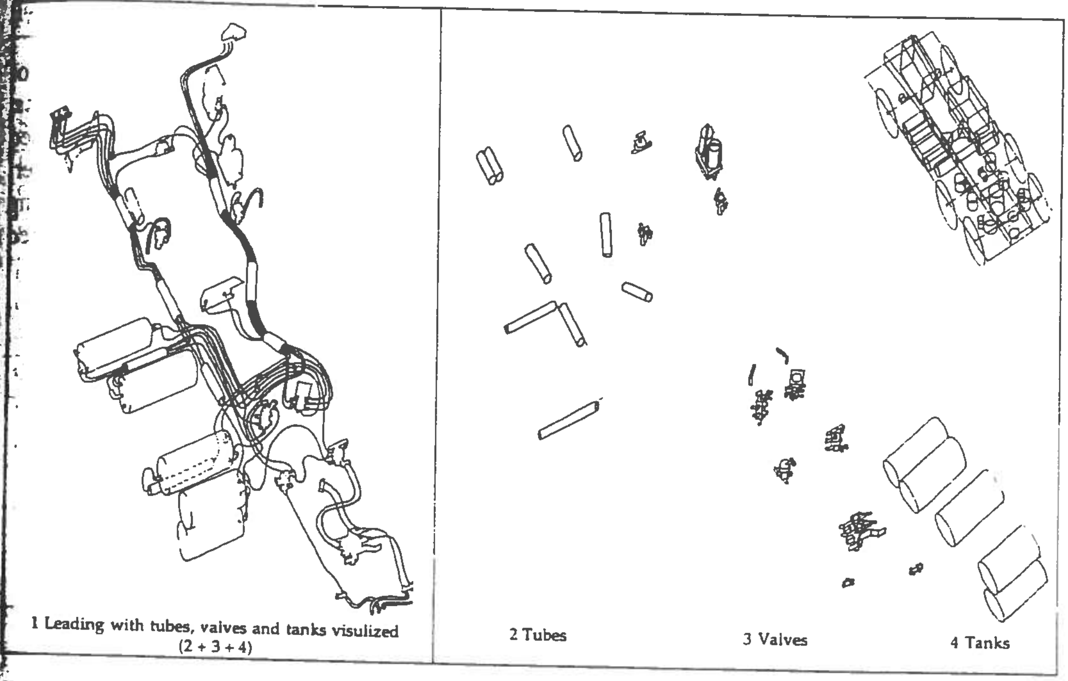


Figure 3. Figure-ground effect illustrated by truck components. The components are normalised using a schematised outline (in the upper right corner of the figure) corresponding to the vehicle body view diagonally from the rear end, as if entering a truck from the drivers side or as the vehicle ought to be perceived if the members of, e.g., a work group have to determine the redistribution of the assembly work.

5. THE VOLVO AUTOMOBILE ASSEMBLY PLANT IN UDDEVALLA

The Uddevalla plant had six parallel assembly shops, so-called product workshops. These workshops were grouped around two test workshops, where media (petrol, water etc.) were added and the automobiles were test driven. The materials workshop prepared and supplied kitting fixtures to final assembly.

Each one of the workshops contained seven work groups. In workshops 1–3, the automobile body was moved once, while in workshops 4–5 (the sixth workshop was never fully utilised) the body remained stationary at one work station during the whole assembly while the operators moved between the work stations.

In both types of product workshops, so-called "assembly active buffers" were used, i.e. one did not have maximum operator concentrations around the automobile body. The subassembly work, i.e. assembly of doors, engine, instrument panel, etc., was integrated into the work group and the subassembled components were used as an internal buffer. This buffer design was necessary in order to absorb the variation in assembly time caused by products, product variants or humans forming a work organisation best described by the various intra-group work patterns chosen (Engström and Medbo, 1994). In workshops 1–3, all subassembly work was integrated into the work on the body, while in workshops 4–5, a specific work group member normally carried out most of the subassembly work.

In the Uddevalla plant, the cycle time was increased to a minimum of 80 minutes, instead of 1–3 minutes as practised in all major American, European and Japanese final assembly plants, thus improving the ergonomic conditions because (1) the cycle time was substantially increased thus making the assembly work less repetitive and (2) due to using a device to rise and lower, as well as to tilt, the car body based on experiments which were carried out in a special training work shop. These experiments showed that the standing straight upright posture now occurred in more than 80 % of the total assembly time (Kadefors et al., 1995).

