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## CONTENTS

# SOME KEY FIGURES, FACTS AND EXPERIENCES REGARDING THE LEARNING OF LONG CYCLE TIME ASSEMBLY WORK WITHIN THE SWEDISH AUTOMOTIVE INDUSTRY – Illuminating some aspects of assembly system design in relation to the learning

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ABSTRACT:

This paper will, based on the authors' research and development experiences gained within the Swedish automotive industry, illuminate some figures and facts concerning long cycle time assembly work in unorthodox assembly systems (i.e. parallel product flow assembly systems). These experiences comprise long periods (2 – 5 years) of co-operation coalitions between practitioners and researchers. Namely the cases; (1) the defunct Volvo Uddevalla plant and (2) the Autonova plant, now Volvo Car Corporation, also located in Uddevalla, (3) the Volvo Truck workshops in Tuve in Gothenburg and (4) the Volvo Bus plant in Borås.

As a way of introduction, i.e. in order to establish more profound frames of theoretical and practical frames of references, the paper initially reports on data gained through questionnaire surveys, shop floor interviews and internal personnel statistics from the Volvo Uddevalla plant (case #1). Thus forming a base for further discussion of the three other cases (case #2 – #4). A discourse which primarily is based on some key figures defining assembly system designs, such as cycle times, product flow patterns and number of products available for assembly work (i.e. number of "assembly active" products, etc. taking advantage of a classification which embrace product flow patterns and so-called work-station system design. All which conveys to a deeper understanding of assembly system designs in relation to the learning aspects.

## I INTRODUCTION

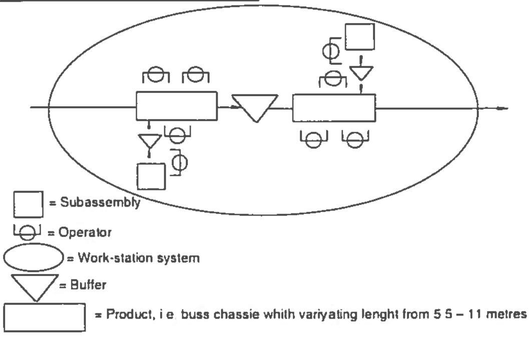
The assembly line has been a matter of debate for various reasons (see e.g. Walker, Guest and Turner 1956). In some cases has alternative assembly system designs been introduced. System designs, which in extreme application have included parallel product, flow comprising so-called autonomous work groups.

Work in autonomous work groups is in this paper denoted collective working to emphasise the fact that operators work together on one or more products, having common responsibility for production output. Note that efficient collective working requires that the product is of sufficient size, or available in sufficient quantity, so that the operators do not block each other during the assembly work. 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 research (Wild 1975). Wild originally formulated and established the theoretical frames of references for what is sometimes referred to as analysis of production losses, or loss analysis. However important and interesting the aspect of efficiency is just touched upon in this paper. Although it must be noted that one of the main arguments restricting the introduction of parallel product flow, long cycle time assembly systems, regards the assumption that it is impossible to learn long cycle time assembly work. Consequently, it is of importance to outline the context of industrial learning.

### 1.1 Serial product flow versus parallel product flow assembly systems

In the light of recent developments in the international automotive industry, as well as the authors' experiences from alternatives to the assembly line featuring autonomous work groups in the Swedish automotive industry during the last 25 years, two lines of development with regard to assembly system design have crystallised. These lines are (1) refining repetitive, short cycle time work, in serial product flow assembly systems (assembly lines), drawing inspiration from Japanese success cases. Respectively, (2) developing unorthodox long cycle time work in parallel product flow assembly systems, which might be recognised as a new manufacturing paradigm, drawing inspiration from Swedish experiences.

In a serial product flow assembly system, the product being assembled passes all work stations along the product flow. The cycle time is short. In a parallel product flow assembly system, on the other hand, the product passes only one work station, and the work is less repetitive due to the increased cycle time. The work station design varies between assembly systems. In particular, work stations may accommodate a varying number of products and operators. If operators co-operate on one or more products collectively there is a special type of working i.e. collective working in a defined sub-system of work stations and operators, i.e. work-station systems comprising a number of internal work stations.




Schematised work-station systems for the Volvo Arendal assembly workshop (1974).

Photograph of the Volvo Arendal assembly workshop.

Figure 1. To the left the work-station system in the Volvo Truck Arendal assembly workshop initiated in 1974, this was a work-station system which in most respects is similar to the one used 17 years later in the Volvo Truck assembly workshops in Tuve at 1991. In both cases were the subassembly work stations integrated into the work-station systems. The assembly workshop in Arendal was the most innovative assembly system within the Volvo company during the 1970s. The setting up of this workshop was initiated by the fact that the production capacity of the regular Lundby plant had reached its limits, and there was an urgent need for an additional manufacturing capacity of 400 trucks a year. The vehicles put together in the Arendal assembly workshop were the most complex and labour-intensive trucks manufactured by Volvo during this period. In this assembly workshop, a work group of twelve people assembled complete trucks. This type of work-station system is often denoted "two-stage dock" by practitioners, i.e. the chassis was moved once during the assembly. In the Arendal case there was a possibility to buffer one chassis in an aisle between the two stages. To the right, a photograph of the Volvo Arendal assembly worksshop (courtesy of Bertil Johansson retired manufacturing engineering at Volvo).

The parallel product flow alternative has been assumed to be contradictory to traditional production engineering practice, striving for reduced manufacturing costs and using mechanisation and standardised work as important means towards this goal. Instead, this new alternative has been supported by the argument that, due to humanisation, the sick-leave and turn-over would decrease, and this would in turn compensate for the increased manufacturing cost. This might earlier have been an relevant argument, but during the recession in 1990s, and considering the Japanese automotive manufacturers´ well-published international market successes, this argument for parallel product flow production principles has in most respect lost much of its appeal.

The fact is, however, that parallel product flow production does, correctly designed, simultaneously achieve increased efficiency and a more humane work compared to the traditional assembly line (see e.g. Karlsson 1979; Eckerström and Södahl 1981). Admittedly, most of the Swedish efforts to replace the assembly line during the 1970 – 80s were not entirely successful, although some delimited exceptional examples exist. The explanation for the varying success of non-traditional assembly systems, discussed in this paper, generates important insights into man-machine interaction in complex assembly systems. To be frank, however, the forefront of these experiences was in fact British Leyland. Though this specific experience was during a short period of time and it is not sufficient documented (Blackler and Brown 1978).[1]

The traditional learning curve model

In manufacturing engineering, the learning curve model by Wright (1936) is used to establish the need of resources for manufacturing. The time or cost is assumed to decrease as the number of a manufactured product increases. This learning curve model makes it possible to evaluate organisational learning through gathering relevant data, and has been widely spread (Shtub et al. 1993).

Another aspect of industrial learning is the application of the learning curve model focused on repetitive work (De Jong 1964; Hancock and Bayha 1992). The conception of learning through learning curves means that learning is mainly regarded as a mathematical problem and, for example, every time the number of work cycles is doubled, the time per work cycle decreases by a fixed percentage.

