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CONTENTS

ILLUMINATING AND ANALYSING THE PERFORMANCE OF THE CLOSED DOWN VOLVO UDDEVALLA PLANT

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ABSTRACT:
The closing down of the Volvo plant in Uddevalla in 1993 stirred up an international debate since this plant was in many respects a full-scale symbol of the sociotechnical system design approach. The plant utilised a parallel product flow and long cycle time assembly work combined with unorthodox materials feeding techniques (i.e. kitting of materials). Sceptics proclaimed "the death of the Swedish experiments", thereby in the authors' opinion revealing, among other things, a lack of the appropriate manufacturing engineering knowledge concerning this type of assembly system design. However, the performance of this specific plant was, despite criticism and various public misunderstandings, in fact, substantially exceeden that of the traditional assembly line manufacturing in the Volvo main plant, viz. 2 – 4 hours per automobile manufactured, according to the authors' video recordings. Unfortunately, this fact was not fully understood or correctly communicated.

This paper will specifically illuminate various aspects of assembly system performance aspects by means of simulations, taking advantage of secondary data such as predetermined motion and time systems, budget figures, etc. and by means of direct observations on the shop floor. This performance can be expressed as time losses in relation to a hypothetical assembly system or as man-hours per product assembled. The man-hours could be defined on different levels, such as (1) total blue-collar man-hours in assembly workshops, obtained from weekly man-hour reports from the assembly workshops, and (2) assembly man-hours in assembly workshops, measured by video recordings, and finally (3) total blue-collar man-hours for the entire Volvo Uddevalla plant, obtained from weekly man-hour reports.

For example, the observed assembly man-hours in the assembly workshops (1) constituted less than 30 per cent of the total blue-collar man-hours of the entire Volvo Uddevalla plant, while the total man-hours in the assembly workshops constituted less than 50 per cent of the total blue-collar man-hours of the entire plant.

The paper also reports on other merits of parallel product flow, long cycle time assembly systems concerning product quality and flexibility aspects. The latter concerns annual model change cost, need for tools and fixtures as well as space requirements.

The assembly performance of the plant was, in fact, also higher than stipulated, according to predetermined motion and time systems on an individual level. This efficiency was gained in a plant not fully developed in various aspects. Especially, the manufacturing planning and control system proved to hamper the total performance, as is explained in the paper. Although some methodological problems regarding the data presented remain, these data certainly illuminate the potential of the parallel product flow and long cycle time assembly work, all consistent with earlier theoretical and practical frames of reference.

1 BACKGROUND

The birth of the unorthodox assembly system design of the Volvo Uddevalla plant in 1988 stirred up some international interest from the start as did its closing down in 1993. Both resulted in an international debate (e.g. Sandberg 1995) including the questioning of the actual assembly system design. A question asked was: Can the closing-down decision be interpreted as criticism of the manufacturing principles applied or were there other reasons? Whatever the case, the performance aspects and other merits of parallel product flow, long cycle time assembly systems, combined with unorthodox materials feeding techniques (i.e. kitting of materials), call for some clarification. This since, among other things, in the authors' opinion, the criticism displays a lack of adequate manufacturing engineering knowledge concerning this type of assembly system design.

The closed down Volvo Uddevalla plant's mode of operation was, however, as will be explained in this paper, far from optimal in several respects. It is the authors' considered opinion, based on their involvement in the design of the Volvo Uddevalla plant and their prolonged research collaboration with the personnel at this plant and other Volvo facilities, that the "proper way" to operate the plant was not fully understood during the running-in and full-scale production phases. In fact, even today, the experiences from the Volvo Uddevalla plant are not fully analysed or understood by practitioners and researchers. Nevertheless, the experience from the Volvo Uddevalla plant underlines the fact that it is possible to create efficient work that is humane. It provided proof based on full-scale production of the efficiency of parallel product flow, long cycle time assembly systems. Note also that the parallel product flow manufacturing principles were utilised with success in the Saab Scania's body shop in Trollhättan during the 1970s (Karlsson 1979), while the Volvo Uddevalla plant experience also confirmed the earlier assumptions about the saving in terms of space and number of tools compared to the assembly line.

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The Volvo Uddevalla plant had six parallel assembly workshops with parallel work groups. 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 groups 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.[1] 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.

The assembly workshops in the Volvo Uddevalla plant normally contained eight work groups using one of two different layouts (figure 1). 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 groups 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.

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[1] 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 realise. The experiences from Arendal, Borås and Tuvein 1991, as well as the authors' research, indicate that a less complex and expensive system for handling the product 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 Buss plant in Borås is in fact to be a much more flexible. Admittingly requiring an exceptional clean floor which might be seen asn a merit.

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

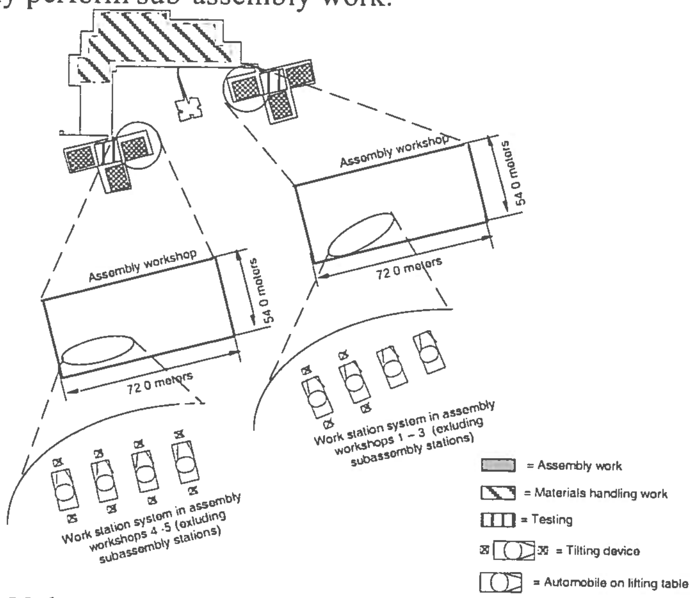

Figure 1. Layout of the Volvo Uddevalla plant assembly work shop 1 – 3.

2 FRAMES OF REFERENCE REGARDING PERFORMANCE ASPECTS

Traditionally, manufacturing engineers use mean operation times based on predetermined motion and time systems when calculating the cycle times, thereby neglecting the fact that operators have an inherent variation in pace and efficiency in the performance of repetitive work. Such variation in time required for assembly work occurs both as inter-operator variation and as intra-operator variation, i.e. variation between operators on the same assembly line and variation between successive work cycles for a particular operator. Furthermore, the amount of assembly work to be performed at each work station will vary between work cycles and work stations due to different product variants. There will also be process variation due to tools and mechanised equipment, etc.

