Agile Manufacturing: 21st Century Manufacturing Strategy

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The Method of Successive Assembly System Design Based on Cases Studies within the Swedish Automotive Industry

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ABSTRACT

This chapter presents and illustrates a design procedure applied at several Swedish assembly plants during the last 15 years. It has been used for the design of the Volvo Uddevalla plant in 1984 – 93, the Volvo Truck plant in Tuve in 1988 – 90, the redesign of the Volvo main plant in Torslanda in 1989 – 90 and the design of the Autonova plant located in Uddevalla in 1996 – 1997 as well as for the restructuring of the information system at the Scania diesel engine assembly in the main Södertälje plant in 1998 – 99.

The first four cases concern the design, or redesign, into unorthodox parallel product flow, long cycle time assembly systems, while the fifth Scania case deals with improving the shop floor information in a traditional serial flow assembly system (an assembly line), i.e. improvement of work instructions and product variants codification, as well as handles the organisation of introducing product design change orders.

A more efficient introduction of product design change was an unforeseen consequence of the adoption of parallel product flow, long cycle time assembly systems, which require a restructured information system. This merit was not fully recognised by the management responsible for the first four cases but turned up, more or less, as a side effect of the unorthodox assembly system designs.

The parallel product flow, long cycle time assembly systems, have merits in form of efficient flexible manufacturing compared to traditional assembly systems owing to reduction of losses (due to the fact that fewer operators have to be co-ordinated), increased flexibility (accepting higher product variation, shorter time for introducing product design change orders, etc.) and better space utilisation than for serial product flow assembly systems. Although these merits are mentioned in this chapter and covered by appropriate references the authors have focused on highlighting some specific aspects of general interest by presenting the design procedure used, i.e. the common denominator between the five cases, which has successively been refined during the last years' work. This design procedure is denoted successive assembly system design.

1. INTRODUCTION

The concept of agile manufacturing summarises various trends used for designing and implementing advanced manufacturing systems, thus underlining the integration of technology, organisations and people (Kidd and Krawowski, 1994, pp. 7). Agile manufacturing views manufacturing system design as an interdisciplinary activity, and organisation and people issues need to be addressed in parallel with technical issues, that is, using a concurrent engineering approach rather than a serial engineering one according to Kidd (1995, pp. 46), who states that the design paradigm of agile manufacturing is characterised by: (1) Holistic systems-based approach; (2) Concurrent engineering concepts applied to the design of the manufacturing enterprise; (3) Application of insights from the organisational and psychological sciences to the design of the technology and overall manufacturing enterprise; and (4) Consideration of organisation and people issues at all stages, from the formulation of business strategy right through to the design and implementation of systems. The authors' experiences from assembly system design during the last two decades, support this design paradigm.

Some Swedish assembly plants comprise unorthodox designs in the international perspectiv, since these plants utilise *parallel product flow with patterns* combined *long cycle time assembly work* based on a holistic systems approach. These system designs have merits in form of reduction of losses (due to that fewer operators have to be co-ordinated), increased flexibility (accepting higher product variation, shorter time for introducing product design change orders, etc.), better space utilisation than on the *serial product flow assembly system*, i.e. the assembly line (see e.g. Engström, Jonsson and Medbo, 1999). However, these assembly system designs call for an intriguing design procedure in order to realise their potentials.

Though sometimes viewed as 'social experiments', these plants have successively during the last two decades generated a rational design procedure denoted *successive assembly system design* (Engström, Jonsson and Medbo, 1997). This fact is not always noted in the international discourses concerning merits and malfunctions of various assembly systems.

This chapter will describe and illustrate successive assembly system design which has been refined and used by the authors in five case studies involving long time co-operation between industry and university. The design procedure was initiated and used for the Volvo Uddevalla plant design and was revised in the redesign of the Volvo Torslanda main plant, a redesign which was never implemented (see Engström, Jonsson and Medbo, 1999), and for the Volvo truck plant in Tuve, as well as for the Autonova plant. All these four cases used or use parallel product flow, long cycle time assembly systems. The last case is the reopening of the Volvo Uddevalla plant operating as a joint venture between Volvo and Tom Walkinshaw Racing (TWR), denoted Autonova. This company manufactures exclusive coupés and convertibles for Volvo.

Finally, restructuring of the information system at the Scania diesel engine assembly at the main Södertälje plant utilises the same design procedure, but with the aim to improve the quality of data supplied to the operators on the workstations along the existing assembly line as well as to facilitate the introduction of product design change orders in order to, e.g., ensure product quality (Portolomeos and Schoonderwall, 1998). These five cases, #1 the Volvo Uddevalla plant, #2 the Volvo Torslanda plant, #3 the Volvo Truck plant, #4 the Autonova plant and #5 the Scania assembly line, underline the generality of the design procedure. See Table 1.

Table 1
Summarisation of the five cases on which the successive assembly system design is based.