However, it should be noted that the learning curve model does not contain the "conditioned learning time", i.e. the time required for the operator to learn during the initial time period when he or she barely knows how to perform the work. This time period is often long since trial-and-error learning is most often practised in the manufacturing industry (Hancock and Bayha 1992).

Boucher (1987) discusses short series and batch production on assembly lines, resulting in a significant production volume during the early period of learning. The assembly line balancing becomes a trade-off between production losses (i.e. balancing losses and materials handling increase with shorter cycle time, due to more assembly stations) and cycle time length (i.e. a longer cycle time increases the learning time). Increased cycle time, often synonymous with job enlargement, is thereby claimed to reduce the number of repetitions, which in turn decreases the productivity gained, according to the learning curve model (De Jong 1957).

Chakravarty and Shtub (1988) discusses the effect on the learning curve model of a parallel product flow assembly system with increased cycle times. They claim that reduced learning should be balanced against reduction in absenteeism and turnover as a result of increased satisfaction due to work enlargement. The design of, for example, the assembly system is therefore a question of optimising the cycle time.

New concepts of learning

Cross-disciplinary, applied research, influenced by psychology within the field of cognitive engineering focuses on learning by means of improving human perception. Cognitive engineering is mainly concerned with the design of computer-based information systems to support work in complex, socio-technical systems (Vicente 1999). Extensive research, especially concerning the design of control and safety systems for industrial process plants, has been carried out. Rasmussen (1986) developed a framework for "cognitive task analysis" describing decision tasks in terms of information processes. The framework consists of five classes of behaviour shaping constraints (Vicente 1999), based on the assumption that all possible tasks cannot be anticipated and therefore not trained.

A number of design principles have emerged from Rasmussen´s research as, for example, ecological interface design, which facilitates operators' flexibility to adapt to unanticipated events. It is based on "work domain constraints" rather than on a task analysis which defines "one right way" to perform anticipated tasks (Vicente and Rasmussen 1992).

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[1] This paper focuses on experiences within Volvo, but a similar experience from Saab-Scania (today Saab Automobiles) also deserves mention. In 1975, a new work organisation was introduced in Saab's automobile body shop in Trollhättan. The work groups were given responsibility for productivity, quality, maintenance and budget, and the assembly line was replaced by a parallel product flow system. Cycle times were increased from three minutes to 45 minutes. As a result, productivity increased by 40 per cent. Furthermore, labour turnover decreased from 80 per cent to 14 per cent and absenteeism due to illness decreased from 20 per cent to 13 per cent. These figures were better than those found in other departments of the Trollhättan plant at this time (Karlsson 1979).

Jones (1995) observes that cognitive engineering research has focused on the study of humans supervising complex, dynamic, highly automated systems. In these systems the human supervises highly automated processes rather than participating in continuous direct control of a process.

Researchers within both psychology and pedagogy treat learning but they use different research methods, resulting in different perspectives on learning. Within pedagogy, the research tradition in Göteborg led by Marton (Gibbs 1982) stresses that analysis of learning must be done in relation to what is to be learned, i.e. the human conception of the reality. Characteristic of this research tradition is that learning is not synonymous with adding of knowledge and that the direction (i.e. intention) and organisation of learning are regarded as important.

Marton (1970) stresses the importance for the human being of creating an internal, mental representation – a structure – to facilitate learning. It is especially important to construct a mental structure ("building up an internal representation as a structure") in the initial phase of the learning, leading to higher performance in later phases. Complex knowledge cannot be composed out of small pieces. Thus, an alternative concept of learning (contrasting with the learning curve model) emanates, where the learning and understanding depend on the relation between former and new knowledge. Marton argues that learning proceeds from an undifferentiated, poorly integrated understanding of the whole to increased differentiation and integration of the whole and its parts. The learning thus has a direction from the whole to the detailed and not the opposite. – "To learn something you have to have an idea of what you are learning about" (Marton and Booth 1997). The learning can therefore be regarded as either holistic, hierarchical integration of knowledge, or atomistic, focusing on the "parts" (see Svensson 1984).

A similar concept of learning emerged through the reading of texts and through the resemblance to linguistic research regarding rules for formalisation of language. Chomsky (1957; 1975), who created the theory of transformational-generative grammar, argues that human beings have an innate facility for understanding the formal principles underlying the grammatical structures of a language. Chomsky distinguished between two levels of structure in a language; "surface structures" which are the actual words and sounds used, and "deep structures" which carry a sentence's underlying meaning. Humans can create and interpret sentences by generating the words of "surface structures" from "deep structures" according to a set of abstract rules. The same rules are present in all languages and, though limited in number, they allow for an unlimited variation.

Nilsson (1981), who is a part of the pedagogy research tradition in Göteborg, has pointed out how holistic learning principles can be utilised in assembly work. Nilsson applies the phenomenographic perspective of Marton on assembly work. He claims that all orientation is related to time and space. This means that those phenomena that are to be treated must be described with regard to their position and distance in both time and space. Unfortunately, people have, for various reasons, different time perspectives. On the other hand, the time perspective can be changed provided that the humans are allowed to perform tasks they can see a purpose in and have an opportunity to accomplish. It is also important that they experience themselves as successful and can feel happy about their success as well as other people's confirmation thereof. Their time perspective is then expanded and provides the opportunity to successively formalise one´s own experience and regard it in relation to earlier knowledge. The technological structures, which previously dictated the scope of the work, are hereby seen to be possible to influence.

According to Nilsson (1995), it is important for the operators to obtain information at different precision levels, both during learning in real life situations and as a reference in the long-term perspective. Also Ellström (1996) argues that the use of real-life situations as a base for learning creates new possibilities to adapt to a changing environment and to improve processes. Kjellberg (1996) maintains that development of individual competencies requires work enlargement and work enrichment and that the introduction of "group layouts in flow-oriented production organisations" has facilitated an "orientation towards holistic learning". For assembly work the concept of so-called holistic learning is operationalised by utilising so-called structural congruence.[2]

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[2] An important work hypothesis regarding in the design of parallel product flow, long cycle time assembly systems is that of structural congruence. This work hypothesis demands agreement between (1) operators' perception of the

## 1.2 The Volvo Uddevalla plant a brief description

The Volvo Uddevalla plant had six parallel assembly workshops with parallel work-station systems. The product flow structure was similar to a so-called organic product flow pattern. The flow of automobile bodies first diverged into a number of work-station systems and later converged. At the start of this flow is e.g. the automated robot fitting of the windshield, while at the end of the flow there was the roller testing of the complete automobiles. Therefore, the assembly workshops were grouped around two parallel workshops that tested the vehicles, where media (petrol, freon, etc.) were added and the automobiles were test driven. A separate materials workshop prepared structured materials kits comprised in materials fixtures.

These materials kits, which contained the components needed to assemble complete automobiles, were transferred to the assembly workshops by an AGV-system, which used fixture stands at each end of each individual transport assignment for the AGVs carrying the materials kits.[3] That is, these AGVs was fitted whit a lifting table on top thus needing delivery points above floor level (i.e. at a fixture stand). Also individual AGVs delivered the automobile bodies.