In line assembly, inter-operator or intra-operator variations are normally not taken into account. As a result, if the time the product is available at a work station is equal to the mean time needed to complete the work tasks assigned to that work station, which means that inter-operator and intra-operator variation is neglected, idle operator time will occur in some cases while unfinished work will result in other cases. If the production pace is increased, idle time will decrease whereas unfinished work will increase; if the production pace is decreased, unfinished work will decrease whereas idle time will increase (the allocation of work tasks to work stations is often based on the product variant requiring most work, i.e. the most time consuming product variant will pace the product flow). Thus, it is possible to define time losses as added upon the value-adding time such as net assembly time, i.e. provided that the operator assembled the complete product and got the appropriate tools and materials in his or her hands at the right moment. The definitions include losses, such as balance loss (difficulties experienced by operators during the work cycle), division of labour loss (the shorter cycle time, the larger the proportion of the work cycle that is utilised for handling of materials and tools) and system loss (based on the fact that the time distribution of a non-machine paced operator is skewed and not normal as is usually assumed, e.g. Dudley 1968), which is consistent with the findings of Wild (1975). This way of assessing performance aspects as the relations between value and non-value adding activities is in many respects a more constructive way than, as is usually the case within the automotive industry, to solely base the performance evaluation on man-hours used, i.e. dividing the number of employees by the number of product manufactured.

The important conclusion is that line assembly systems – in fact any assembly systems that fail to accommodate inter-operator and intra-operator variation – generate idle operator time and/or need for re-work. In both cases, time is lost, that is productivity suffers see Wild (1975) and Rosengren (1982) which are based on computer simulations.

The authors have, over the years, estimated time losses for various assembly systems designs by simulations, taking advantage of secondary data such as predetermined motion and time systems, budget figures, etc. and recently by means of direct observations on the shop floor.

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There are several approaches/methods of avoiding these time losses. Four main approaches will be considered for reforming the assembly line, namely:

1 To reduce intra-operator variation through standardisation of product and work, e.g. through reducing product variation, enforcing standardised work methods, improving component quality, selective recruitment of assembly operators, etc.

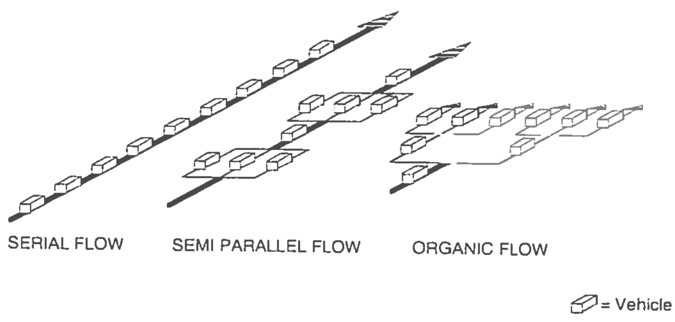
2 To introduce so-called collective working with a flexible division of labour between work groups of operators, so that operators can use otherwise idle time to help other operators.

3 To introduce intermediate buffers between operators or work groups, consisting partly of completed products that absorb inter and intra-operator variation in required assembly time.

4 To break up an assembly line into many short, parallel product flows with non-machine paced flows. As mentioned above, production time losses in a non-machine paced flow tend to increase with the number of operators along the product flow. This means that decreasing the number of operators along each flow can decrease time losses.

Note that these four approaches/methods do not rule each other out, making it possible to combine two or more approaches. On the other hand, when time losses have been reduced through the application of one method, there is less need to use another. For example, when variation in required assembly time is reduced by standardisation in a specific assembly system, it might not be worthwhile to reduce time losses further through the use of buffers, group work or parallel product flow, since this requires extensive re-engineering, although these arrangements may serve other important functions. It should be noted, though, that some of the production time losses are generated by human variation which, in fact, can never be eliminated.

Conversely, in parallel product flow assembly systems (with only one work station in each flow), variation in required assembly time does not generate time losses. This makes it futile to try to reduce that variation in order to reduce time losses.



	Serial product flow	Semi-parallel product flow	Organic product flow
Balance loss:	30	15	5
Division of labour loss:	25	20	15
System loss:	80	30	20
In total:	135	65	40

Figur 2. Time losses for different assembly system designs in accordance with Wild (1975), based on secondary data. The compared assembly systems designs represent three real assembly systems that are normalised regarding, for example, subassembly work and the product's influence on manufacturability. The systems represented are: the serial product flow of the Volvo Torslanda plant, the semi-parallel product flow of the closed down Saab Automobile plant in Malmö, and the organic product flow of the closed down Volvo Uddevalla plant (Ellegård et al. 1992).

3 SOME GENERAL CONSIDERATIONS CONCERNING PERFORMANCE ASPECTS OF THE VOLVO UDDEVALLA PLANT

Industrial decision-makers and researchers alike are generally interested in comparative evaluations of e.g. assembly system designs and manufacturing principles. A key issue in the assessment of manufacturing principles is productivity. For example, Womack et al. (1990, pp 102) claim that "the productivity of the Uddevalla system is almost certain to be uncompetitive even with mass production, much less lean production".

Womack et al. (1990) also claim that so-called lean production is much more efficient than other manufacturing models in the automotive industry. This claim is based on estimates of man-hours worked per product manufactured in a world-wide sample of assembly plants. Unfortunately, their measurement process is inadequate in several respects. As discussed in detail by Jonsson (1995), the International Motor Vehicle Program (IMVP) failed to pay sufficient attention to a number of aspects that significantly affect man-hour counts. These aspects include manufacturability of products, product variability, extent of out-sourcing, degree of automation, work intensity, overtime and capacity utilisation. As a result of insufficient attention to these factors as well as other problems (Jonsson 1995), the estimates of man-hours worked per product manufactured reported by Womack et al. (1990) are likely to be grossly distorted. With the measurement approach used, this is indeed almost unavoidable.

From a productivity measurement point of view, Womack et al. (1990) treat the manufacturing system in a sense as a black box. They do not discriminate between line assembly and parallel product flow assembly, as hinted above; in fact, there is no indication that they are aware of the theoretical frames of reference outlined above. They do not discuss e.g. product flow, standard assembly times based on predetermined motion and time systems, work cycle time variation or other statistical process parameters. They simply treat man-hours worked and products manufactured as input to and output from, respectively, a manufacturing system, multiply the man-hour counts by ad hoc correction factors and compute input/output ratios (Krafcik 1988). The productivity of different manufacturing systems can then be compared only on the generalised ceteris paribus assumption that "all other things" than man-hours worked and units produced are equal or have been taken into account by applying appropriate correction factors.

Needless to say, the truth of such an assumption is hardly ever guaranteed, particularly not if plants producing different products are compared. To check estimates of input/output ratios, it is essential to "look into" the black box as well and to investigate the internal workings of the assembly system. Two of the three approaches mentioned above for doing this will be briefly elaborated below. Namely, direct observations, where one sub-approach consists in simply observing assembly operators so as to determine the time actually needed to complete various work tasks and to compare the empirical work cycle times with standard assembly times based on predetermined motion and time systems. To make this method practical, the authors have used a camcorder to register assembly work and analysed the video recordings by means of specially developed video-synchronised computer equipment, as described below (Engström and Medbo 1995).

Another approach is by simulation, i.e. to model the assembly system as a stochastic process, i.e. to represent it by a mathematical model based on probability theory. Various performance parameters can then be estimated either analytically or by means of computer simulations. This approach takes different product flows into account but requires that certain statistical parameters pertaining to the assembly process are known (e.g. means and variances of events such as work cycle time and machine time distributions).