Case:	Product:	Co-operation [years]	Aim:	Comments:
#1 The Volvo Uddevalla plant:	- Automobiles (Volvo 740-model).	1984 – 93	- Design of assembly systems.	- Parallel product flow assembly system. - Cycle time of 80 – 100 minutes.
#2 The Volvo Torslanda plant:	- Automobiles (Volvo 200-, 700- and 800-models).	1989 – 89	- Design of assembly systems.	- Parallel product flow assembly system - Cycle time of 110 minutes.
#3 The Volvo Truck plant:	- Trucks (F-mod, 6 x 2).	1989 – 90	- Design of assembly systems.	- Parallel product flow assembly system - Cycle time of 240 minutes.
#4 The Autonova plant:	- Automobiles (Volvo 800- and C70-models)	1995 – 97	- Design of assembly systems.	- Parallel product flow assembly system. - Cycle time of 90 – 150 minutes.
#5 The Scania assembly line:	- Diesel engines (Scania D12 engine).	1998 – 99	- Restructuring the information system.	- Serial product flow assembly system. - Cycle time of 4 - 8 minutes.

Since parallel product flow, long cycle time assembly systems have more degrees of freedom than traditional serial product flow assembly systems, the design procedure is more demanding and requires an elaborate theoretical foundation, a foundation not yet fully crystallised and internationally communicated among practitioners as well as researchers.

The *work hypothesis* for design of parallel product flow, long cycle time assembly systems (Engström and Medbo, 1992), demands agreement between (1) operators' perception of the assembly work, (2) the materials display at the work station, and (3) the information at the work station in form of e.g. work instructions and product variants codification.

This will in turn require (a) an assembly-oriented product structure, i.e. a product structure that describes the product and its components from an assembly point of view – in contrast to the existing, traditional design-oriented product structure used within the Swedish automotive industry based on the so-called function group register (codifying a vehicle into the main groups) and (b) a non-traditional materials feeding technique by means of kitting. Since parallel materials addresses are required, resulting in numerous stockkeeping units, there will not be enough space for the materials volumes feed by unit loads.[1]

[1] If traditional continuous materials feeding technique, alternatively batching, is utilised in parallel product flow assembly systems, control of the number of components to store, replenishment, and the numerous product design change orders will be complicated to administer and handle. That is, in practice it will prove extremely difficult to secure that the correct components are available at the workstations and fitted to a specific vehicle since it will be impossible to keep track of all small components with continuous materials supply. In kitting the accuracy is increased and the number of stockkeeping units (SKU) are drastically reduced given a parallel flow, in principle just one unit for each part number e.g. Bozer and McGinnis (1992).

A correctly designed parallel product flow, long cycle time assembly system in accordance with these theoretical foundations will result in (c) an increase of the economically viable cycle time, (d) an efficiency potential gain in form of reduction of the production losses, i. e. system, balance and division of labour losses (Wild, 1975), and (e) increased flexibility including rapid market response.

Thus, parallel product flow, long cycle time assembly systems call for a non-traditional materials feeding technique as a precondition for efficiency and flexibility, while the assembly-oriented product structure is needed for assembly system designs that bridge the competence requirements, based on the assumptions that it is impossible to learn the increased work content within reasonable learning times due to the requirement of extensive repetitions of specific work tasks (De Jong, 1956), by turning so-called atomistic learning into holistic learning (Marton, 1970 and 1981). For a more detailed explanation of theoretical and practical frames of references, which is not possible to include in this chapter, see e.g. Medbo (1999).

The elaborate design procedure comprises restructuring of several subsystems as is hinted above, as well as the questioning of traditional knowledge and practice within the automotive industry. This chapter reports on experiences made in assembly system designs by describing successive assembly system design used for work structuring by means of disassembly of products taking advantage of the product information which proved to be already available mainly through the design-oriented product structure but also through the existing product and manufacturing process data.

The assembly system designs considered shall mainly consider work in autonomous work groups, utilising so-called 'collective working' in order to emphasise the fact that operators in an assembly system work together on one or more products, having common responsibility for production output within a so-called *work station system*.

Example 1:

An example of findings regarding the performance of parallel flow, long cycle time assembly systems is the author's video recordings which showed that the observed assembly time in the defunct Volvo Uddevalla plant was 15 – 20% shorter than the standard assembly time settled by predetermined motion-and-time systems. Actual learning time needed to attain the required assembly competence was substantially shorter than previously reported by some researchers. Also the annual model change cost per automobile for the same automobile model at the Volvo Uddevalla plant proved to be lower than for the serial flow assembly system at the Volvo Torslanda when manufacturing the same product (see Engström, Jonsson and Medbo, 1999).

2 USING PRODUCT DISASSEMBLY AND AVAILABLE PRODUCT INFORMATION IN ASSEMBLY SYSTEM DESIGN

An important work hypothesis involved in the design of parallel product flow, long cycle time assembly systems is that of structural congruence. As stated above, this hypothesis demands agreement between (1) operators' perception of the 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.