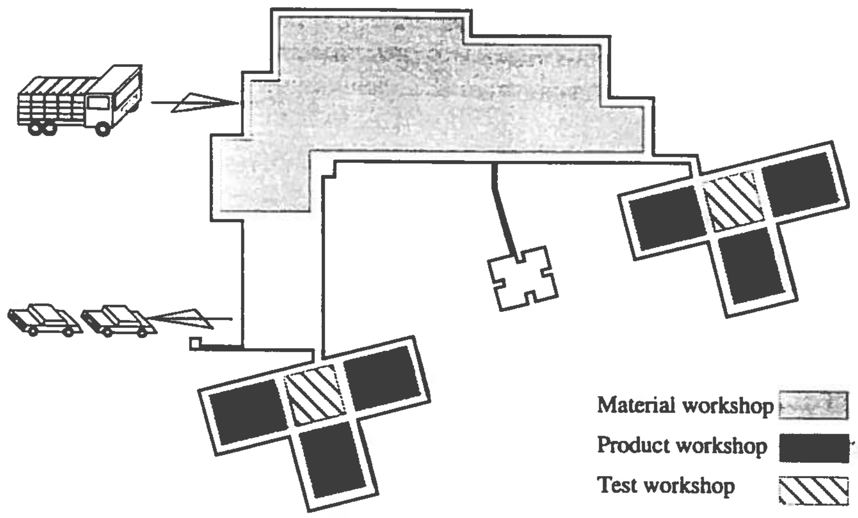


Figure 4. The Uddevalla final assembly plant with its product workshops grouped around two test workshops and the central materials workshop which made the materials kits and fed them to the assembly workers in the product workshops.

Performance characteristics

Performance characteristics of the five workshops are summarised in Table 5. These figures are from the autumn of 1992, before the closing-down decision and have been calculated using data collected by the production engineers, originally used for calculating salary bonuses, etc. Note that in Table 4 productivity is expressed in terms of budget fulfilment, not in terms of the losses discussed above. Video recordings of three work-groups revealed that they worked at a pace of 16 %–19 % above the norm performance calculated by production engineers using time-and-motion studies (Engström and Medbo, 1994).

Table 5
Performance characteristics of the five workshops

	Workshop 1	Workshop 2	Workshop 3	Workshop 4	Workshop 5
Starting up time:	May 1989	January 1989	May 1988	May 1989	October 1989
Productivity [% of budget fulfilment]:	87	93	94	92	84
Productivity variation:	low	medium	low	medium	high
Quality [mean number of quality remarks per automobile]:	49	45	46	51	56
Quality variation:	medium	high	low	high	low
Number of excellent work groups:	1	5	3	1	1
Number of unsatisfactory work groups:	0	1	0	0	1
Throughput time [hours]:	11	9	9	8	10

Productivity and quality figures are from the autumn of 1992 before the closing-down decision. Quality performance is measured in so-called "quality remarks", where a large number of remarks corresponds to low quality. According to this study, excellent work groups had less than 50 average remark points, low variation and more than 90 % productivity with low variation. Unsatisfactory work groups had more than 60 average remark points and less than 80 % productivity. Throughput times data reported above are from the spring of 1992 (Engström et al,. 1994).

These performance figures supply further evidence that parallelized assembly is economically viable. This is, of course, a precondition for the introduction of long cycle time assembly and hence for the improvement of occupational health in this way.

Assembly competence

In workshops 1–3, the work required to assemble an entire automobile was normally divided into seven phases, whereas the assembly work was normally divided into nine phases in workshops 4–5. In the questionnaire, assembly workers were asked to assess the number of phases they mastered at full pace and also the number of phases they could perform at less than full pace.

Figure 5 reveals a level of assembly competence previously believed to be impossible to attain in automobile assembly. For example, more than 50 % of the assembly workers mastered at least four phases out of seven; of those mastering exactly four phases, ca. 4 % mastered all four at full pace, ca. 15 % mastered three phases at full pace, ca. 4% mastered two phases at full pace and ca. 6 % mastered only one phase at full pace.

