CMC 2003

PRIMARY AND SECONDARY EFFECTS OF USING A PARALLEL PRODUCT FLOW ASSEMBLY SYSTEM DESIGNS: THE REVERSING TRAJECTORY OF ASSEMBLY SYSTEM DESIGN

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ABSTRACT

This article in short recapitulates some the Swedish automotive industries' efforts to substitute the assembly line. Apart from briefly explaining some of the theoretical and practical frames of references, the article also brings forward two examples of analysis carried through in order to compare traditional and unorthodox assembly systems designs. One example deals with the assembly time consumptions and is based on video recordings, while the other example exemplifies work satisfaction based on two questionnaire studies. Both examples illuminate the efficiency of the parallel product flow assembly system. Thus might the ongoing transformation of the Swedish automotive industry be debated and questioned. Especially so with regard to exactly what manufacturing principles and practises are a copied or transferred from e.g. Japan as is obviously by some of the facts underlined and brought forward in the article.

Keywords: assembly system design, long work cycles, work organisation.

INTRODUCTION

The authors have been involved, for a long period of time, in the Swedish automotive industries' efforts to substitute the assembly line (having a serial product flow) with parallel product flow assembly systems using autonomous work groups. Thus the authors' have insights to recapitulate and reflect on some of these experiences as well as interpret an extensive data collected during more than two decades.

This data comprise e.g. video recordings of assembly work performed both in unorthodox as well as traditional assembly systems designs based on the traditional assembly line, archives from closed down plants or assembly systems, various types of manufacturing engineering documents and data files, personal registers, public relation materials. As a result the authors' have extensive data from the Volvo Uddevalla plant and the Volvo Car plant in Uddevalla, the Volvo Kalmar plant, the workshops in the Volvo Tuve plant, the Volvo Torslanda plant, the Volvo Skövde plant assembly system, etc. These plants and assembly systems assembled, trucks, automobile doors and diesel engines, respectively and was close down or rebuild into more traditional assembly system designs in 1993, 1995, 1995, 2002, 2001 and 2002, respectively. See explanation just below and figure 1 below for a brief principal explanation of traditional versus unorthodox assembly system designs.

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Thought the unorthodox assembly system designs where extensively debated on an international level both during the design and running-in (e.g. Rehder, 1992), especially so during the closing down of the Volvo Uddevalla plant (e.g. Sandberg, 1993) since this specific plant was the first full-scale assembly of automobiles using extremely long work cycles, advanced materials feeding techniques (i.e. materials supplied as materials kits structured in order to enhance the long work cycles), an assembly-oriented product structure (i.e. in order to describe the product and supply the materials in accordance to enhance learning and to improve the materials handling efficiency and autonomous work groups working in so-called workstations systems where a number of operator perform work on a number of products (i.e. in order to reduce the number of planning units and organisational levels). These manufacturing principles and practices developed and realised in some of the most unorthodox assembly systems are explained by e.g. Engström and Medbo (1994), Engström, Jonsson and Medbo (2000).

SOME PRINCIPAL ASSEMBLY SYSTEM DESIGNS AND SOME COMMENTS ON METHODS FOR REDUCING THE PRODUCTION LOSSES

In principal, the product flow may be designed in three different ways. Namely, as serial or parallel product flows, but also a hybrid product flow exists which in denoted as semi-parallel product flow having "waists" of serial flows with high transport frequencies of the products combined with sections of less transport intensive sections of parallel product flows. On the other hand, also a derivate of the downright parallel product flow exists; the organic product flow which has a successively decreasing transport frequency. Almost, figuratively speaking, like the branches on a tree (see figure 1 below). The Volvo Uddevalla plant was one example of an organic product flow, while the Saab Automobile or the Volvo Kalmar plants where examples of semi-parallel product flow assembly system designs. All these three plants are now closed down, while the Volvo Uddevalla plant has been reopened in the form of the Volvo Cars plant (first operated as the Autonova plant).