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[2] as well as (d) materials display at the work station and (e) the layout and product flow pattern within each work station system.

Due to the requirement for structural congruence, the design of one subsystem simultaneously has to take restrictions on other subsystems into account, and the total design procedure is an iterative process which successively crystallises and refines defined subsystems – rather than a linear process proceeding from the design of (a) to the design of (d). For analytical purposes, however, the design procedure may be regarded as starting with the design of a suitable hierarchical product structuring scheme (a).

Although an ideal design procedure of parallel product flow, long cycle time assembly systems ought to be based on total congruence between (a), (b), (c), (d) and (e), this chapter will mainly report experiences on (a) and (b), thus only briefly sketching on (c), (d) and (e) these have been reported elsewhere (see e.g. Engström and Medbo, 1994). The total design procedure developed and used will be discussed below. However, it will mainly be illustrated by the Autonova plant design procedure (case #4) but also by data from the other cases.

Example 2:

Disassembly of products are shown in Figure 1. These products were used for design of assembly systems and for restructuring of an information system respectively. To the left there is a photograph of a disassembled automobile (Volvo 800-model) from the design procedure of the Autonova plant in 1995 and to the right a photograph of a diesel engine, disassembled at the Scania engine assembly plant in 1998. In principle, these disassemblies constituted an additional development of analyses done for the design procedure of the Volvo Uddevalla plant more than ten years earlier.

The removed components were organised according to so-called work modules in the Autonova case as well as according to the individual operators' work at specific work stations along the existing assembly line in the Scania case. In both cases the components were separated by means of wooden lathes.

Note, for example, in the photograph from the Autonova case the labels fixed to the components representing various product variants as described in example 5 and the small cards guiding the disassembly, positioned on the tables.

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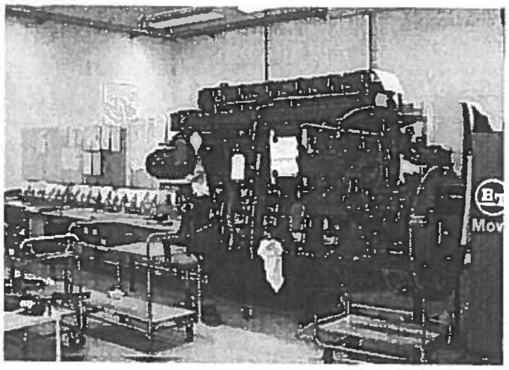
[2] In the case of the Volvo Uddevalla plant. In this case the modules corresponded to the working position and the position of the automobile body. The modules were designed in accordance with the tilting device which enabled the automobile body to be altered (adjusted in height respectively rotated along the longitudinal axle of the automobile in order to improve ergonomics). Thus, for example one work module was denoted "tilt over" corresponding to assembly work on the upper side of the vehicle as well as on a tilted automobile body.

Disassembly at Autonova (Uddevalla) in 1995 for design of assembly systems (case: #4).



Disassembly at Scania (Södertälje) in 1998 for restructuring of the information system (case: #5).

Figure 1. Disassembly of products.

To support long cycle time assembly work, there is a need for a reformed product perception using product information which has proved to be already available mainly through the design-oriented product structure but also through the existing product and manufacturing process data. This is an essential requirement since it facilitates the design procedure and promotes the introduction of e.g. non-traditional materials feeding techniques (i.e. it is necessary for the function of the new assembly system to communicate with the design-oriented product structure).

To design a hierarchical product structuring and a corresponding hierarchical assembly work, structuring schemes have been developed through disassembly of some automotive products, i.e. the Volvo 200-, 700- and 800-models, as well as the Volvo truck F-model. The methods used, in the case of the Volvo Uddevalla plant design procedure, were in many respects an interactive search process during a period of approximately 8 – 10 months, engaging two of the authors who were involved not only in this activity.[3] This was in almost all respects a tedious manual process, i.e. making notes by hand during the disassembly, using photocopy machines, basing different types of analysis on insufficient and often incomplete data, as well as searching for the appropriate information and personal contacts within Volvo.

Though the process was time-consuming, it certainly resulted in the building-up of knowledge, as well as serving as a method to formalise practitioners' knowledge, e.g. by having Volvo expertise continuously checking the work by e.g. cross-reading constructed alphabetical registers and 'dictionaries' describing product functions, explaining anachronisms, calling for specific documents required for the running in of the plant in the form of assembly instructions and variant specifications, etc.

The development of the hierarchical product structuring scheme and a corresponding assembly work structuring scheme involves a constant change between the components from the disassembled products placed on the floor of an experimental workshop which was at the researchers disposal, and production documents and data printouts placed on large tables. The

[3] This procedure has later been speeded up considerably and further refined by the use of e.g. database programmes, personal contacts with expertise within Volvo for the supply of information on diskettes, printouts of specially required labels etc, thus, as was the case in the Autonova plant, making it possible to engage both operators and the plant´s engineers in the procedure, thereby bridging the practical gap between practitioners and researchers.

development work was practically performed by moving the physical components around, modifying data printouts, photographs and drawings, using scissors and glue to compose new documents until a logical coherence between physical and logical descriptions was achieved. This was a procedure which also served as an illustration of the work structuring principles and methods successively crystallised during this process.