For example, the materials kits were carried from a specific fixture stand in the materials workshop to another specific fixture stand in one of the assembly workshops. That is, the materials delivery points were located in the middle of the workshops utilising automatic docking stations at the entrance of one-fourth of the assembly workshops. Thus the AGVs did not enter into the work areas disturbing the assembly work. See figure 4, which illuminates that it was possible to buffer automobile bodies in (1) the parallel automatic docking stations and (2) in-between, the two parallel work-station systems. In fact assembly work and adjustment of the complete automobile were carried out on these positions.

The assembly workshops in the Volvo Uddevalla plant normally contained eight work-station systems using one of two different layouts (figure 2). In one layout, used in the three assembly workshops first started, the automobile was assembled in two stages with one sideway transfer within the work group. Seven operators normally assembled each automobile, and the normal cycle time was about 100 minutes.

In the other (revised) layout used in the remaining three workshops, the automobile was not moved at all within the work-station system during the assembly work. At the end of the final period of full production (i.e. in 1992), normally nine operators alternated between four automobiles. The normal cycle time was about 80 minutes. Of these workshops, only workshop 4 and 5 were used for production purposes, while the sixth workshop was used for training.

In both types of assembly workshop, 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 internal work stations for subassembly, i.e. doors, engine and dashboard. These sub-assemblies were therefore integrated into the work group. There was a slight but important difference between the workshops in that specific work group members performed engine and dashboard sub-assemblies in workshops 4 – 5, while all operators performed

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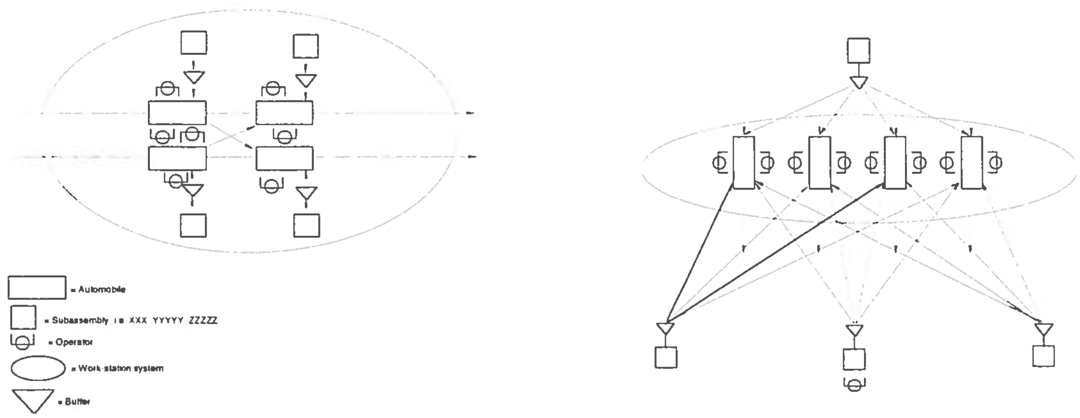
assembly work, (2) the materials display and (3) the information at the work station in form of e.g. work instructions and product variants codification. Thus will e.g. the true product variation form so-called variant tracks defining product characteristics, organised according to how explicitly those are due to the materials (components) already fitted or planned to be fitted, i.e. generativity meaning that one component fitted will define another, which in turn generates long tracks (chains) of interrelated components.

[3] The early experience from Volvo Kalmar plant highlights the practical limitations of an advanced AGV-system. The original aspirations to use the AGV-system to enable the operators to vary their work pace were soon found to be difficult to put in practice. The experiences from Arendal, Borås and Tuve, as well as the authors´ research, indicate that a less complex and expensive system for handling the products is sufficient and in most respects even superior. In the Volvo Uddevalla plant, an AGV-system was used to transfer automobile bodies and materials kits to the assembly workshops, but this was a technical overkill, a fad not really necessary. It is evident that both neglecting to use AGVs saves space and investments. In fact the Autonova plant has omitted this way transportation. The ease of use of air-cushions, as in the case in the Volvo Bus plant in Borås is in fact more flexible though requiring an exceptional clean floor which might be seen as a merit.

work on automobile bodies as well as sub-assemblies in workshops 1 – 3, allowing otherwise idle operators to temporarily perform sub-assembly work.

It should be noted that the variation in e.g. assembly sequences, were quite small even though a large variation in intra-work group patterns and work group sizes existed in the Volvo Uddevalla plant (Medbo 2001). In one extreme case, two female operators regularly assembled complete automobiles by themselves.

24 x schematised work-station systems for case #1a. 16 x schematised work-station systems for case#1b.




The Volvo Uddevalla plant (1989) assembly workshops 1 – 3. The Volvo Uddevalla plant assembly workshops 4 – 5.

Figure 2. Schematisation of the work-station systems in the different assembly workshops at the defunct Volvo Uddevalla plant. Note the extra free work positions along the automobile bodies in the workshop 1 – 3 at the second internal work stations, in fact work positions which represents assembly work of a compete automobile. This product functions as an invisible buffer, since the work corresponding to an extra automobile is "floating around" inside the work-station systems. Therefore any product inside the work-station systems is available i.e. the worker concentration (the number of operators per product) is not maximised.

## 2 METHODS AND DATA

The authors of this paper were involved in the development of materials feeding techniques, layouts, work structuring, etc. of the Volvo Uddevalla plant. That is, the design of the most critical features in the plant (case #1). During this plants total life the authors also had the possibility to collect data. This included, among other things, a survey using a questionnaire covering ergonomics, psychosocial aspects and operator competence as well as personal data concerning age, education, time of employment, gender, etc. This data collection also comprised video recordings, structured as well as unstructured interviews and storing of all relevant documentation within the plant in an archive. This archive includes approximate 2 500 binders. The results from various partial analysis of this vast amount of materials have been published in e.g. Engström, Jonsson and Medbo (1996).

In 1993, i.e. during the closing down period the questionnaire survey was carried out. The respondents to this survey were randomly selected among the approximately 800 employees by Volvo staff. The subjects answered the questionnaire anonymously during working time. A researcher explained the purpose of the study and was also present during the data collection.