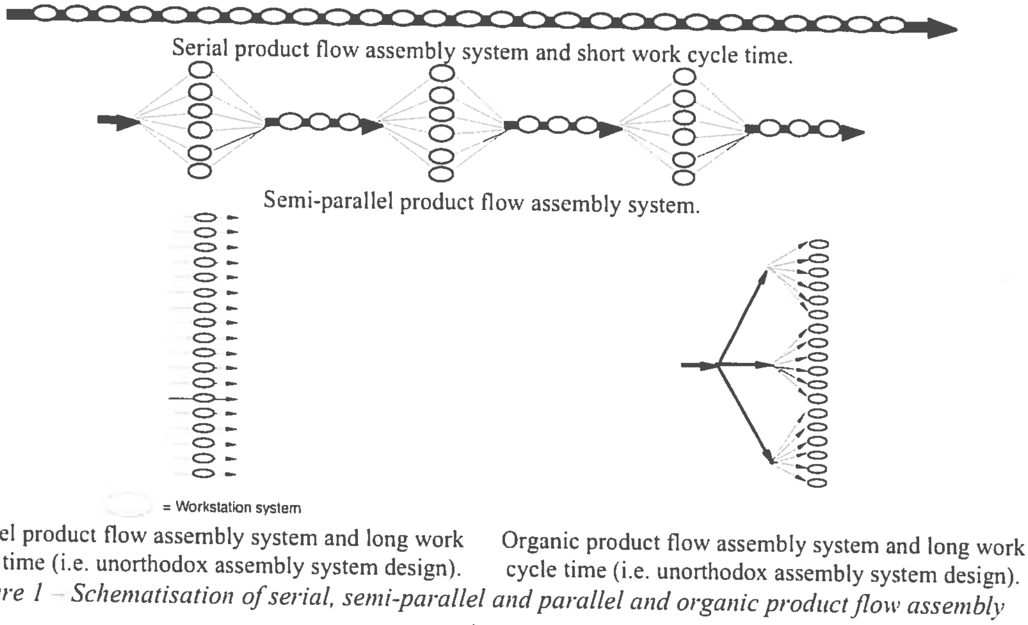


Figure 1 – Schematisation of serial, semi-parallel and parallel and organic product flow assembly systems.

Briefly explained, in parallel, organic and semi-parallel product flows the mechanism for reducing production losses (i.e. system, balance and division of labour losses according to Wild 1975). is inherited in these assembly system designs by the fact that the products are allowed to pass each other on a intra-workstation or workstations system level. Though sometimes is re-sequencing also at hand at inter-workstation level, i.e. within a workstation system or on the workstation.

The fact that the products are allowed to pass each other results, among other things, in that the sequence for products entering some types of assembly system design are not identical to the products leaving, which of course will imply the use of some intriguing production control methods. In semi-parallel product flows it is normally necessary to restore the sequence due to materials supply reasons. Such re-sequencing involves the need of large buffers or alternatively puts restrictions on the freedom for the products to pass each other. Thus, also semi-parallel product flows will embrace considerable production losses. This re-sequencing of products may, appear also on a serial product flow by use of so-called sorting buffers, though this is not common at all within the automotive industry.

On the other hand, a serial product flow with buffers, there the product sequence are less intriguing to consider, will also have substantially reduced production losses due to the eventual existence of intermediate buffers. Thus in principal, parallel product flow or the serial product flow with intersected buffers may be considered as two contradictory ways of reducing the production losses both having their different merits and malfunctions, respectively.

From product flow point of view, there are several, more or less obvious, method to reduce the production losses. In all the authors' have below choose to recognised and summarise four main clusters of methods of which three are considered in this article:

1 Using a parallel product flow, that is to break up a serial product flow into many, short product flows. As mentioned, production losses in serial product flow assembly systems increases with the number of operators along the product flow, so splitting up a serial product flow into a number of parallel product flow combined with decreasing the number of operators along each product flow decreases production losses.

2 Introduce intermediate buffers intersected between workstations or workstation systems in a serial product flow assembly systems. These partly completed products will absorb the inter- and intra-operator variation.

3 Introduce so-called "collective working", that is using flexible division of labour between operators, preferably with overlapping competencies, so that operators can use otherwise idle time to help their co-operators.

4 Increase to content of work within a workstation system/work group by means of e.g. integrating sub-assembly workstations, increase the number of product available for assembly (i.e. "assembly active" products) or by integrating other work tasks than assembly work within an work group.

On the other hand it is also possible to:

5 Reduce intra-operators variation, this may be 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. Or by reforming the product architecture to decrease the adjustment and fiddling often

necessary to complete a product. That is to reduce the number of components needed, shorten the tolerance chains, reduce the number of cables and wring harnesses, etc.

Note that these five clusters of methods do not rule each other out, so two or more clusters of methods may be combined. On the other hand, when production losses in a specific assembly system have been reduced through the application of one method, there is less need to use another.