These work structuring principles and methods have proved to be generally applicable to most vehicles and are based on five characteristics, generic to all vehicles. As illustrated by the photos in Figure 4 there is at least one obviously generic characteristic implying the existence of general structuring principles and methods, i.e. the components are distributed around a symmetrical axle running in the middle of the body, back to front – an organic symmetry where some components are symmetrical in pairs around the mid axle, while others appear only once, almost like a human body. In fact, automobiles and trucks, as well as most other automotive vehicles, show five *generic characteristics, or symmetries*, which form the basis of the work structuring: (1) similarity to the organisms as mentioned above, (2) product functions, (3) plus/minus relationships, (4) generativity and (5) diagonal symmetry (Engström, 1991).

The disassembled products, laid out for long periods of time on the shop floor in the experimental workshop, also explained the unorthodox assembly system design developed, including the materials feeding techniques (e.g. kitting fixtures, kitting process, etc.). The experimental workshop also served as a vital source of information for the management, Volvo expertise and qualified external visitors approved by Volvo during the period 1985 – 1991.

Very briefly described, in general terms, the design procedure used for work structuring contains four phases, denoted A – D, as described below.[4] These *work structuring phases* are:

A. Collecting information used in later stages.
B. Preparing for disassembly.
C. Disassembly and checking through assembly.
D. Considering the effect of product variants.

Example 3:

The assembly-oriented product structure separates the components hierarchically into groups that have common characteristics from an assembly perspective, i.e. product function, form, material or modules of the product, thus making it possible to discriminate between the groups of components (see section 4 for a more detailed explanation). Below in Figure 2 the assembly-oriented product structure for the Scania diesel engine is shown.

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[4] This procedure can of course have different scopes according to e.g. vehicle model and the range of product variants.

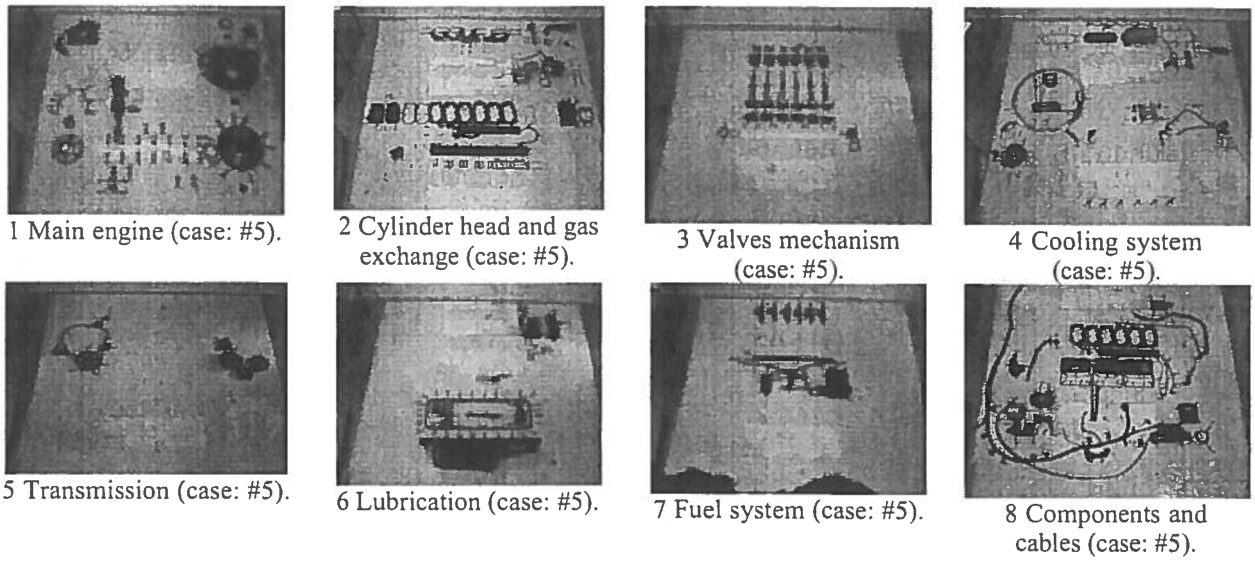

Figure 2. Disassembled diesel engine at Scania in 1998 expressing an assembly-oriented product structure. The components are positioned on the floor according to their position on the engine. The paper silhouettes illustrate various views of the engine (Portolomeos and Schoonderwall, 1998).