The response rate was approximately 90 per cent. 97 questionnaires were returned, 6 from white-collar employees and 91 from blue-collar employees. The blue-collar employees included 21 operators working with materials handling and 68 assembly operators. The statistical analysis focuses on the assembly work and the assembly operators, since this was the most interesting category and the number of other employees in the sample was too small to permit detailed analysis.[4]

[4] The interpretation of the answers to the questionnaire must of course consider the specific circumstances during the closing-down period, which evoked indignation with the employees. This irritation may have affected the validity of

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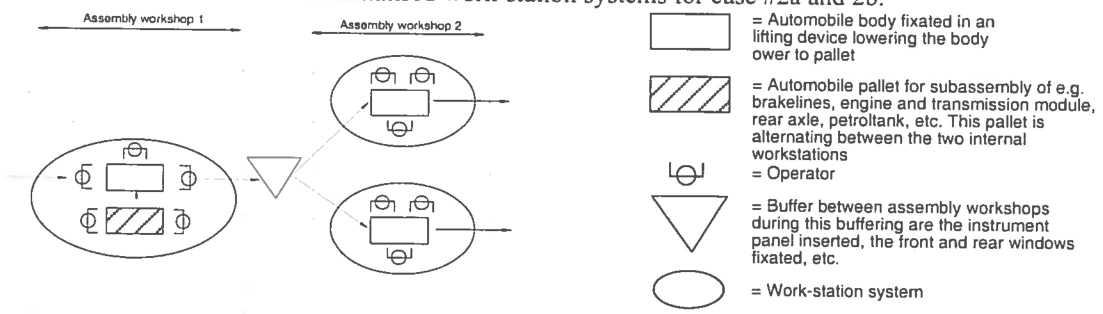
A similar state of affair regarding availability of data and joint-venture coalitions between practitioners and researchers concerns the design of the Autonova plant now belonging to the Volvo Car Corporation (case #2). In this case the authors were involved with e.g. work structuring resulting in intra-group work pattern, design of materials feeding techniques, etc. Se article by Engström, Jonsson and Medbo (2000) which explain the method used for design of assembly system used by the authors for several cases within the Swedish automotive industry. This method is based on achieving structural congruence as is briefly mentioned above.

In particular, this congruence might be formulated as a need for conformity between (a) a hierarchical product structuring scheme used to describe the product as a structured aggregate of components resulting in an assembly-oriented product structure and (b) a hierarchical assembly work structuring scheme used to describe the assembly work as a structured aggregate of assembly operations resulting in (c) the intra-group work pattern, i.e. the allocation of assembly operations expressed in so-called work modules, aggregates of work tasks, to operators within each work group responsible for the assembly as well as (d) materials display at the work station and (e) the layout and product flow pattern within each work-station system. However, it is not the purpose of this paper to explain these details. All this in order to facilitate an “orientation towards holistic learning” in form of gaining information at different precision levels, both during learning in real life situations and as a reference in the long-term perspective (Nilsson 1995).

Specifically, the Volvo Uddevalla and Autonova experiences was a long term co-operation between practitioners and researchers which involved taking part in the starting–up and running-in phases comprising various tasks such as materials flow simulations of body shop and assembly systems, education of operators, evaluation of assembly performance, etc. Concerning the other cases described in this paper they have in various forms also been involved in the authors work during more than two decades. Thus it might seam fair to say that the authors knowledge of the cases #1 – #4 are in fact quite extensive.

18 x schematised work-station systems for case #2a and 2b.




The Autonova plant in Uddevalla (1997).

Figure 3. To the right a schematisation of the work-station systems in the Autonova plant, which consists of two assembly workshops, each assembling half of the automobile. The “first” workshop has 16 parallel work groups assembling the first half of the automobile by means of a pallet, on which engine module, rear axle, petrol tank, etc, are fixed before the pallet is rolled under the body (marked as sub-assembly in the figure), which is then lowered over the pallet (i.e. marriage point). In the “second” workshop, 32 parallel work groups complete the second half of the automobile.

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some questions; especially subjective questions dealing with psychosocial work environment and job satisfaction. On the other hand, the questionnaire also included many factual questions, which might not have been heavily influenced. Since a researcher was available during the time required for answering the questionnaires and since the answers appear to reflect a serious commitment by the employees, it is the authors´ opinion that the questionnaire survey was treated as a serious investigation which quite well reflected the working conditions during the full pace production in the Volvo Uddevalla plant.

## 3 EXPERIENCES FROM THE VOLVO UDDEVALLA PLANT (CASE #1)

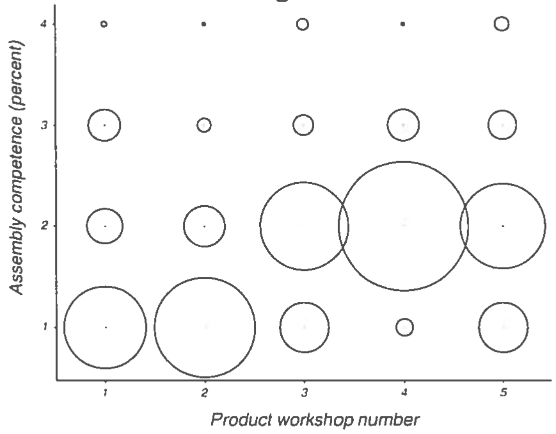
Below are the assembly competence according to the Volvo personnel statistics outlined (section 3.1), but also assembly competence according to the authors' questionnaire survey (section 3.2). In general the high assembly competence as is evident by data presented below, in the plant may to a large extent depend on the principle of pre-structuring of the components in the materials kits, constituting "structured jigsaw puzzles" thus facilitating the long cycle time assembly work.

### 3.1 Assembly competence according to the Volvo personnel statistics

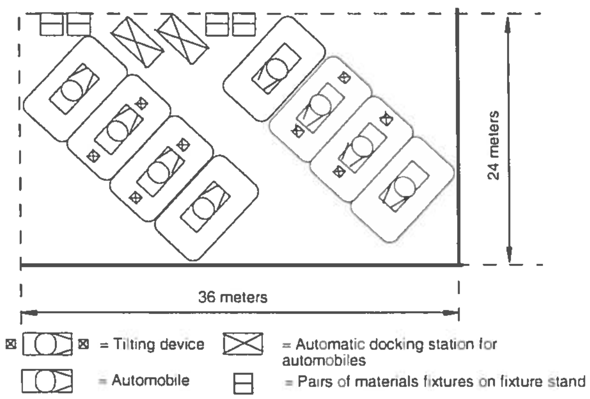
An example of analysis of these data, is presented in figure 4, which illustrates the assembly competence in the different assembly workshops. The diagram is based on wage-related personnel statistics, which divide the assembly work into four steps 29 – 40 per cent, 41 – 60 per cent, 61 – 80 per cent and 81 – 100 per cent of the work to assemble a complete automobile.

To summarise this data, 64 per cent of the assembly operators learnt to assemble at least 61 per cent of an automobile at full pace, and 4 per cent were even able to assemble complete automobiles single-handedly at full pace, which they proved by performing a special test. Note, however, that the competencies according to wage-related personnel statistics might have been slightly overrated according to the authors' interviews with the assembly operators.

Note that in this case the authors only report competence according to how the assembly operators mastered the different types of assembly work. Therefore it is called "assembly competence", thus not considering other vital aspects of competence, some of which were included in the wage system, for example, social competence in introducing new members to the work groups. The wage system was quite advanced, and it was constantly being reviewed and debated during the plant's total life. Thus successively being transformed from prioritising collective achievements on plant level down to underlining individual incentives.




Distribution of blue-collar assembly competence in the different assembly workshops.