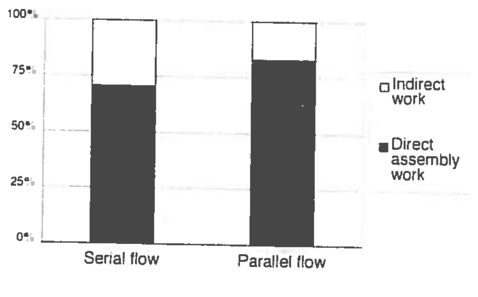
SOME EXAMPLES AND COMMENTS REGARDING EFFICIENCY AND WORK SATISFACTION

Below, two examples illustrate some of the aspects brought forward in sections 1 and 2. The first example has not been presented earlier and deals with comparing efficiency in traditional and unorthodox assembly system designs. The other example also compare traditional and unorthodox assembly system designs with regard to work satisfaction. Though in this case not inserted in the context brought forward in this article.

<u>Example 1: Observed assembly time consumption in an traditional and orthodox assembly system designs based on data from the authors' video recording conducted in 2001 and 2002, respectively:</u>

This example is based on the authors' own video recordings at the Volvo Car plant in Uddevalla where, for various reasons, the parallel product flow assembly system of this plant has been transformed into a traditional serial product flow. That is instead of completing the automobiles in two separate workshops calling for an internal transfer in-between, the automobiles are now assembled on an assembly line. The work cycle time is now 10 minutes instead of 90 respectively 150 minutes as was the case earlier in the two workshops.

The products assembled are the same in both different assembly systems (i.e. a Volvo C70 cabriolets) and the assembly work analysed is also similar. The analysed video sequences comprise 150 minutes and 53 minutes for the serial and parallel product flows, respectively. The number of operators' video recorded and analysed where four and three, respectively.



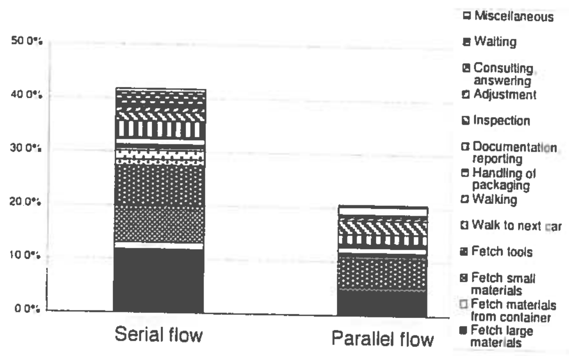


Figure 2 – To the left the operators distribution of working hours into direct assembly work and indirect work according to the authors' video recordings. The indirect work include all observed work tasks that is not assembly work. To the right, the detailed observed time consumption of indirect work for parallel product flow and serial product flow, as share of direct assembly work.

The analysis of the time consumption in the different assembly system designs has been conducted by means of a computer synchronised video equipment according to Engström and Medbo (1997). The present equipment, consists of a video camera, video tape recorder, TV-monitor, and personal computer including self-developed software. The analysis is made by categorization into predefined activities identified on the video tape as shown on the TV-monitor. What is sometime denoted as "activity analysis" is performed by clicking the cursor on "buttons" in windows on the computer screen, where each button corresponds to one activity. The design of the windows on the computer screen is arbitrary and can be made according to the requirements of a specific case in the form of e.g. the number and position of the buttons.