3. COLLECTING INFORMATION USED IN LATER STAGES (WORK STRUCTURING PHASE A)

This work structuring phase mainly includes:

- A.1. Collecting the relevant product information including e.g. so-called materials control codes complemented with information about suppliers, materials feeding techniques and quantities, weight, the need for or use of special packaging, etc.
- A.2. Collecting the 'correct' translation of product variant codification into true product characteristics.
- A.3. Collecting correct component name and descriptions of product systems function including clearing out synonyms and homonyms.
- A.4. Obtaining data files stating the assembly times for each detailed assembly task.
- A.5. Reconstructing an assembly sequence from various plants or alternatively from some persons familiar with this sequence. The latter might prove to be difficult since overview of the detailed sequence neither was, nor is, within one specific practitioner's knowledge within the Swedish automotive industry.

Collecting the relevant product information in the case of Volvo automobiles requires among other things: (1) to have a data file of the design-oriented product structure containing the component's name/position on the product, variant code, etc. and (2) to get hold of the detailed assembly instruction from the central Volvo product and process department, so-called process and control instruction[5], as well as other types of relevant information such as workshop manuals, service instruction material, interviews, etc.

Collecting the correct 'translation' of product variant codifications and turning these codes into e.g. true, real product characteristics, component names and product properties was (and still is) quite another matter within Volvo since some of the codes (e.g. type of market, type of emission system or type of springing and dampening) are not related to product characteristics relevant on the shop floor. The reason for this is that these characteristics do not influence the product on the shop floor in a logical way. Therefore a deep knowledge of the design-oriented product structure and product and manufacturing process data is necessary to decode this information. The overall knowledge concerning these matters is not available at a single source within the company or promoted as a necessity since it is divided between numerous individuals.

The authors have therefore in all cases of application of this specific phase in the cases mentioned above been required to construct alphabetical registers and 'dictionaries' themselves based on workshop manuals, service instruction material, interviews, etc.

Work in this work structuring phase, in the Volvo Uddevalla case, proved to be time-consuming since the product perception on the shop floor, as well as from the manufacturing engineering's point of view, proved too fragmented to even allow systematic disassembly of an automobile. The general understanding of which components were interconnected or related to other components due to product functions or true product variant characteristics was also lacking.This knowledge is obviously present within the company mainly in the design department, who expresses their work by means of the design-oriented product structure, but during the transformation of information from the design department to the shop floor, both logic and information are deformed, mutilated or lost (see Engström and Medbo, 1993; Medbo, 1994).

Note that the different engineering documents within Scania and Volvo did not, and still do not, possess a coherent stringent vocabulary. Thus it was, and still is, extremely difficult to cross-read or get hold of the total mass of information available, which in fact has proved necessary in both the Volvo automobile and truck companies as well as at Scania.

Example 4:

> The photographs in Figure 4, from the Volvo Uddevalla plant design, show the components in a Volvo 740-model. Each photograph corresponds to 1/8 of an automobile, approximately 1 hour's assembly work. The suggested assembly system design comprised work station systems with three operators resulting in 20 minutes' cycle time, a division of labour suggested by the manufacturing engineers at Volvo since it was assumed to be the maximum economically viable cycle time (leading to a learning time of 4 – 8 weeks to achieve a work pace of 115 MTM).
>
> These photographs proved to be valuable when formulating and communicating the work structuring principles and methods as described in this chapter, and by placing them beside each other, they helped illuminating the assembly work in a plant where 1/8 of an automobile was assembled in eight separate assembly workshops in series as is schematically shown below in Figure 4.

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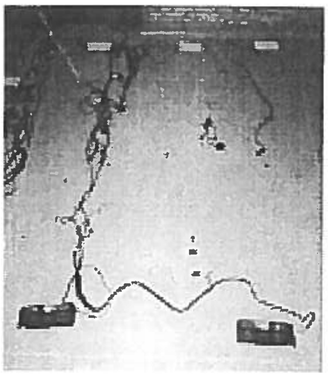
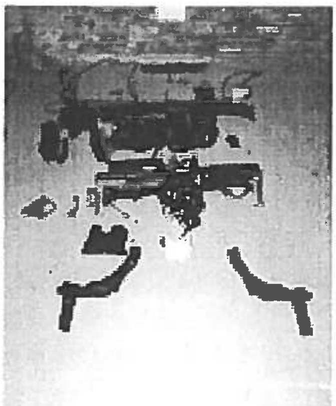
[5] These instructions contain, among other things, illustrations of the detailed assembly work.

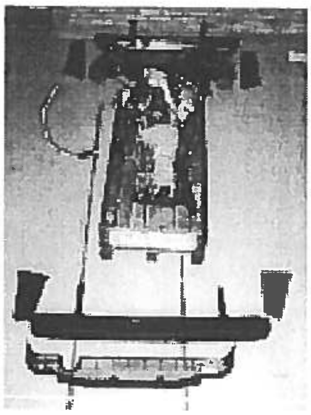
This made it evident that such a plant would require either large intermediate buffers between each assembly workshop or a constant shifting of operators according to time differences between individual products and product variants; consider for example the components needed for an air conditioner added to the components shown in the photographs. This way the suggested division of labour would imply extra space requirements and system losses as well as a degradation of the product perception by basing it on only 1/8 of an automobile.