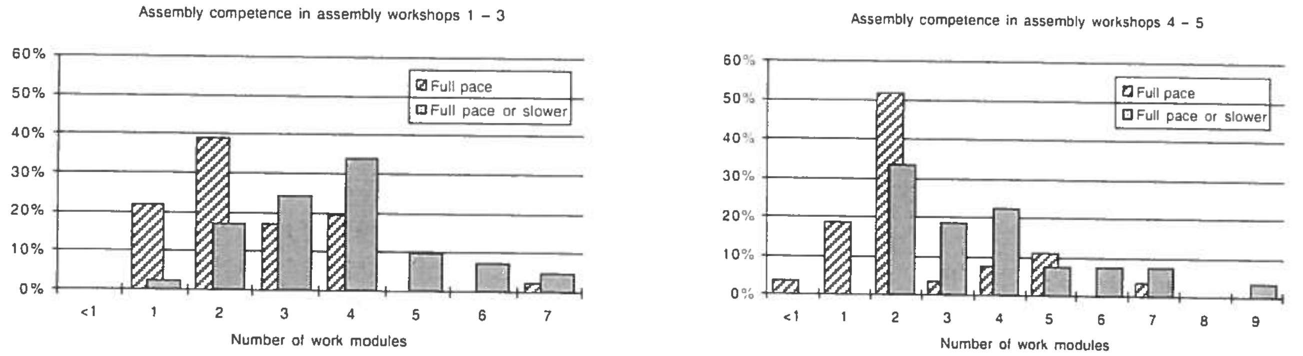



Physical layout of the Volvo Uddevalla plant assembly workshop 1 – 3.

Figure 4. To the left, distribution of blue-collar assembly competence in the different assembly workshops based on wage-related personnel statistics. Note that step 4 in the diagram equals the ability to assemble complete automobiles, i.e. 100 per cent (Engström, Jonsson and Medbo 1994) (Source of data: Volvo personal files). To the right, the physical layout of one-fourth of assembly workshop 1 – 3, organised in two parallel work-station systems. The layout in the figure occupied one-quarter of an assembly workshop. The materials delivery points were situated in the middle of the workshop both i.e. materials kits and automobile bodies, as well as the use of automatic docking stations at the entrance of one-fourth of the assembly workshop. Thus, the AGVs did not enter into the work areas, disturbing the assembly work.

3.2 Assembly competence according to the author's questionnaire survey

In the full production phase, the assembly work in assembly workshop 1 – 3 was divided into seven work modules, while it was divided into nine work modules in workshop 4 – 5. In the questionnaire survey described, the authors put the questions "Which work modules or work tasks are you able to perform at full pace?" and "Which work modules are you able to perform at a lower pace?" The number of work modules, which the assembly operators considered themselves to be able to perform, is shown in figure 5.

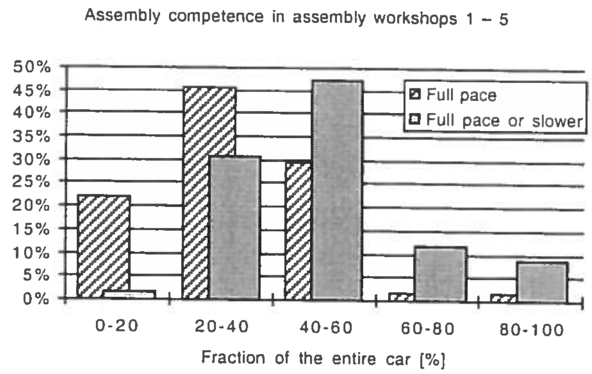



The Volvo Uddevalla assembly workshop 1 – 3. The Volvo Uddevalla assembly workshop 4 –

Figure 5. The left histogram shows the number of work modules that the assembly operators considered themselves able to perform in assembly workshop 1 – 3, n=39. The histogram shows the number of work modules that the assembly operators considered themselves able to perform in assembly workshop 4 – 5, n=27. Source of data: the questionnaire survey (Engström, Jonsson and Medbo 1996).

Figure 6 illustrates how much (in percentage terms) of the assembly work needed to build a complete automobile those assembly operators considered themselves able to perform. The percentage figure is based on the number of work modules mastered. Thus, a complete vehicle equals 100 per cent while e.g. two work modules in assembly workshop 3 equals 29 per cent of a complete automobile.

Among the respondents to the questionnaire survey, the mean self-estimated assembly competence was 49 per cent of a complete automobile, 32 per cent at full pace. Thus, the mean full pace competence corresponded to approximately 66 per cent of the mean assembly competence in a broad sense.




The Volvo Uddevalla assembly workshop.

Figure 6. Histogram of self self-estimated assembly competence for all assembly operators included in the questionnaire survey, n=68. Source of data: the questionnaire survey (Engström, Jonsson and Medbo 1996).

Figures 5 and 6 reveal a level of assembly competence previously believed to be impossible to attain in automobile assembly. For example, approximately 70 per cent of the assembly operators considered that they could assemble at least 40 per cent of an automobile while approximately 20 per cent of the assembly operators could assemble at least 70 per cent of an automobile.

Furthermore, approximately 80 per cent of the assembly operators could assemble at least 20 per cent of a complete automobile at full pace, while approximately 30 per cent were able to assembly at least 40 per cent of a complete automobile at full pace.

It should be noted that the levels of competence reported by the assembly operators themselves in the questionnaire did not exceed the competence, as assessed by supervisors and other assembly operators considered by the wage system. This latter data form the basis for the wage-related personnel statistics, as is illustrated to the left in figure 4.

This fact this might be explained by a successive "inflation" of the competence-related part of the wage system during the running-in and full production periods 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 modules mastered though not necessarily at full pace.

The relationship between blue-collar workers' characteristics and assembly competence is shown in figure 7. As discussed further below, the assembly competence increased with the time of employment. The fact that the male operators had somewhat higher competence than the female operators may be in line with expectations. More surprising is maybe the tendency that elderly assembly operators had higher assembly competence than the younger ones and that the operators without senior high school education had a higher competence than the operators with senior high school education.

| | Full pace or slower: | | Full pace: | |
|---|---|---|---|---|
| Age (< 30 years versus ≥ 30 years): | 47% | 51% | 31% | 34% |
| Time of employment (< 4 years versus ≥ 4 years): | 41%* | 55%* | 28%+ | 35%+ |
| Education (no senior high school competence versus at least senior high school competence): | 55% | 47% | 36% | 31% |
| Gender (males versus females): | 50% | 47% | 34%+ | 26%+ |

* significant p<0,01 ; + p<0,10. (t-test)

Figure 7. Assembly competence in percentage of a complete automobile in relation to background variables, n=68. Source of data: the questionnaire survey (Engström, Jonsson and Medbo 1996).

### 3.3 Comments on learning

The official learning time for individual assembly operators in the Volvo Uddevalla, plant as given by Volvo and reported by both researchers and practitioners, was 16 months. In the international debate, this extensive learning period has been underlined as a disadvantage. This may be a hasty conclusion, however. The fact was that the government financially supported a 16 months training program, but this did not necessarily mean that long learning time was required.

It should also be borne in mind that much training occurred simultaneously with the starting up and running in of the five assembly workshops. During the first years of operation, there were indeed no fully developed work methods to learn. Learning was an open-ended process that should not be compared to training in performing well-specified work tasks, supported by extensive manufacturing engineering work.