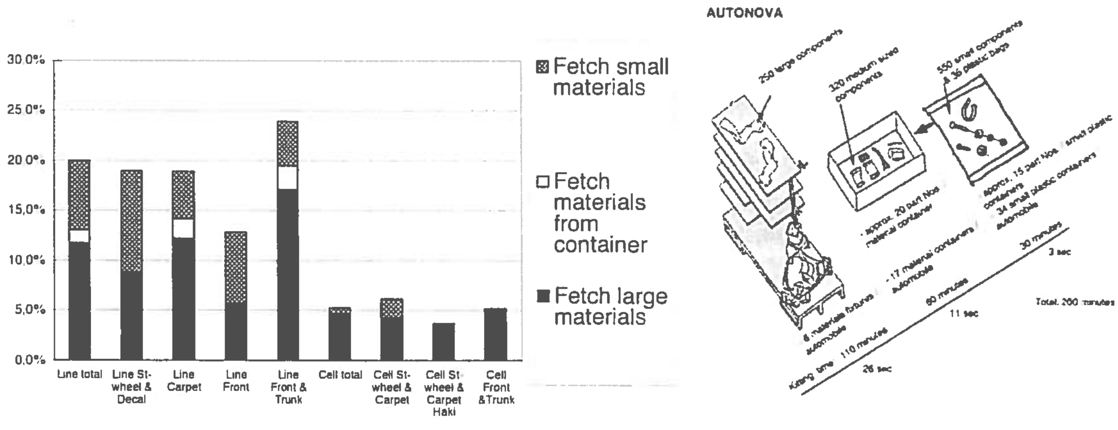


Figure 3 – To the lefts is the time consumption for fetching components in the observed parallel product flow and the observed serial product flow illustrated. The components are divided into three categories and the time consumption is reported as share of direct assembly work. To the right is the materials kit used in the parallel product flow presented according to the three categories of components. Note that especially for the medium sized components supplied in materials containers, does the materials kit involve a considerable time reduction in the parallel product flow case. This depends on that the operator brings the materials kit container to the assembly position, while in the serial product flow assembly system, practising line stocking, the operator have to walk along the line to pick the components.

The analysis by means of the computer synchronised video equipment showed that a larger amount of the operators working hours was devoted to assembly operations in the parallel product flow than in the serial product flow where indirect work tasks took up more time, i.e. 83% compared with 71% respectively, see figure 2 to the left.

It was found that the indirect work is twice as much, i.e. 42% versus 21%, in the serial product flow as in the parallel product flow, when normalised against direct work, see figure 2 to the right. Principally it was less need of materials handling activities in the parallel product flow assembly system that was the cause of this difference, see figure 3 to the left. Note that the materials feeding technique practiced in the parallel product flow assembly system utilised materials kits which means that the operators do not have to walk as long as in the serial product flow assembly system to fetch components, see figure 3 to the right.

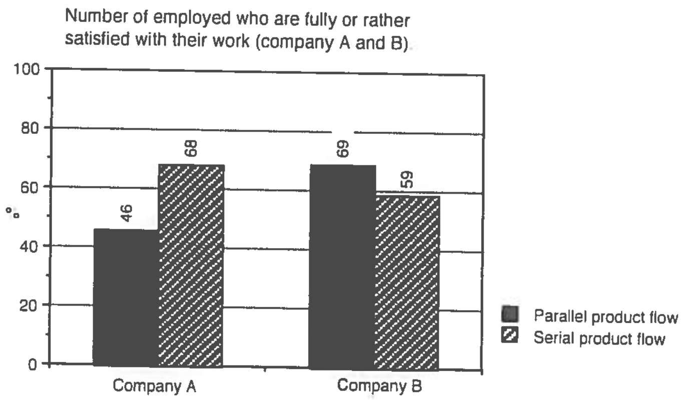
In conclusion, this example, consequently illustrates the efficiency potential in parallel product flow assembly system.

Example 2: Comparisons in-between two different production/assembly system designs in two companies with regard to work satisfaction

This example is based on two questionnaire studies, denoted I and II, conducted in 2002 and 2001 at the Volvo Car (denoted A below) and Volvo Truck (denoted B below) plants in Gothenburg. These two questionnaire studies comprised 1 600 and 1 800 operators, respectively. The questionnaire studies I and II where primarily aimed at evaluating the flexible work time scheduling, so-called “customer-oriented work time”. The response rate was 70% for both questionnaire studies rate was: See Engström and Blomquist (2002) for more details.

One specific feature of both these questionnaire studies where the use of department numbers in the questionnaire forms which made it possible to link the questionnaire data to each department. This in turn made it possible to construct tables comprised of data from each department investigated. On the other hand, the function of each department in turn was understood due to both earlier research and development work by one of the authors, by means of study visits at work sites, as well as discussions with various employees and union representatives.

Questions regarding work satisfaction in a general sense have been included in the questionnaire studies. Figure 4 compares the departments using serial product flow respectively parallel product flow assembly systems at companies A and B regarding whether or not blue-collar employees are satisfied with their work.



N = 465 446

Figure 4 – Diagram illuminating percentage of blue-collar employees at companies A (Volvo Car) and B (Volvo Truck) involved in direct production regarding the questions of work satisfaction for blue-collar employees working at serial and parallel product flow assembly systems respectively. Sources of data: questionnaire studies I and II (Engström and Blomquist, 2002).