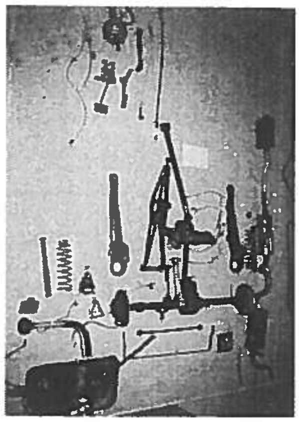
Assembly work shop 1 (case: #1).



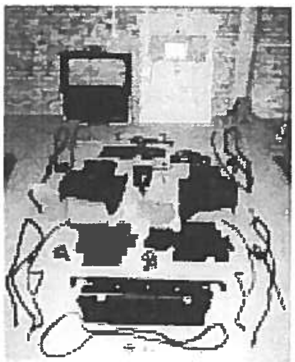
Assembly work shop 2 (case: #1).



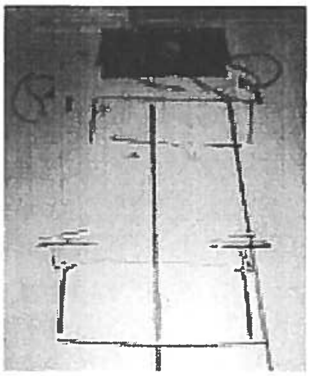
Assembly work shop 3 (case: #1).



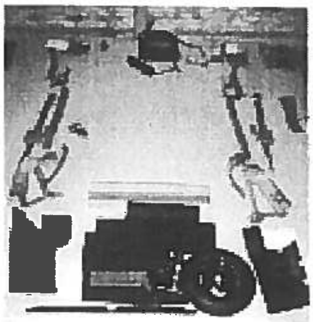
Assembly work shop 4 (case: #1).



Assembly work shop 5 (case: #1).



Assembly work shop 6 (case: #1).



Assembly work shop 7 (case: #1).

Assembly work shop 8 (case: #1).

Figure 3. A disassembled automobile where the components are positioned on the floor according to their position in the automobile body.

4. PREPARING FOR DISASSEMBLY (WORK STRUCTURING PHASE B)

This work structuring phase mainly includes:

B.1. creating small cards describing the detailed assembly work (see Figure 4).

B.2. creating labels comprising information from the design-oriented product structure, (see Figure 5). These labels also contain information concerning the components suggested to belong to other types or groupings or information as to whether the same materials control code is used for one or more components fitted in different positions on the vehicle. [6]

B.3. excluding all the small cards that are not assembly-relevant due to the scope of and restrictions on the design procedure (e.g. excluding punching the identification number on the vehicle, automatic gluing of the windshield, work performed in the testing workshop after assembly, and other tasks which are performed outside the work station systems).

B.4. grouping the small cards according to a suggested assembly sequence into suggested work modules, i.e. different levels of the detailed assembly sequence, depending on specific shop floor preconditions, forming the suggested intra-group work pattern.

During the design procedure of the Autonova plant, the work was supported by having the design-oriented product structure available on line, as was also the case for the Volvo truck plant as well as for Scania. An *analysis data base* composed of different data files including information such as size of materials containers, weight, suppliers, etc. was created for the Autonova plant design. This was not possible to accomplish during the early Volvo Uddevalla plant design ten years earlier.

Thus it was possible to conveniently document the successive results from the disassembly, as well as to transfer the results for the total design of an assembly system, regarding among other things, materials requirement, space utilisation for stored materials, etc. In fact, in the Autonova case the design procedure, as well as the starting-up of this plant, was based on this specific analysis data base.

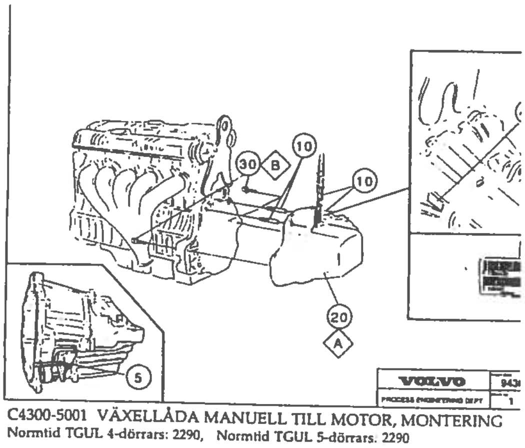
Example 5:

During the design of the Autonova plant 1 000 small cards of approximately 14 x 10 centimetres were used, containing illustrations of detailed work tasks forming a work