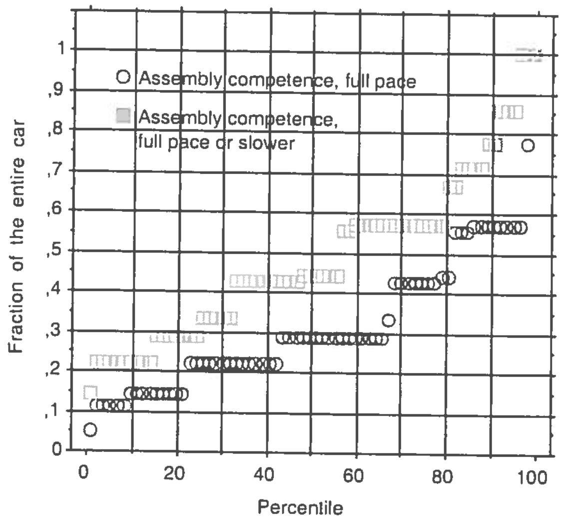
The learning times during the last period of production with a stable workforce and reasonably stable work preconditions can be illustrated by the fact that, according to the authors´ interviews, a person who was already able to assemble about half of an automobile required one extra week to learn 10 to 15 per cent more (i.e. approximately one additional hour of assembly work).

In one case, a work group from the materials workshop was able to build three automobiles day, i.e. 3/4 of the specified full production pace, after a learning period of about four weeks. This suggests that collective competence was probably just as important as individual competence.

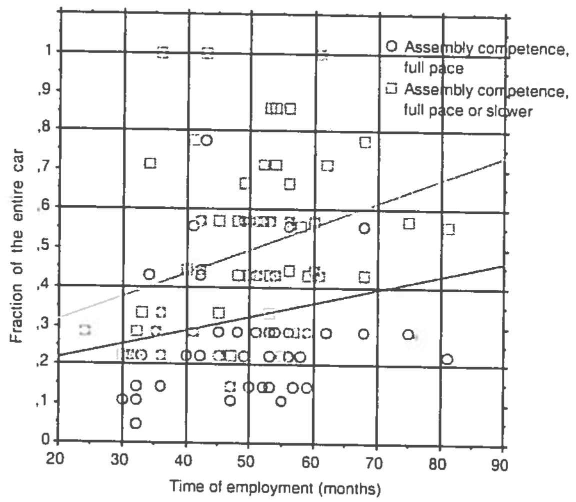
A fair estimation of the learning time required for a newly recruited assembly operator should, according to the authors′ experiences be about one month for learning 25 per cent of a complete automobile at full production pace, provided that the individual is assigned to a competent work group. In this case, 4 – 5 days of pre-learning before beginning group work would be necessary.

Figure 8 shows self-rated assembly competence (i.e. how large part of an automobile an assembly operator can assemble single-handedly) as a function of time of employment at the Volvo Uddevalla plant. There was a positive correlation between time of employment and assembly competence in the wide sense (r=0.31), and a weaker correlation (r=0.21) between time of employment and full pace assembly competence. On the other hand, figure 8 also shows that the individual variation in assembly competence and speed of learning was large. Only 5 per cent of the variation in full pace competence, respectively 10 per cent of the variation in assembly competence in a broad sense, was accounted for by the variation in time of employment.

While the assembly competence is impressive compared to the corresponding competence among assembly line operators, and also compared to what has been believed to be possible to learn, the authors' would not draw any conclusions about the potential for learning from the data. These data, however is believed, to not primarily reflect the potential for learning long cycle time assembly work but the requirements and incentives for learning in the Volvo Uddevalla plant. The authors believe the potential for learning to be greater than what is suggested by figure 8 since this specific plant was in fact not fully developed. Note also that all assembly operators had been employed for at least 30 months. However, the data certainly illuminates some interesting points of departures concerning learning of long cycle time assembly work. Experiences such as the influence of various approaches to learning represented by the different assembly workshop managers initiates are e.g. explained in Engström et al. (1995)




Cumulative distribution of self-estimated assembly competence for assembly operators.




Relationship between time of employment and assembly competence.

Figure 8. Cumulative distribution of self-estimated assembly competence for assembly operators regarding the relationship between time of employment and assembly competence. Assembly operators, n=68. Source of data: the questionnaire survey (Engström, Jonsson and Medbo 1996).

## 4 THE FOUR CASES COMPARED

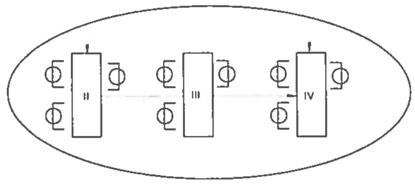
During the mid 1970s, Volvo established a bus factory in Borås, and the experiences from Arendal indicated the potential of non-traditional production principles and work organisations. In the Volvo Bus plant, four parallel so-called "three-stage docks" were used (see figure 9). The chassis were moved five times during the assembly, but the possibility to buffer chassis between internal work stations, as in the Arendal assembly workshop, was missing.

One important argument, in this specific case, for not using a traditional assembly line for buses was the fact that buses are manufactured in smaller series and in a wider range of product variants than is the case for automobiles or even trucks. The pre-production and manufacturing engineering work necessary for each product variant on a traditional assembly line would have been time-consuming and expensive.

Initially, production in the Volvo Bus plant encountered some problems, mainly concerning quality. The main causes of these problems were that the training and education of the people involved in the design and running-in period had been neglected. For some time, the possibility to replace the "three-stage docks" with an assembly line was considered. After three years of production, the productivity and quality achieved in the bus plant increased substantially, however. This improvement occurred during a short period of time. Eckerström and Södahl (1981) reported that production in Borås was 26 per cent more efficient than traditional line assembly, but they were unable to provide any theoretical explanation for this phenomenon.

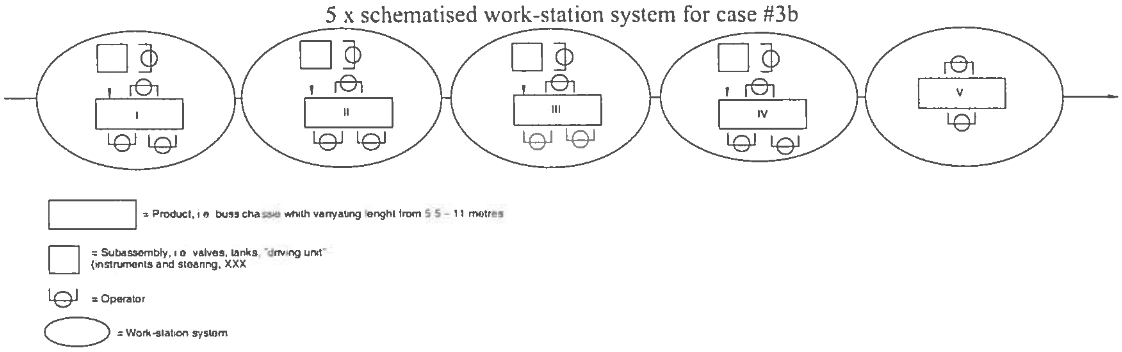
The rise in productivity in the Volvo Bus plant was generally met with scepticism within Volvo Corporation, but nevertheless the experience influenced the then ongoing design of the truck factory at Tuve, as it indicated the need for buffers in the product flow. It also provided a source of inspiration for Saab-Scania's final assembly plant for buses in Katrineholm, which represented an improvement since in this case intermediate buffers were introduced. The main Volvo Tuve plant, however, with two assembly lines represented an assembly system design in-between the Volvo Bus plant and a traditional design.