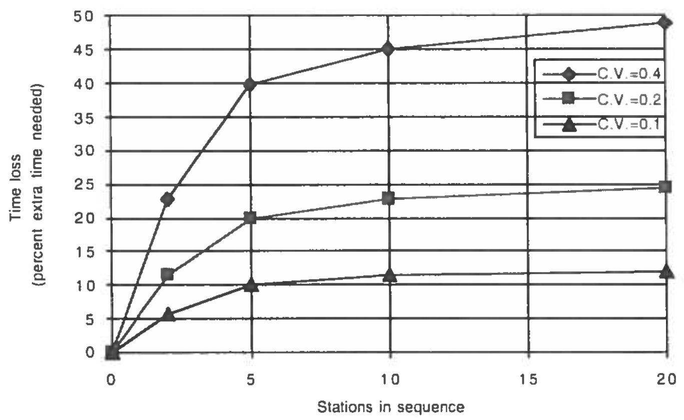


Figure 3. So-called system losses due to intra-station variation in assembly time, according to the length of the line and the coefficient of variation (C.V.) for the assembly time, at each work station (Engström, Jonsson and Medbo 1996).

To provide a quantitative illustration of time losses in serial product flow assembly systems, the authors have performed simulations of non-machine paced assembly lines of moderate length with different amounts of relative intra-station variation in assembly time. It should be noted that the time losses according to figure 3 are due to intra-station variation in assembly time and do not include losses due to inter-station variation in assembly time.

While these simulations map non-machine assembly lines, a similar analysis applies to paced assembly lines. In this case, there is a strong pressure to keep up with the pace of the assembly line. This does not mean that time losses are eliminated. However, working "too fast" or "too slow" leads to adverse effects in efficiency terms. For example, working "too fast" may generate re-work at the end of the assembly line.

To some extent, it is possible to reduce intra-station variation in assembly time by reducing product variation, e.g. by including all "options" in all automobiles or by combining options into a few "packages". This means, however, that customers have to buy what the manufacturing system is good at producing rather than the manufacturing system being good at producing what customers want. The resulting "invisible cost" in the form of lost revenue is not evident from calculations of assembly man-hours per automobile, but may nevertheless be considerable.

3.1 Blue-collar assembly workshop man-hours per automobile gained through secondary data

Weekly man-hour reports from the assembly workshops in the Volvo Uddevalla plant provided one basis for productivity assessments. Each week, mean assembly workshop blue-collar man-hours per automobile were reported for each work group. Thus, each data point represented the mean assembly workshop man-hours reported for automobiles assembled by a particular work group during a particular week.

The data reported below are based on man-hour reports for automobiles assembled from August 1991 to October 1992. In the beginning of November 1992, the decision to close the plant became known, and for obvious reasons productivity decreased sharply.

As shown in figure 4, mean assembly workshop times were reduced from approximately 25 hours per automobile to approximately 17 hours per automobile during the course of 57 weeks. Thus, roughly every third man-hour was eliminated within little more than one year. There was an even progression during the period considered. Thus, the conjecture that the productivity increase in the Volvo Uddevalla plant was "crisis learning" due to the threat of an imminent close-down (Adler and Cole 1995) is not supported by these data.

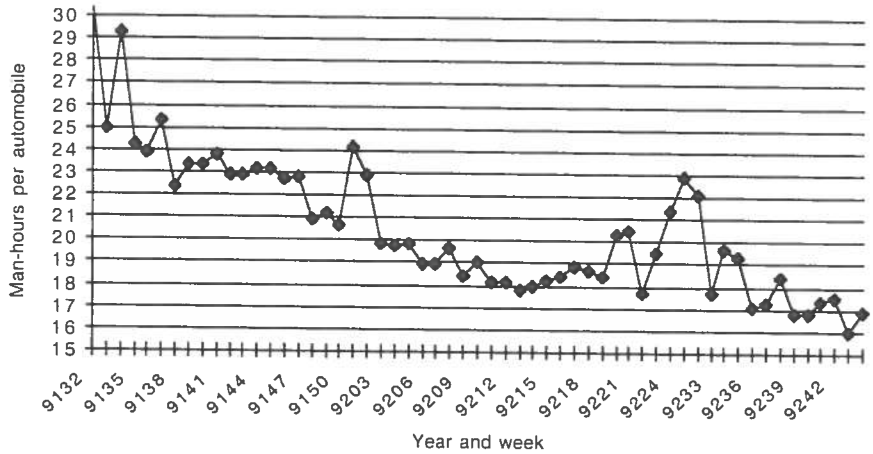


Figure 4. Weekly mean total blue-collar assembly workshop man-hours per automobile in assembly workshops from week 32, 1991, to week 44, 1992. Data from week 31, 1991, were also available but were not included in order not to exaggerate the rate of productivity increase. This was the first week after the summer vacation and also the week when annual product changes were introduced. The apparent lapses in productivity around week 32, 1991, week 02, 1992, and week 32, 1992, may be attributed to periodical product changes (Engström, Jonsson and Medbo 1996). Source of data: the Volvo Uddevalla archive.[2]

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There were six or seven work groups in each one of the five assembly workshops running at full production pace in the Volvo Uddevalla plant. As shown in figure 5, the mean assembly time varied considerably between work groups – between 16.1 and 27.3 blue-collar assembly workshop man-hours per automobile for the period August 1991 – October 1992 and between 14.7 and 22.4 man-hours per automobile in October 1992. Also note that the increase in the assembly plant productivity, as shown in figure 4, is reflected in the work group data presented in figure 5.

[2] During the closing down period, the author had the opportunity to collect all documents from the Volvo Uddevalla plant. These documents are now stored in an archive at Chalmers University of Technology.

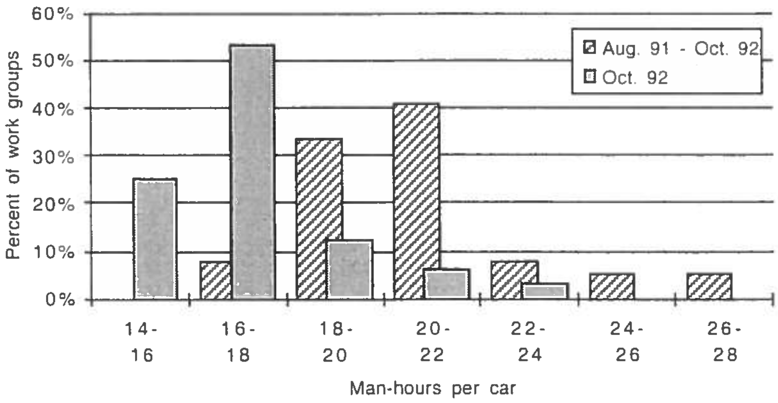

Figure 5. Work groups' mean blue-collar man-hours per automobile in the assembly workshop, according to weekly man-hour reports. Data for August 1991 – October 1992 are based on 39 work groups, while data for October 1992 are based on 32 work groups (Engström, Jonsson and Medbo 1996). Source of data: the Volvo Uddevalla archive.

The assembly workshop man-hour counts, used in figure 5, may be compared to expected man-hour counts according to the man-hour budget in the Volvo Uddevalla plant. The budgeted man-hours per automobile varied according to the work volume represented by each particular automobile, as estimated by predetermined motion and time systems. Furthermore, the budgeted man-hours per automobile were reduced successively, as the plant was considered still to be in the breaking-in phase.