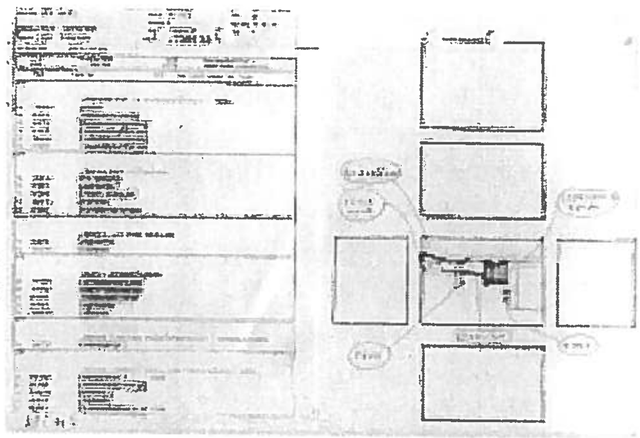
[6] There are at least three explanations for the time-consuming work to create a database related to the Volvo design-oriented product based on disassembly, i.e. to designate the correct physical component to the 'right administrative position' in the design-oriented product structure. This is a reversed process to the ongoing work in a running plant to use the bills-of-materials (derived from the design-oriented product structure) to trigger the materials to be delivered. One reason is that in the original Volvo design-oriented product structure the smallest identifiable unit (material control code) is equal to the materials address along the traditional assembly line. Thus identical components could be fitted at different positions on the product and it is time-consuming to identify and designate the components correctly. Another reason is that the information systems within Volvo are not designed for this type of analysis. They have in fact been developed over the years into a complex conglomerate of information systems suited when steering a complex, constantly changing organisation where work moves around between manufacturing facilities, sub-assembly and final assembly stations, etc. Finally, the information is constantly changing and the different files containing information are not synchronised. Therefore, each existing local assembly plant transforms the design-oriented product structure according to the specific assembly system design and the product variants manufactured (see e.g. Engström and Medbo, 1993).

operation and product variant codification. Each card included name of the work operation and the assembly time for the work operation required for two selected product variants.

These small cards were derived from the Volvo process and control instructions, which contained illustrations of the work, name of the detailed work operations, etc. The original document was extensive and included 1 – 10 pages of front illustrations as well as standardised forms of 1 – 45 pages, depending on work tasks and product variants comprising assembly sequence and materials required (defined by component number, component name, variant codification, tools, torque, control instructions, quality demand, etc.).



Small cards used at Autonova.



Small cards used at Scania.

Figure 4. Small cards used for guiding the disassembly at the Autonova plant design in 1996 and for the restructuring of the information system at Scania in 1998.

The method used to create these cards requires shrinking of the illustrations by means of a photocopy machine and transferring of the name of the work operation and the design-oriented product structure codes. The cards were also complemented with a sequence number, in this case from 1 to 997, first in order to be able to find the Volvo process and control instruction, i.e. the original card (some were prone to get lost), and second since the result of the procedure might need a future update due to product design change orders.

The total procedure was complicated by product design change orders which necessitated keeping various generations of information 'in the air' simultaneously. This fact called for synchronising the content on the small cards regarding the physical components of the existing automobiles disassembled, as well as the analysis data base by means of the Volvo design-oriented product structure.

On the other hand, for the restructuring of the information system at the Scania diesel engine plant, it was first a matter of understanding an existing assembly system and a number of interrelated information systems in form of Scania's design-oriented product structure, the information system which generates assembly instructions and the work orders for each diesel engine, i.e. the specification of the components required for individual engines. This, accordingly, led to the construction of small cards, of approximately 14.5 x 21 centimetres, one for each of the 43 work stations along the existing assembly line.

Each card contained six views of the engine (the components assembled at a specific work station were sketched for each view) as well as shrunk information from the work orders of the respective work stations etc. for a specific product variant. By this procedure all available information along the existing assembly line for the engine to be disassembled was gathered on these cards. This information was first checked and modified by collecting small components put into plastic bags fetched from the assembly line as well as by interviewing the operators.

The disassembly and understanding of the information systems was facilitated by the complement of folders for each work station that contained assembly instruction, engineering drawings, work orders for other product variants etc.

During the disassembly of the diesel engine, guided by the small cards, cross-reference of the removed components with the small components fetched from the assembly line, and marking of the appropriate documents contained in the binders resulted in the understanding of both the physical product, the existing assembly system and the information systems. This procedure underlined e.g. various anomalies of the present information system.

94 82 10
bandklamma 45.
3730-1001
2
2.0

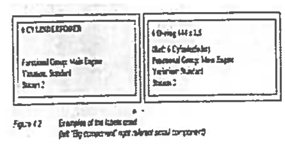
Label used in 1987 during disassembly used for the design of the Volvo Uddevalla plant (case #1).[7]

GOLVMATTA,BLÅ A 1 001
V FRAM
1310002 855301O 011 1
V-STYRD GLES LUG BLA MAT
GOLVBEKLADNAD
golvmatta främre V, V-styrd, lågnivå

Label used in 1989 during disassembly used for the design of the Volvo Torslanda plant (case #2).[8]

PLUGG,SVART
FIXERING AV BOTTEN-
^SVALLARKABLAGE
LEDNING,BOTTENSVALLARE
16st 3760 010 515 1264326 011100
flera åtgångar
V:2 C3760-5001 deladat LB014
80
Mont.fas: Delfas: Delad med:

Label used in 1995 during disassembly used for the design of the Autonova plant (case #4).[9]



Label used in 1998 for disassembly used for the restructuring of the information systems at the Scania assembly line (case #5).