As is evident in figure 4 there are quite extensive differences between companies A and B regarding the answers to the question of work satisfaction. According to earlier research (Karlsson, 1978) the authors' might have expected an increased work satisfaction at the parallel product flow assembly systems. This was the case at company B even though the noted differences were not especially large, but in company A the pattern was reversed.

It must be noted that the expected increased work satisfaction presumes correctly designed parallel product flow assembly systems, i.e. that e.g. the manufacturing engineering as well as the running in and full pace production has been done according to the manufacturing principles and practices established for parallel product flow assembly systems.

According to one of the authors' knowledge and insights regarding assembly system design, based on twenty five years research and development work within the Swedish automotive industry, the assembly systems in companies A and B were not correctly designed in all respects.

The assembly work at the parallel product flow assembly system in company A was in fact not "true" group work, i.e. no collective work was at hand. It was a parallel product flow assembly system consisting of individual workstations characterised by extreme individual working up, i.e. in some cases the operators individually completed their stipulated work of the day and were able to leave approximately 2 – 4 hours earlier. This situation was partly explained by management practices and ideologies as well as by assembly system design.

Another reason for the extreme situation was the fact that in company B, on the other hand, did the parallel product flow assembly system for several reasons and in most respects represent more of a "true" group work, i.e. collective work was at hand. The operator cohesions and co-operation were extreme and the working up took place on a collective level. The work groups usually completed their stipulated work approximately 2 – 3 hours earlier if materials were delivered as expected, if the required components were available and if sufficient quality product and assembly information was at hand, something which however was not all too common. In fact, company B´s product was far more complex and included relatively less product design engineering hours than did the product of company A. Somewhat roughly stated it might be considered more or less as a prototype.

In most cases the state of the art sketched above is common for all parallel product flow assembly systems introduced in Sweden during the last two decades. For a more detailed explanation of the merits and idiosyncrasies of assembly system design using autonomous work groups using parallel product flow assembly systems, see Engström, Jonsson and Johansson (1996), Engström, Jonsson and Medbo (1996) as well as Medbo (1999).

CONCLUSIONS AND FINAL COMMENTS

It can be argued that most of these unorthodox assembly system designs realised in Sweden actually never reaped the potential in the form of efficiency due to the reduced production losses. Neither was increased flexibility accounted for. Flexibility gained due to the possibility to e.g. man the appropriate number of parallel product flows or work groups required. In fact though the actual existence of these merits, they where in a general sense often not even recognised, as have been proved and explained by e.g. Engström, Jonsson and Medbo (1996) or by Medbo (1999). Both examples presented above illuminates these facts. Thought in two different ways. That is example 1 concretely shows the efficiency of the parallel product flow in the form of e.g. improved materials handling efficiency. Example 2, on the other hand, underlines an unfortunate extreme working up due to defective management, which may not be considered as a feature of the assembly system design in a strict technical sense. Albeit such an extreme working up in not possible in a serial product assembly system. Anyhow, obviously does an efficiency potential exists, as is evident by both examples – even if this efficiency potential may be expressed and realised in quite different ways.

Furthermore, the peculiarity of substituting the more efficient assembly systems designs maybe clarified by distinguishing between (1) original design assumptions and specific manufacturing preconditions during the period of time for the decision and design of these plants and assembly systems and (2) effects actually gained at full-scale production. It might thus, for analytical reasons be appropriate to talk about primary and secondary effects, thus referring to effects sought for (i.e. primary effects) and effects actually gained (i.e. secondary effects).

What is more, These designs assumptions have also varied during the last two to three decades. That is earlier in the Swedish automotive industry being based on a more genuine effort to improve work (by e.g. improved ergonomics and work satisfaction) and work conditions of the repetitive short work cycle time assembly work predominating during periods of business booms and labour shortage within the automotive industry. Thus allowing unorthodox assembly systems in specific socio-economic and socio-.politic conditions of Sweden. Where e.g. some of the industries earlier use and disposal of profits where partly controlled by politics, but also e.g. due to political controlled resources specifically aimed at established job opportunities in rural areas or areas having lost employers such as was the case for the Uddevalla and Malmö areas.

However, during the last decades a successive transformation has merely underlined efficiency by utilising traditional international manufacturing principles and practices. The interpretation has involved serial product flows and short work cycle times. Thus refereeing to, or being inspired, by the Japanese success story, which also in a peculiarity since while the Japanese automobile industry has chosen to preserve the serial product the Japanese electronic industry has to a large extent abandoned the traditional assembly line and has introduced so-called production cells.