In figure 6, productivity goal attainment has been calculated by dividing the budgeted blue-collar assembly workshop man-hours per automobile by the actual man-hours per automobile. As evident from figure 6, the rate of productivity goal attainment varied significantly between work groups. While the mean rate of productivity goal attainment in October 1992 did not differ noticeably from that for the entire period August 1991 – October 1992, a division between "high-productivity work groups" and "low-productivity work groups" can be discerned in the October 1992 data.

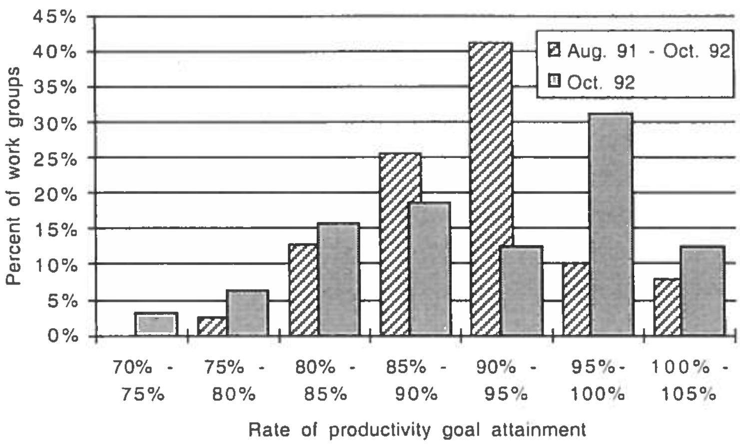

Figure 6. Work groups' rate of productivity goal attainment according to budget and weekly reports. Data for August 1991 – October 1992 are based on 39 work groups, while data for October 1992 are based on 32 work groups (Engström, Jonsson and Medbo 1996). Source of data: the Volvo Uddevalla archive.

3.2 Observed assembly man-hours per automobile in the assembly workshops

In order to analyse the assembly work at the Volvo Uddevalla plant in detail, an integrated video/computer system specially developed for this purpose was used. This development work was necessary due to, among other things, the extensive recording done in the plant by the authors during the closing-down period, making analysis of the video recordings virtually impossible with conventional equipment.

The equipment used time-codes of each picture frame on the recorded tape. This makes it possible for the computer controlling the video recorder to identify each individual frame. Thus it is possible for the software to relate video-recorded activity sequences to the time dimension, i.e. to define the activity types and activity times for a recorded video sequence. Similar equipment has been developed by others (Bengtsson and Björnsson 1983; Bengtsson and Björnsson 1986; Oba et al. 1993) but for quite different purposes, such as predetermined motion and time systems of construction work and to achieve a discrete visual simulation system with digital input.

The recordings forming the basis for the results reported here included practically all assembly work on nine specific automobiles. The assembly work on the doors of these automobiles was analysed separately. Each camcorder followed an individual operator during a normal working day. The work pace and methods were judged not to be negatively affected by the closing-down decision. Thus, it was possible to gain authentic data from the shop floor.

Actual assembly times versus standard assembly times

For all nine automobiles studied, actual assembly times were shorter than standard assembly times. Observed assembly times corresponded to a mean work pace of 118 per cent of the work-pace norm for entire automobiles and 125 per cent for doors. The work pace norm was derived from predetermined motion and time systems, specifically from standard assembly times according to the standard used at Volvo. Note that the door subassembly was carried out as a part of the total assembly work, i.e. the same operators in the work group performed both the work on the automobile body and that on the door subassembly stations.

The work-pace distributions for the nine automobiles that were video-recorded as well as for the corresponding 36 doors are shown in figure 7. The skewed work pace distribution observed is consistent with previous findings (e.g. Dudley 1968). The diagram also shows that some work groups had an extremely high work pace (corresponding to 140 – 150 per cent of the MTM norm) on the specific doors that were video recorded. The difference in work pace between automobile body assembly and door subassembly is most likely primarily due to the fact that the materials kit was better designed for door assembly than for automobile body assembly. For automobile body assembly, the materials kit was a compromise between the two different layouts and intra-group work patterns of assembly workshops 1 – 3, on the one hand, and workshops 4 – 5, on the other hand. Also, the door subassembly was performed as individual work, which meant that materials kits and work station features could more easily be adjusted to fit each operator's needs.

Assembly operators thus proved to be able to perform very long cycle times (80 – 100 minutes) assembly work at a high work pace. Even for extremely long cycle times (300 minutes), the work pace was higher than the standard assembly time according to the predetermined motion time systems. Two automobiles analysed were assembled entirely by two female operators, resulting in mean cycle times in excess of 300 minutes. As shown in figure 8, their work pace was some 10 per cent above the standard assembly time. However, it should, of course, be kept in mind that the number of automobiles observed is small. Consequently, any conclusions about the relationship between cycle time and work pace have to be regarded as tentative.

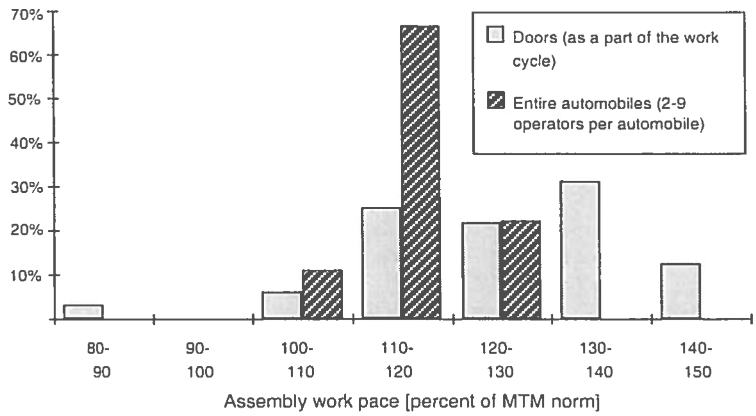

Figure 7. Observed assembly work paces for nine entire automobiles and 36 doors in the Volvo Uddevalla plant relative to the work pace norm, corresponding to MTM-based standard assembly times (Engström, Jonsson and Medbo 1996). Source of data: the authors' video recordings.

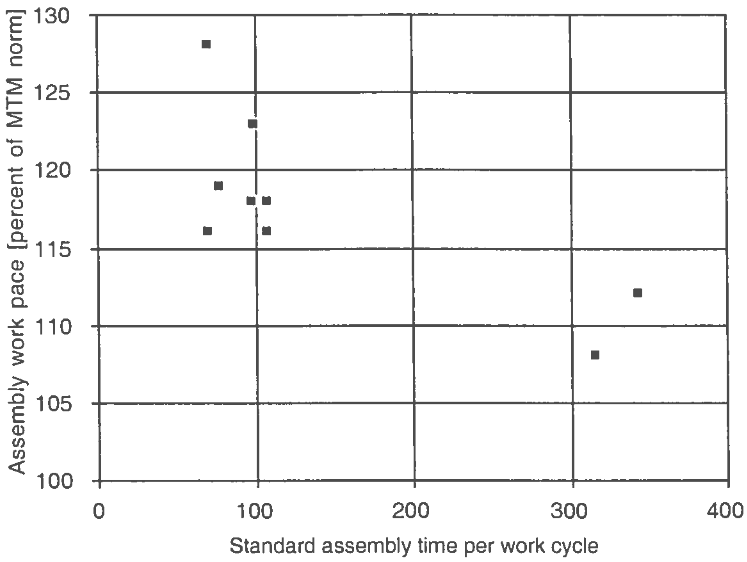

Figure 8. Assembly work pace for entire automobiles as a function of standard assembly time per work cycle (Engström, Jonsson and Medbo 1996). Source of data: the authors' video recordings.