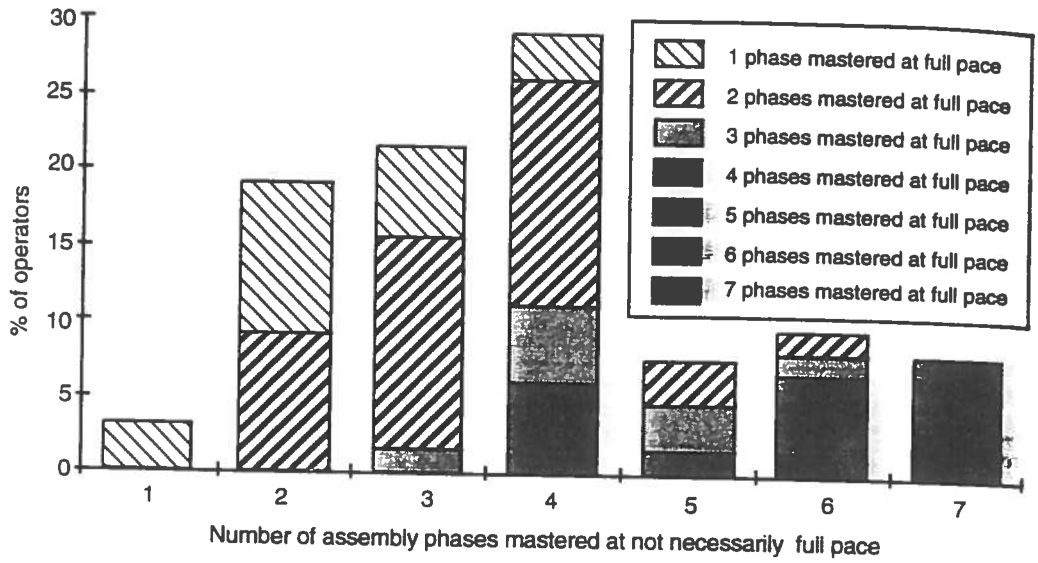


Figure 5. Assembly competence in the Volvo Uddevalla plant at the closing down period according to the questionnaires (Engström et al., 1994a). The diagram shows how many assembly phases operators were able to perform at not necessarily full pace and also how many phases they were able to perform at full pace. The high assembly competence, as well as competence overlap between co-workers in the same work group, is a precondition for long cycle time work.

It should be noted that the levels of competence reported by the assembly workers themselves did not exceed those assessed by supervisors and other assembly workers for the purpose of settling wages (Engström, Jonsson and Medbo, 1994). This fact might be explained by a successive "inflation" of the competence-related part of the wages during the running-in and full production period of the plant's life, or by the fact that the wage was not related to the individual's pace of performing a specific task, but only to the number of work phases mastered at not necessarily full pace.

Psychosocial work environment

Since the Uddevalla experiences included important social dimensions, a "multi-disciplinary" questionnaire was also developed covering social and technical aspects. This questionnaire was distributed to the subjects during working hours. The subjects were randomly selected and answered the questionnaire anonymously. The participation rate was approximately 90 %. The researcher explained the purpose of the study and was present during data collection. The total study included 97 employees, of which 64 were assembly workers (Engström et al., 1994a).

The operators' attitudes to their job were assessed using a "standardised" questionnaire (Rubenowitz, 1994) measuring five important psychosocial factors:

"Influence on and control over work". 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.
"Supervisor climate". 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.
"Stimulus from the work itself". 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.
"Relations with fellow workers". 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.
"Psychological work load". 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 includes 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).