4 x schematised work-station system for case #3a




The Volvo Bus plant in Borås (1978).

5 x schematised work-station system for case #3b




The revised Volvo Bus plant in Borås (2000).

<u>Figure 9</u>. On top is a schematised work-station system of the Volvo Bus plant in Borås (1978). In bottom is a schematised revised layout of the Volvo Bus plant in Borås, (2000). In the latter case five of these work-station systems are now used, while the early plant design comprised four work-station systems grouped around a each other, forming a quadrangle thus promoting intra-work-station system overview. This overview is not present in the revised layout there, by the way, the five serial flow assembly systems are organised primarily in accordance to specific customers, i.e. coach builders, and secondly in accordance to product design. In order to illuminate that e.g. the actual work content in the two types of work-station systems, the roman figures approximately defines what work is similar. The initial assembly on the frame was carried out outside the work-station system in the early layout, similar as the adjustment and quality control on the completed bus chassis. It must also be noted that the number of product variants and product complexity has increased substantially during the last 20 years, as is also the case with the Volvo trucks.

The Volvo truck assembly workshops in Tuve was introduced in 1991 as a complement to the more traditional assembly lines. This was initially a two-stage dock, in many respects similar to the one used 17 years earlier in the Arendal assembly workshop. The truck is assembled on two internal work stations by five operators in each station. Six additional operators in each work-station system perform inspection and repair, serves as team leaders, etc. Engine subassembly is integrated into the work-station system (see figure 9).

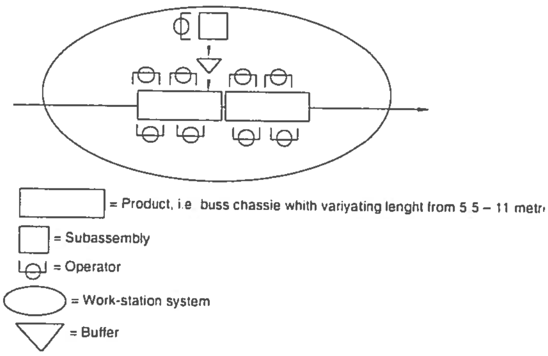
In this context it also ought to be mentioned that the designers of the original Volvo truck assembly in Tuve, which from the start in 1981 comprised two assembly lines, did not have any theoretical explanation as to why extended cycle times sometimes proved viable and sometimes not. The cycle time in the Volvo Bus plant in Borås was two hours, but this plant had some quality problems during the period when the Tuve plant was being designed. As a compromise, a cycle time of 40 minutes was chosen in Tuve. Experience from the Volvo Bus plant had shown that intermediate buffers were necessary, and this was the reason for using a great deal of space for buffers in the Tuve plant, i.e. the work-station systems along the assembly line was intersected with intermediate buffers.

During recent years, the original Tuve assembly lines have been modified. Today, the two lines for the assembly of chassis, on the other hand, are still intact, but the intermediate buffers has been removed combined with an extension of the assembly lines into 39 work stations with a cycle time of 15 minutes. Initially, in 1981, the assembly lines comprised four work-station systems in series intersected by buffers, each work-station system comprising two trucks in series with a worker concentration of three operators per chassis (see Engström, Jonsson and Johansson 1996).

*

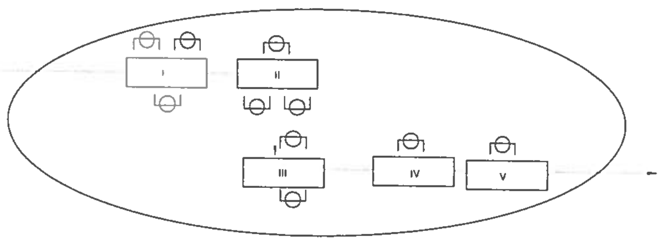
The Tuve assembly workshops was later modified and the number of workshops was also increased due to expanded production volumes. It ought to be noted that these assembly workshops help to smooth the flow on the two assembly lines, since the most complex trucks are assembled in these workshops.

2 x schematised layout #4a




The Volvo Truck assembly workshops in Tuve (1991).

6 x schematised layout #4b




The revised Volvo Truck assembly workshops in Tuve (2000).

Figure 10. To the left, schematised layouts of Volvo Truck workshops in Tuve introduced in 1991. Two of these work-station systems was initially used at the introduction, which was latter expanded into six parallel workshops. To the right, a schematised revised layout from Volvo Truck assembly workshops in Tuve (2000). Note that the operators are re-painting and test-driving the trucks on both a rolling road and outside. Thus, the trucks are completed by adding oil, petrol and other media within the work-station systems. The materials are delivered from the left to the product flow, while the complete vehicle is delivered by the assembly operators to a outside courtyard situated directly outside the assembly workshops.

| | The Volvo Uddevalla plant (case #1): | | The Autonova plant (case #2): | | The Volvo Bus plant in Borås (case #2): | | The Volvo Truck assembly workshops in Tuve (case #4): | |
|---|---|---|---|---|---|---|---|---|
| | Layout #1a | Layout #1b | Layout #2a | Layout #2b | Layout #3a | Layout #3b | Layout #4a | Layout #4b |
| Cycle time [min.]:* | 80 | 100 | 90 | 150 | 180 | 90 | 240 | 240 |
| Number of operators per work-station system: | 7 | 9 | 5 | 3 | 9 | 23 | 10 | 9 |
| Worker concentration:** | 1.8 | 2 | 2.5 | 3 | 3 | 3 | 4 | 3 |
| Integrated sub-assembly stations: | Yes | Yes*** | No**** | No | No | Yes | Yes | No |
| Materials feeding technique for large components: | Materials kits by AGVs **** | Materials kits by AGVs | Materials kits by truck train | Materials kits by truck train | Traditional | Traditional | Traditional | Traditional |
| Materials feeding technique for semi-large components: | Materials kits by AGVs | Materials kits by AGVs | Materials kits by AGVs | Materials kits by AGVs | Traditional and materials wagons ***** | Traditional | Structured kits | Structured kits |
| Materials feeding technique for small components: | Plastic bags | Plastic bags | Small plastic containers | Small plastic containers | Traditional | Traditional | Traditional | Traditional |
| Space for work-station system [square metres per operator]: | 53 | 36 | 19 | 16 | 46 | 37 | 66 | 73 |
| Production capacity (number of products per year] | 700 | 900 | 900 | 450 | 900 | 900 | 450 | 700 |
| Means of transportation of products to the works-station systems | AGVs | AGVs | Truck | Truck | Air cushions | Air cushions | Truck | Truck |
| Means of transportation of products to and within the works-station systems: | Manual wagons | Manual wagons | Manual wagons | Manual wagons | Air cushions | Air cushions | Manual wagons | Manual wagons |

* For assembly operators.
** Number of operators per product performing assembly work.
*** A pallet, of the size of an automobile is used for fixating of engine module, rear axle, petrol tank. The pallet is rolled under the body, which is lowered over the pallet (i.e. marriage point), thereafter, the assembly work proceeds.
**** The materials kits are structured to facilitate learning.
***** The materials wagons were used for learning since the newly employed operators first learned to pick components at the materials store and thus later to assemble on the various internal work stations or vice versa (see Kjellberg and Sjösten 1979).