Some parameters pertaining to assembly work paces are given in figure 9.

	Assembly of automobiles	Assembly of automobile doors
Approximate mean standard assembly time per work cycle [minutes]	80 / 100 /300*	23
Mean actual assembly time per work cycle [percentage of standard assembly time]	85**	18
Mean work pace [percentage of work pace corresponding to standard assembly time, i.e. MTM 100]	118	125
Relative variation in standard assembly time [coefficient of variation]	0.11	0.04
Relative variation in actual assembly time [coefficient of variation]	0.12	0.13
Relative variation in work pace [coefficient of variation]	0.05	0.10

* Excluding the two female assembly operators who regularly assembled complete automobiles.

Figure 9. Cycle time, mean work pace and relative variations in work pace, standard assembly time and actual assembly time for entire automobiles and doors (Engström, Jonsson and Medbo 1996). Source of data: the authors' video recordings.

3.3 The Volvo Uddevalla plant versus the Volvo Torslanda plant

The authors have also compared assembly times at the Volvo Uddevalla plant with corresponding assembly times at the main Volvo Torslanda plant, where the same model, the Volvo 940, was assembled on two lines during the same period. This kind of comparison is much more meaningful than comparisons between the Volvo Uddevalla plant and Japanese assembly plants, which are distorted due to differences in manufacturability and extent of external subassembly work. For example, Adler and Cole (1995) compare 9.1 hours per automobile for Japanese luxury producers with 25.9 hours for the Volvo Uddevalla plant. On the other hand, Berggren (1992) reports that the standard assembly time for a door to a Saab has been found to be about four times as long as that for a Honda door. If this ratio applies to the entire automobile, a Japanese plant might have required 36.4 (9.1 x 4) hours to assemble a Volvo. Under the same assumption, the Volvo Uddevalla plant might have required only 6.5 (25.9 / 4) hours to assemble a Japanese luxury automobile. Of course, neither these nor Adler's figures prove anything about productivity, since there is insufficient information about standard assembly times, which is exactly the point (see also Berggren, 1994, concerning the international debate about the Volvo Uddevalla plant productivity or Hancke 1994).

The comparison between the Volvo Uddevalla plant and the Volvo Torslanda plant in figure 10 shows that, for the same automobile model and the same operations, the Uddevalla plant required on average 10.8 hours per automobile, while the two assembly lines at the Volvo Torslanda plant required 15.5 and 17 hours per automobile, respectively. The comparison takes into account the assembly and materials handling at the individual work stations. The Volvo Torslanda data are derived from figures defining the manning of these assembly lines, which have been normalised with respect to subassembly work, adjustment and controlling, roller testing, final adjustment and filling of media. This is in order to make them comparable with the Volvo Uddevalla plant, thus obtaining a rough estimate of the corresponding assembly man-hours.

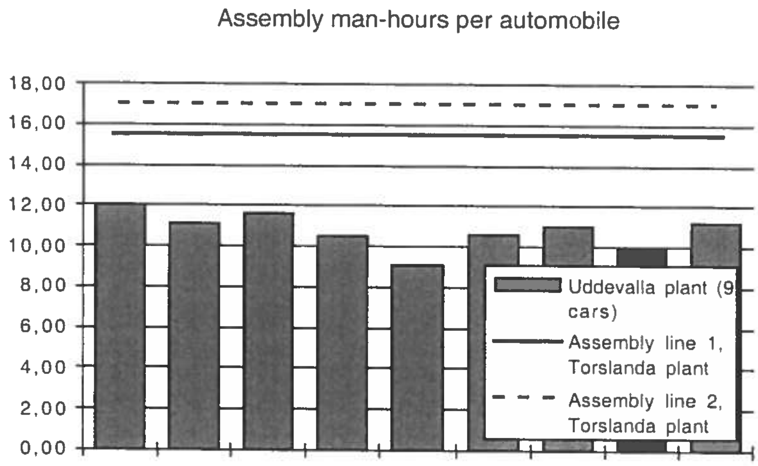

Figure 10. Observed assembly times for the nine video recorded automobiles in the Volvo Uddevalla plant compared with the corresponding times for two assembly lines in the Volvo Torslanda plant 1992 – 1993 (Engström, Jonsson and Medbo 1996). Source of data: the authors' video recordings, Volvo data and The Volvo Uddevalla archive.

The parallel product flow assembly system in the Volvo Uddevalla plant thus required 4 – 6 assembly man-hours less per automobile than the serial product flow assembly systems in the Volvo Torslanda plant. In percentage terms, 30 to 90 per cent more assembly man-hours per automobile were required in the serial product flow assembly systems.

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It may not be clear how the assembly times reported above, 9 – 12 hours per automobile, relate to the 33 – 36 hours per automobile reported by Volvo (Tidningarnas Telegrambyrå 1992) and by Berggren (1994). This gap is explained by the fact that the latter figures refer to the blue-collar man-hours for the entire plant, whereas the former figures refer specifically to the main assembly work. Using detailed man-hour reports from the Volvo Uddevalla plant, the authors have calculated blue-collar man-hours for the entire plant for the last five weeks before the decision to close the plant was announced, a period covering October 1992. During this period, the blue-collar man-hour count for the entire plant was 37.5 hours per automobile according to official figures. This figure includes indirect as well as direct work, and assembly work as well as non-assembly work. A detailed breakdown is presented in figure 11.

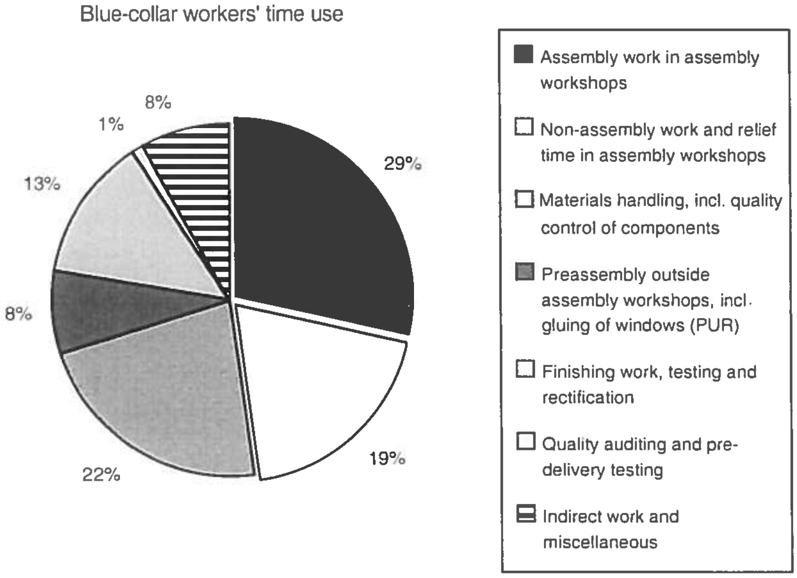

Figure 11. Breakdown of blue-collar man-hours for the entire Volvo Uddevalla plant. Non-assembly time in assembly workshops includes time for meetings, quality assurance, adjustment, training, replacing faulty components, etc. (Engström, Jonsson and Medbo 1996). Source of data: the authors' video recordings, Volvo data and the Volvo Uddevalla archive.