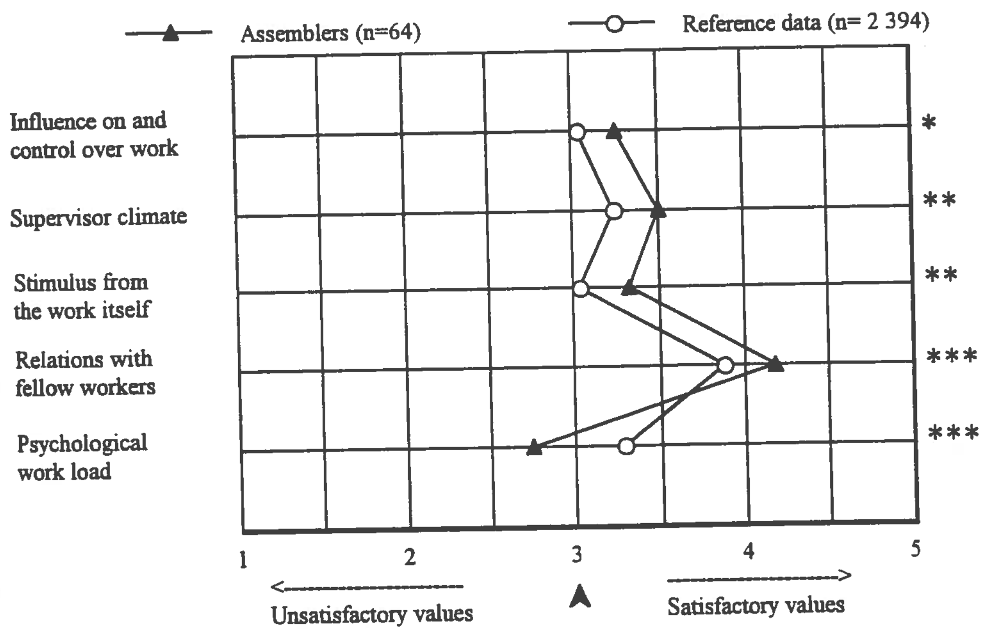


Figure 6. Profile of attitudes to work, showing psychosocial job factors by mean values. Note: Significant differences (according to a two-tailed t-test) between the assembly workers and reference data (industrial blue-collar workers) are marked with asterisks (•p<0.05; •• p<0.01; ••• p<0.001) (Engström et al. 1994a).

Examination of the differences between the assembly workers and reference data (Figure 6) showed 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 ($t = -4.82$, $df = 63$, $p<0.001$).

As shown in Table 6 below, gender, age and time of employment are to some extent related to the assembly workers' ratings of "influence on and control over work", "stimulus from the work itself" and "psychological work load". The most pronounced differences were obtained with regard to age and time of employment, with older employees and employees with longer times of employment reporting the most satisfactory assessments of psychosocial job factors.

Table 6
Psychosocial job factors in relation to background variables. Note: significant differences between groups (according to a two-tailed t-test) are marked with asterisks ($^{+}$ $p<0.10$, * $p<0.05$, ** $p<0.01$) (Engström et al., 1994)

	Gender		Age		Time of employment	
	Male	Female	<30 years	≥30 years	<4 years	≥4 years
Influence on and control over work	3.36	3.50	3.30	3.48	3.23^{+}	3.50^{+}
Stimulus from the work itself	3.34	3.60	3.17*	3.60*	3.12**	3.59**
Psychological work load	2.93	2.79	2.82	2.96	2.71^{+}	3.02^{+}

In general, a relatively more satisfactory psychosocial work environment was thus reported by the assembly workers at the Volvo Uddevalla plant compared with industrial blue-collar workers with respect to four factors out of five.

This was especially the case for the factors "influence on and control over work" and "stimulus from the work itself". The latter includes the items whether the work is stimulating, whether it is varied and diversified, opportunity to use talents and skills and opportunity to learn new things at work. Previous research shows that if the opportunities to learn new things at work are restricted, this will increase the risk of stress-related disease, especially in combination with a work-situation under high pressure (Karasek and Theorell, 1990). The balance between demands and ability to control is optimal in situations characterised by lack of excessive demands and a high level of control. When demands are matched by control possibilities, a healthy degree of challenge exists, which is a condition for growth and regeneration. The situation of active learning and motivation to develop new behaviour patterns increases skills.

The results from the questionnaire indicates that work was organised well so that the assembly workers had good opportunities for contact with fellow workers and supervisors. It is well known that social support at work is an important buffer between stress and ill-health (Johansson 1994; Johnson 1985; Karasek and Theorell, 1990). This perceived work situation in the Volvo Uddevalla plant may in terms of stress be characterised as "effort without distress", whereas traditional assembly-line work often is perceived as "effort with distress" (Frankenhaeuser, 1986).

6. CONCLUSIONS

The facts reported above imply the possibility of combining high productivity and product quality with extensive assembly competence and a favourable work environment in the final assembly of motor vehicles. The public debate in Sweden has in many respects focused on social aspects of extended cycle times and work participation, almost neglecting the production engineering aspects. The fact that long cycle time parallelised flow assembly constitutes a production form developed and refined during the last two decades which is superior from a production engineering point of view has been overlooked.

The production principles sketched above are fully in harmony with the existing theoretical frames of reference, as well as practical experiences gained within the Swedish automotive industry. In fact, the most recent experiences underline the importance of implicit work structuring through adaptation of the technical and administrative precondition on the shop floor to the human.

This new production form is not compatible with an extremely high external turn-over and requires a skilled work force, but more importantly it requires a different mental approach from the system designer and researcher as well as the managers. Note the possibilities to take advantage of a work force consisting of both young and old, as well as female and male employees.

The obvious question to ask is whether there is a valid Scandinavian sociotechnical design theory revitalised from decades of development and research work? According to experience such a theory certainly exists, but it is not yet fully articulated or internationally recognised.

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