Figure 11. Table stating some key figures defining assembly system designs.

The cases described above provide an important input for the ongoing discussion of the merits of assembly systems with autonomous work groups and long cycle time as compared to the traditional assembly line.

It is evident that buffers between work-station systems, as well as buffer volumes within work-station systems, improve the performance of the assembly system as well as the psychosocial work environment. However, buffers between numerous work-station systems, each assembling, for example half of the product, as in case #2, are in fact a necessity.

In general, it is wise to deliberately introduce a certain slack in the form of non-occupied working positions along the product and/or at subassembly stations rather than to maximise the production output at the expense of this slack. Other measures to take account of this slack are, for example, the introduction of indirect work (administrative tasks or maintenance work, use of subassembly stations, etc.). According to the authors′ experience, this increase in buffer volumes leads to a relatively negligible increase in capital cost for materials in relation to profits in the form of e.g. reduced production losses. Such buffer volumes are not to be confused with buffer stocks of components, automobile bodies, complete automobiles, etc. often found outside the assembly area.

Furthermore, it is preferable to have many work-station systems in parallel, since there is then less need for buffering of e.g. products between sequential work-station systems and the flexibility also increases through the opportunity to re-sequence products within the work-station systems on different levels, as was the case for the Volvo Uddevalla plant, i.e. re-sequencing of automobiles on assembly works shop level, between work-station systems within an assembly workshop, at the automatic docking stations at the entrance to the work-station systems, the area between the automatic docking stations and the work station systems, and finally by utilising the parallel internal work-station systems. Note that a similar re-sequencing procedure was also available for the automobiles leaving the work groups. That is, the automobiles not fully completed were allowed to be re-sequenced to enable them to be further worked upon if necessary For example, a product that requires prolonged assembly work could remain accessible longer than other less demanding products, which can be allowed to proceed.

| | The Volvo Uddevalla plant (case #1): | | The Autonova plant (case #2): | The Volvo Bus plant in Borås (case #2): | | The Volvo Truck plant in Tuve (case #4): | |
|---|---|---|---|---|---|---|---|
| | Layout #1a | Layout #1b | Layout #2a and b | Layout #3a | Layout #3b | Layout #4a | Layout #4b |
| Number of work-station systems in sequence: | 1 | 1 | 2 | 1 | 5 | 1 | 5* |
| Number of work-station systems in parallel: | 24 | 16** | 16 and 32 | 4 | 6 | 2 | 6 |
| Buffers between work-station systems (capacity/type): | Not relevant | Not relevant | Yes (used by all work-station systems) | Not relevant | Not relevant | Not relevant | Not relevant |
| Buffers within work-station systems: | Yes | Yes**** | No***' | No | No | No***** | No***** |

* In this case are the intentions to amalgamate the five work-station system into one system by promoting surplus competencies.
** The plants sixth assembly workshops was never used for full production but for training purposes for e.g. assembly operators who was on sick leave, in military service, giving birth to children.
*** Note that, in the Volvo Arendal case there was a possibility to buffer one chassis in an aisle between the two stadges, as mentioned above.
**** Specifically this assembly system design includes buffer functions in form of (1) the parallel automatic docking stations and (2) space in-between, the two parallel work-station systems. In fact, assembly work and adjustment of the complete automobile were carried out at these positions.
***** The zigzagged product flow has same extra space usually utilised for the materials kits. The proximity to the outside courtyard combined with the facts that the trucks are completed and running introduces e.g. extra flexibility.

Figure 12. Some characteristics regarding assembly system design for cases #1 – #4.

In the case of the Volvo Uddevalla plant the materials workshops functioned as a serial flow delivering materials kits according to a defined production sequence. However, this sequence was often formally changed for a number of reasons, like lack of appropriate components, inferior automobile bodies, etc. i.e. disturbances that were noted in advance. This pre-planned sequence imposed severe restrictions on the work groups, who obviously could not assemble without materials (each automobile called for exactly the right components being contained in three separate materials kits). Thus, the queue of materials kits had to be synchronised to the planned production sequence of the work groups. However, within the frames of this synchronisation, unplanned and informal re-sequencing in fact occurred often, especially concerning the automobiles leaving the work-station systems.

## 5 CONCLUSIONS AND FINAL DISCUSSION

Some people have regarded the assembly operators in the Volvo Uddevalla plant as "professionals" or as "craftsmen", and their work has been characterised as "skilled work" or as "neo-craftsmanship" (Womack et al. 1990). This is a natural view considering the length of the cycle times in the assembly workshops. The assembly operators' cycle time was approximately 100 times longer than in traditional line assembly. It is wrong, though, to assume that the assembly work in the Volvo Uddevalla plant was "100 times more difficult" than traditional assembly work. As discussed elsewhere (e.g. Engström and Jonsson 1993), the assembly work in the Volvo Uddevalla plant was qualitatively different from short cycle assembly work.

The assembly operators' estimates of competence requirements do support this theory. According to the questionnaire survey, almost nobody considered the assembly work to demand "very high" intellectual competence, and only a few assembly operators (10 per cent) considered the assembly work to demand "very high" manual competence. Note that the need for socio-emotional competence was perceived to be somewhat higher than the need for manual competence. This could be interpreted as indicating that the co-operation within the work groups was experienced as more demanding than the assembly work (see Engström, Jonsson and Medbo 1996 for further details).

In the recent Swedish debate, competence development has been seen as the key to individual success on the labour market as well as to increased competitiveness for the Swedish industry. At the same time, competence development has been treated as more or less synonymous with formal education (SOU 1992:7).

According to the questionnaire survey, most assembly operators in the Volvo Uddevalla plant (approximately 80 per cent), irrespective of level of education, considered themselves to have sufficient education for the work. It was also evident, however, that there was no positive correlation between time of education and assembly competence. What happened in the Volvo Uddevalla plant was probably that generic, inherent skills specific to the human being, especially cognitive skills, were far better utilised than is usually the case for blue-collar workers within the automotive industry. The assumption that a long formal education is a necessary precondition for being able to make an adequate contribution in the factory of the future is thus not necessarily correct. It is a much safer prediction that the ability to take advantage of innate human capabilities will be of critical importance as a means of competition.

However, this will, in the case of assembly work, call for some intriguing assembly system designs concerning various aspects of buffer functions and layout planning, which in the extreme case also calls for some sophisticated materials feeding techniques, matters that have only been touched upon in this paper. These matters have been illuminated by means of the cases reported above. They represent insights gained within Swedish industry going back more than thirty years. Experiences that today, in most respects, seem to have vanished.

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