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To sum up, three different man-hour measures are discussed in this paper:

1 Blue-collar man-hours in assembly workshops. This was obtained from weekly man-hour reports from the assembly workshops and is reported in figures 4 and 5 in section 3.1 above, i.e. 17 man-hours per automobile.

2 Observed assembly man-hours per automobile reported in figures 7 and 8 in section 3.2 above. This was measured by video recordings, i.e. 11 man-hours per automobile.

3 Blue-collar man-hours for the entire plant in this section. This was obtained from weekly man-hour reports, and is reported in this section, i.e. 38 man-hours per automobile.

As shown in figure 11, the observed assembly man-hours in the assembly workshops (1) constituted less than 30 per cent of the total blue-collar man-hours for the entire Volvo Uddevalla plant, while total man-hours in assembly workshops constituted less than 50 per cent of the total blue-collar man-hours for the entire plant.

4 OTHER MERITS OF THE VOLVO UDDEVALLA PLANT

By tradition, productivity tends to be a dominating concern in manufacturing. However, in many industries today, other concerns are now becoming at least as important. For example, labour costs for assembly of automobiles amount to less than 5 per cent of total production costs. This means that, even if labour productivity in final assembly is improved dramatically, the resulting cost reduction is marginal. By contrast, performance aspects that are critical in diversified quality production (Streeck 1992) are increasing in importance, notably an assembly system's flexibility and its capacity to produce products with high quality.

4.1 Product quality

Customer satisfaction data

In Womack et al. (1990), comparative evaluations of the capability of assembly plants to achieve high product quality are based on customer survey data, specifically the JD Powers customer satisfaction survey. As discussed further by Jonsson (1995), these survey data do not, however, provide a solid basis for assessments of assembly plants. First, customer attitudes towards products, as assessed through questionnaires, are affected by many factors apart from product quality, e.g. dealer-customer interaction and marketing efforts. Second, product quality is affected by many factors apart from the assembly system's product quality potential, e.g. product design and component quality. Third, in the JD Powers surveys used by Womack et al. (1990), individual automobiles are not tracked to assembly plants. Consequently, even if the same automobile model is assembled in several plants, these assembly plants cannot be meaningfully compared.

However, in 1992, Volvo commissioned JD Powers to perform a customer survey that overcomes some of these limitations. In this survey, customer satisfaction (mainly in terms of dependability) was assessed for Volvo automobiles sold in the USA from the model year 1992. Volvo automobiles assembled in different assembly plants could be identified in this survey. Furthermore, since the 940 model was assembled in the Volvo Uddevalla plant as well as the Volvo Torslanda plant, a relevant comparison between these plants was possible.

According to the survey, 940s assembled in the Volvo Uddevalla plant exhibited 145.4 problems per 100 automobiles, while 940s assembled in the Volvo Torslanda plant exhibited 165 problems per 100 automobiles. This difference may be more significant than it appears, since many dependability problems are due to the product rather than the assembly process. If these problems were removed, the relative difference between the plants would become greater.

Another piece of evidence is provided by the so-called VOICE customer survey conducted by Volvo (Volvo Personvagnar 1992). For the model years 1991 and 1992 combined, 940s assembled in the Volvo Uddevalla plant received more favourable customer satisfaction ratings in this survey than 240s assembled in the Volvo Torslanda plant as well as 740s, 945s and 850s (introduced in 1992) assembled in the Gent plant. Also, the customer-perceived quality of automobiles assembled in the Volvo Uddevalla plant improved between the model years 1991 and 1992 from 908 problems per 100 automobiles to 686 problems per 100 automobiles.

Note that this survey is not comparable to the JD Powers survey referred to above. The VOICE survey also takes dissatisfaction with “normal”, concept-bound properties of the automobiles into account. Note also that the improvement between model years 1991 and 1992 may partly be due to improvements of the product itself between these model years.

Quality audit data

In Volvo's internal quality audits, a weighted additive quality index, in which defects were assigned 1–100 points according to their degree of severity, was used. The distribution of the resulting assembly defect score for 1 071 automobiles audited during the period August 1991 – October 1992 is shown in figure 12. These defect scores are related to the assembly work and do not correspond to the measures of the JD Powers survey concerning customer satisfaction.

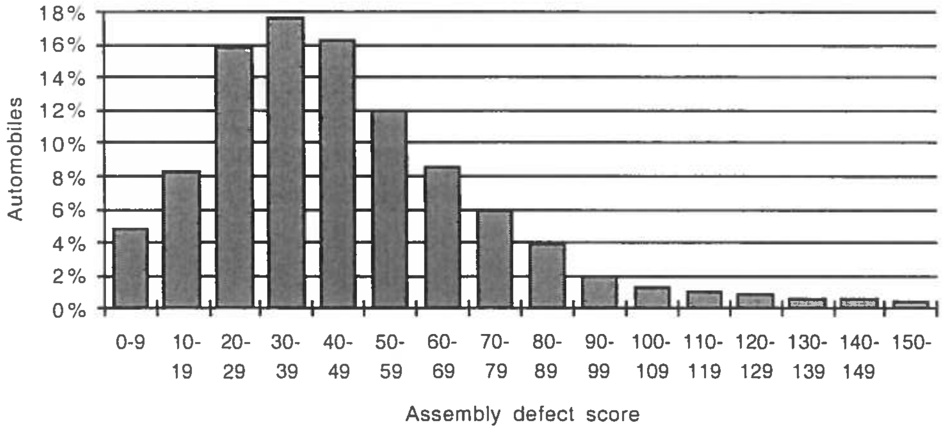

Figure 12. Distribution of assembly defect scores per automobile, based on internal audits of 1 071 automobiles during the period August 1991 – October 1992 (Engström, Jonsson and Medbo 1996). Source of data: the Volvo Uddevalla archive.

The mean assembly defect score was 46.5 units per automobile, but the defect score varied considerably (see figure 12).

Parameter	*Value*
Mean:	46.5
Median:	44
Minimum / maximum:	2 / 206
Coefficient of variation:	0.598

Figure 13. Statistical parameters for distribution of assembly defect scores, based on internal audits of 1 071 automobiles during the period August 1991 – October 1992 (Engström, Jonsson and Medbo 1996). Source of data: the Volvo Uddevalla archive.

Quality audits in the Volvo Uddevalla plant also showed that the assembly defect score tended to increase during the period August 1991 – October 1992 (see figure 14). Note that this finding does not contradict the improvement of customer-perceived product quality between the model years 1991 and 1992, as the 1992 models in the VOICE survey were assembled in the autumn of 1991.