These Japanese production cells are comprised out of a mix of both short serial product flows and parallel product flows usually designed for a specific product variant. In this case are the products completed by a small work group or sometimes by a single operator. Consequently, the Japanese electronic industry neglects the more "one-eyed" design assumption of one single "correct" assembly system design, as is for the moment the case within the Swedish automotive industry. Thereby the Japanese electronic industry has reaped both the efficiency and flexibility of the unorthodox assembly system designs. Asao (2001) report on an efficiency improvement for e.g. assembly of personal computers of o 30%, a space utilisation improvement of 40% and that the cost for manufacturing equipment was reduced by 90%.

The strive for an international one single "correct" assembly system design within the automotive industry is based on a wish for a universal assembly system design that, among other things, allows a global transfer of production volumes as well as manufacturing knowledge. This can be exemplified by Toyota, which now introduce the so-called autonomous complete process common for all their assembly plants globally (Nohara 2002). One interesting fact in this context is the use of intermediate buffers at the Toyota assembly lines of today while at the same time is the Swedish automotive industry for the moment abandoning such buffers and referrers to being inspired by Toyota. In fact the Swedish automotive industry is inspired by earlier Japanese efforts as they are interpreted by Americans and often labelled "Lean production".

These transformations has, according to the authors' recent experiences during Japanese research tours been based on a more pragmatic design procedures than practiced in Sweden

Nevertheless the relevant theoretical frames of references are lacking. The gained efficiency was in most respect unexpected. As was in the case in the Swedish automotive industry two decades ago (e.g. Blackler and Brown, 1978; Eckerström and Södahl, 1981).

Albeit, the electronic products manufactured and the components fitted are small compared to automotive vehicles and thus not calling for an advanced materials feeding techniques. Moreover, the short product life cycles of electronic products forms specific manufacturing preconditions. In fact, the exceptional short product life cycle was the underlying reason in Japan for abandoning the traditional assembly line, i.e. investment in manufacturing equipment as well as the inflexibility of the assembly line more or less forced the Japanese electronic industry to transform their assembly systems. Although it may be argued that most of these manufacturing preconditions maybe just as relevant for the automotive industry (see e.g. Goldman, Nagel and Pries, 1995; Kidd, 1994; Kidd and Krawowski, 1994).

In conclusion, the earlier strive for a humanised assembly work within the Swedish automotive industry meant a realisation of socio-technical oriented assembly systems designs. Some assembly systems were more successful than other, while the cumulative knowledge of these experiences are at this period of time almost, for various reasons, forgotten. In this context it must be noted that most of the unorthodox assembly stems deigns where not, with regard of recent experience and knowledge gained during the 1980s. not correctly designed.

For these reason is might consequently be appropriate to distinguish successive shift in design paradigms within the Swedish automotive industry, i.e. different focus with regard to primary effects. The humanisation of work as a primary effects sought for proved during the 1970 – 1980 to hide a secondary effect of improved efficiency due to technical reasons (i.e. reduction of the production losses). However this specific secondary effect was not explicitly an argument for this transformation, i.e. being just as efficient as comparable serial product flow assembly systems was considered sufficient.

While today is, even thought the comparable higher efficiency of the parallel product flow assembly system design, the primary effect sought for by the Swedish automotive industry is improved efficiency, by appointing to international manufacturing principles and practices. Though most certain do this strive hide dimensions of management fear for "lost" detail control of the shop floor work. Which may be regarded as a general failure for the Swedish society as a whole. Especially so since the labour relation legislations' rules and practices in Sweden comprise mechanisms for sharing of "profits" in the form of e.g. reduce production losses and increased flexibility. A state of art that are not present in e.g. Japanese society.

Moreover an extreme working up, as was the case in example 2, will by no means enhance improved humanisation, but points out the need of rules regulating the internal and external preconditions for work groups and individuals. The secondary effects like improved space utilisation, reduction of the number of manufacturing equipment and tools, as was found by the Japanese electronic industry, was for analytical reasons clear for the authors earlier as has been published elsewhere. Furthermore, the improved flexibility and more efficient manufacturing engineering work due to the use of a so-called assembly-oriented product structure in combination with use of transformed data directly emanating from product designer work (i.e. from the traditional design-oriented product structure) are other merits to be accounted for (see Engström, Jonsson and Medbo 2000 for further explanations).

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