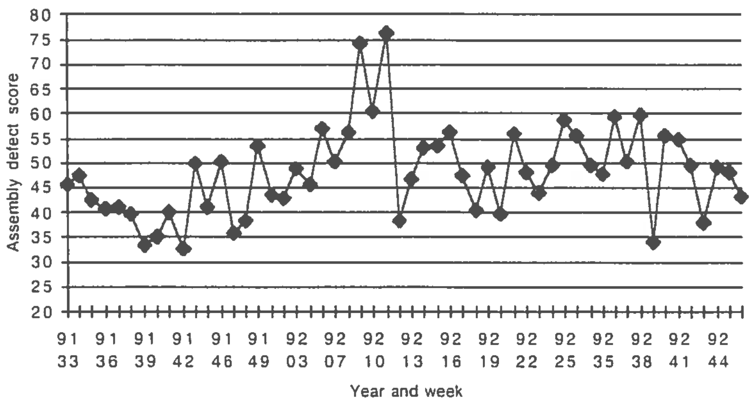

Figure 14. Weekly mean assembly defect scores, based on internal audits of 1071 automobiles from week 33, 1991, to week 46, 1992 (Engström, Jonsson and Medbo 1996). Source of data: the Volvo Uddevalla archive.

As expected, the mean quality according to the audit-based quality index differed between the work groups in the Volvo Uddevalla plant.

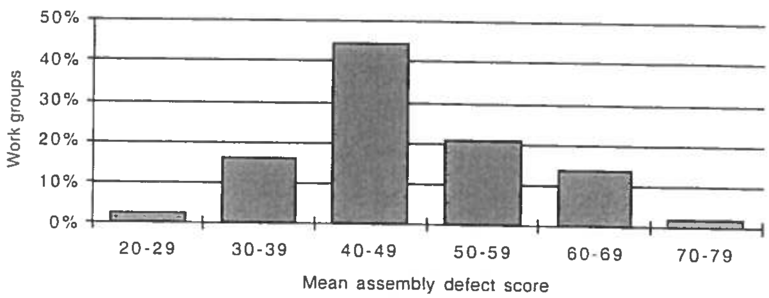

Figure 15. Mean assembly defect scores for 42 work groups, based on internal audits of 1 071 automobiles during August 1991 – October 1992 (Engström, Jonsson and Medbo 1996). Source of data: the Volvo Uddevalla archive.

As evident from figure 14, in particular, the product quality varied considerably and, according to the authors' interviews with quality audit specialists within Volvo, this variation in quality might be one of the important negative aspects of the manufacturing principles utilised in the Volvo Uddevalla plant. No really good explanation could be found for this quality variation. Sometimes the defect was important and obvious to the operator if pointed out, as evidenced by the typical response: "How on earth could we forget this?". Thus, it is better to have a low variation in quality and a slightly lower average quality.

Note, though, that the 940 model was the most difficult Volvo automobile to assemble due to the numerous components included and the fact that the automobile body did not always meet the tolerances specified by the product design. In fact, the 960-model, though more luxurious and equipped with numerous auxiliary equipments, was easier to assemble since it was of a later, more mature design.[3]

4.2 Flexibility

The flexibility of assembly plants is even more important today than it was some years ago due to factors such as greater product variation, shorter delivery times, more customer-ordered products, more frequent model changes, etc. The Volvo Uddevalla plant had a flexibility advantage with respect to the ability to manufacture a broad range of products or product variants as well as to easily change the range of products or product variants manufactured. This flexibility advantage derived from several sources, including those listed below:

1 Since assembly was being performed in approximately 40 parallel work groups rather than on a single assembly line, different product models or product variants could be assembled simultaneously in the Volvo Uddevalla plant much more easily than in a conventional plant.

2 Similarly, new models or new product variants could be introduced in one or more work groups without involving or disturbing the others. In a serial product flow assembly system, on the other hand, the introduction of new products involves a reformation of the total assembly system. This requires as substantial amount of work, as well as equipment, to achieve a smooth flow through all work stations along the assembly line.

3 Long cycle time assembly work requires a more knowledgeable workforce; this knowledgeable workforce is able to handle diverse and changing products.

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[3] A parenthesis illustrating the manufacturability of the product is the fact that in some cases (e.g. the two female operators who assembled complete automobiles by themselves) assembly operators were able, after completed assembly, to identify the automobiles they had built due to certain individual characteristics of the product. When walking along a line of complete automobiles, they were able, at a glance, to pick out the automobile they had built.Tomas.

4 Parallel product flow, long cycle time assembly systems call for multi-purpose, non-specialised tools and production equipment; such tools and equipment will not have to be extensively modified when new products are introduced.

5 Parallel product flow, long cycle time assembly systems require an administrative support for materials handling and assembly work in the form of variant specifications, work instructions, picking lists, etc. designed from the production point of view, which provides an overview of products and product variants. Such administrative support enhances flexibility.

6 Possibilities of pre-series production in the same plant as full-scale production of fully developed products. This eliminates the need for a separate so-called pilot plant, which means opportunities for a closer connection between product designers and production.

The flexibility of the Volvo Uddevalla plant manifested itself in many ways, for example in lower costs in connection with annual model changes, as shown in figure 16.

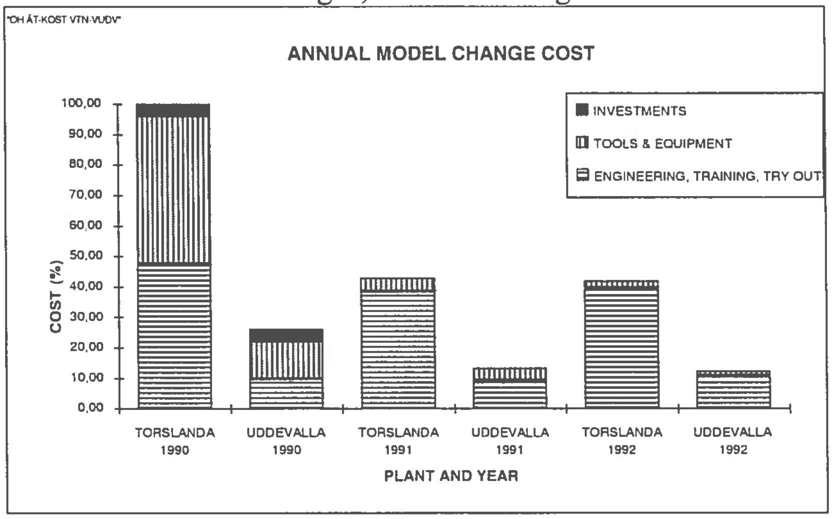

Figure 16. Annual model change cost per automobile for the same automobile models in the Volvo Uddevalla and Volvo Torslanda plants during 1990, 1991 and 1992. In 1990, there was a major product change, which explains the high costs for this year (Engström, Jonsson and Medbo 1996). Source of data: Volvo data and the Volvo Uddevalla archive.

For all three years considered, annual model change costs per automobile assembled in the Volvo Uddevalla plant were merely some 30 per cent of those in the Volvo Torslanda plant. Thus, conventional economies-of-scale did not apply in this case.

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A discussion of the flexibility of the Volvo Uddevalla plant ought to include some other aspects than mentioned above, aspects normally not included in the discussion of performance of automotive plants. Some of these aspects are:

- The need for tools and fixtures does not, as is usually assumed, escalate in a parallel product flow assembly system. In fact, the number of tools decreases, as is noted by Ellegård et al. (1992) and explained in Engström and Medbo (1993a).

- The total need for space in the form of building facilities is decreased substantially compared to the assembly line (Engström 1993).

The problem of high quality variation needs further research, since it may be an important negative aspect of the Volvo Uddevalla plant. On the other hand, the results from the Volvo Truck company concerning parallel product flow assembly indicate an increased product quality. In fact, the most difficult and complex trucks targeted at the demanding Japanese market are manufactured using the Volvo Uddevalla manufacturing principles.

5 COMMENT AND CONCLUSIONS

As noted by the data presented in the previous sections, the performance of the Volvo Uddevalla plant was impressive. For example, the assembly performance was higher than stipulated according to predetermined motion and time systems on an individual level; it almost met the budget figures on the work group level, and it was better than the traditional assembly line. This was achieved in a plant not fully run in, which had certain important malfunctions, further discussed below. Although some methodological problems remain, these results certainly indicate the potential of the parallel product flow manufacturing principles used.

Note that these results are fully consistent with earlier research and certainly better than the modest claim made by Volvo, during the debate in connection with the closing-down decision, that the performance of Volvo Torslanda and Volvo Uddevalla was similar. The productivity advantage was probably not due to higher work intensity in Volvo Uddevalla than in Volvo Torslanda but to smaller time losses due to the parallel product flow assembly system, as discussed above.

It should also be noted that there are other benefits of product quality and flexibility. Flexibility that concerns annual model change cost, need for tools and fixtures, space requirements and reduced lead-time concerning customer orders. All these aspects might today be considered even more important than solely focusing on performance aspects like man-hours.

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One interesting obvious question in this context is; why was this performance and flexibility not recognised?

One reason, touched upon above, is the general lack of appropriate manufacturing engineering knowledge. For example, most manufacturing engineers within the Swedish automotive industry, knowledgeable and experienced in the design and operation of this type of assembly systems, are today retired. In fact, the theory and practice of time losses have not been fully accepted by engineers and managers. In fact, the design process had an "internal logic", in which design options were successively eliminated through irreversible design decisions until only one alternative remained – an unorthodox alternative not previously used in full-scale production of automobiles (see Engström, Jonsson and Medbo 1998 for a detailed description).

Another obvious reason why the performance and flexibility of the Uddevalla plant was not recognised is illustrated by the difference between man-hours presented by e.g. Volvo and by the man-hours according to weekly man-hour reports and the observed assembly man-hours according to the authors' video recordings. For example, the blue-collar man-hours for the entire plant was 32 hours while the actual observed assembly work, according to the video based data, was 10 – 12 hours. One reason, as is evident in figure 10, was that other activities than assembly work were performed within the plant, together representing a large amount of indirect work. Thus, the common focus on blue-collar assembly work should be questioned.

Another less obvious reason, not generally recognised by some practitioners or scientists, was the interaction between the way of manufacturing planning and -control and the materials feeding from the materials workshop to the assembly workshops, comprising approximately 40 parallel work groups. The materials workshops functioned as a serial flow delivering materials kits according to a defined production sequence. For reasons of inter-operator and intra-operator variation, it is preposterous to define one common sequence for the parallel work groups, as this sequence was often changed for various reasons. This imposed severe restrictions on the work groups, who obviously could not assemble without materials (each automobile required exactly the correct components to be contained in three separate materials kits).

In other words, the materials kits were put together in a common materials shop delivering kits of materials to all of the six assembly workshops. The kits as well as the naked automobile body were transported to the assembly workshops by an AGV-system. The manufacturing planning and control system was designed so that each particular materials kit was assigned to one of the approximately 40 work groups and to a specific product weeks in advance, long before the actual picking of the components in the materials workshop and the start of the assembly work.

This procedure actually functioned as a number of separate parallel queues of specified, interchangeable products. Interchangeable in a way that, according to the planners responsible for the design of the system, was not allowed. In practice, it turned out the other way around. This was basically due to the manufacturing planning and control as well as the materials flows being nuance only in the form of product individuals. Hereby, the optional flexibility of a parallel product flow, long cycle time assembly system was restricted, since it was impossible to accumulate the working up between automobiles. In fact, the assembly system was working almost like a number of short paced assembly lines, on which the work group or individuals were not at any time able to work in advance nor given the satisfaction to reach or exceed the production quota. Thus, it was not possible to transfer the time saved (2 – 4 hours per automobile according to figure 10) to the next automobile.

To make things even worse, the naked automobile body was assigned to a specific customer order at the Volvo Torslanda plant, whereby the possibility of replacing a defective automobile body by another automobile body of the same type was lost. This option was especially desirable in automobile manufacturing in Sweden due to the somewhat inferior quality of naked bodies that are mainly manufactured by automated production, as is common practice. For example, the Volvo Kalmar plant had a better planning procedure, partially designed by people with experience from the Volvo Uddevalla plant.

An alternative was to instead base the manufacturing planning and control on a complementary variant codification of product individuals at the Volvo Uddevalla plant, in order to create common queue of planned products between the materials workshop and the parallel work groups in the assembly workshops. This was, however, not possible to achieve since the product variants were not physically substitutable from the assembly point of view. The work groups did not have the competence required to build all variants, and some equipment and tools were specific for certain work groups since some tools were too expensive to multiply.

This restriction could be remedied by classifying the product variants into clusters with various degrees of characteristics relevant to the assembly process. The manufacturing planning and control system would then allow any materials kit to be sent to any of the work groups that had facilities for manufacturing specific product variants, sometimes denoted "assembly variants". The introduction of "assembly variants" required a more developed product description since the original planning procedure did not contain any information concerning assembly characteristics (Engström and Medbo 1992).

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It should perhaps also, in this context, be underlined that the general assumptions about long cycle time contra short cycle time assembly work often implicitly presuppose that the extended cycle time in itself is something to strive for. This is too simplistic, since the qualitative nature of the work tasks is crucial in this connection. A qualitatively different job calls for a more complex conception of manual work, where the term autonomy is an important ingredient. For example, welding one hundred metres instead of one metre hardly makes any difference with regard to humanisation of the work. On the other hand, a repetitive assembly task of two minutes compared to 2 – 5 hours work in a correctly designed parallel product flow assembly plant is something quantitatively and qualitatively different.

Note however that, in the latter case, certain technical and administrative preconditions must be fulfilled in the form of e.g. manufacturing planning and control systems. Neglect to create these preconditions leads, as has often been the case in the Swedish automotive industry, to failure to take advantage of the options offered by parallel product flow assembly systems.

On balance, though, the achievements of the Volvo Uddevalla plant were more important than its imperfections. This pioneering plant provided empirical proof of the viability of parallel product flow, long cycle time assembly of automobiles. It refuted the conventional wisdom asserting the superiority of assembly systems based on extensive division of labour. Its imperfections were imperfections of implementation, not of concept.

The existence of considerable imperfections in the Volvo Uddevalla plant may even be seen as encouraging. The explanation is that, despite these imperfections, the work environment was superior to that in line assembly plants and that the plant's performance was competitive compared to similar plants that produce similar products. In this situation, the significant imperfections of the Volvo Uddevalla plant translate into an equally significant improvement potential.

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