Figure 5. Example of different labels containing product information used for disassembly.

[7] These labels were used for our first work structuring. i.e. the disassembly was aimed at identifying an assembly-oriented product structure, as well as the suggested detailed assembly sequence for the first automobiles assembled in the Volvo Uddevalla plant. In this case a delimited number of specific product variants were first considered.

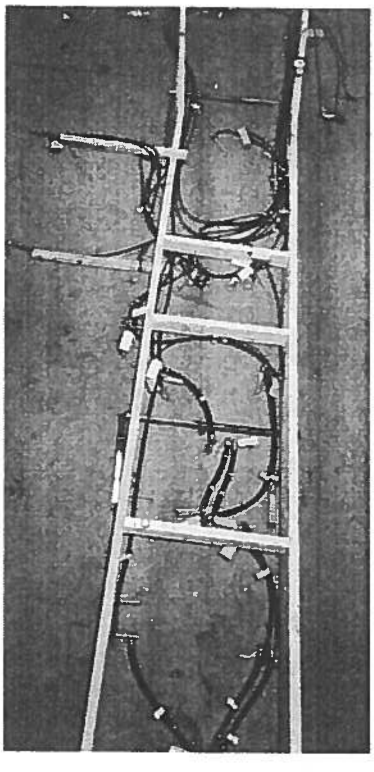
[8] These labels were used for disassembly comparing three specifically different product variants (denoted "A1", "B1" and "C1" on these labels) during a period when no formal product- and process information regarding parallel flow assembly system existed within Volvo. The Uddevalla plant was being designed using inferior information support since this system was under development and the responsibility for the information quality was not defined.

[9] These labels were used to guide the design, for all product variants, of the detailed intra-group work pattern, materials feeding techniques, analysis data base, etc., as well as to guide the unpacking and sorting of components delivered for the first 40 product variants manufactured in Autonova. The unpacking refined the analysis database still further. Note that in this case the assembly-oriented product structure was already regonised. During the actual disassembly, a procedure started to designate the right material control code to the correct assembly position on the automobile. This was performed by letting the components with the same material control code but different assembly positions have as many labels as number of positions chosen, resulting in adapted material control codes through splitting of the original codes.

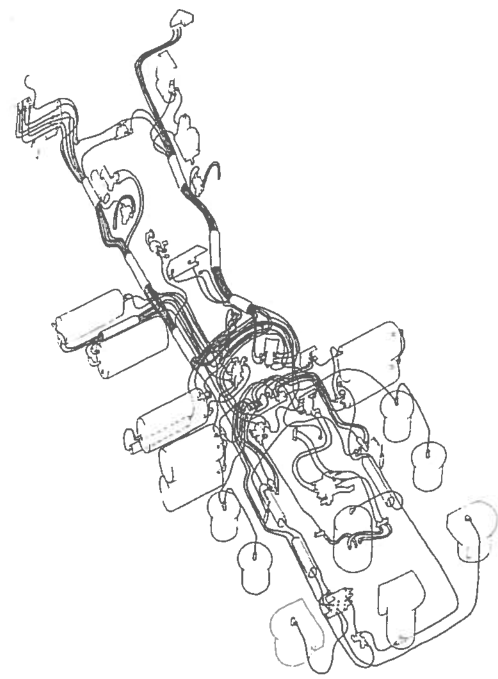
acquire in-depth learning of the product, as well as to establish the interrelationship between the components and the design-oriented product structure. This work was also facilitated by using illustrations reduced in size from those provided by the central Volvo product and process department (see Figure 4), and by the construction of specially designed illustrations as a contextual visual aid. These illustrations contained several interrelated levels and used a standardised outline for normalising the illustrations. The vehicle is viewed diagonally from behind, as if entering an automobile on the driver's side (see Engström, Hedin and Medbo, 1992) and example 6.

Example 6:

Disassembly of a Volvo truck in the experimental workshop in 1988 – 89. During this work a complete truck was disassembled. The components were either placed on the shop floor or, as was the case with all leads, as illustrated in Figure 6, positioned and fixed at a number of wood mock-up frames. Thus a number of systematic, normalised illustrations were created according to similar principles as used for automobiles during the Volvo Uddevalla plant design. This work was the starting point of the introduction of the parallel product flow, long cycle time assembly system at the Volvo Tuve plant, in 1991.



Wood mock-up of truck frame and leads.



Leads normalised against a transparent outline.

Figure 6. To the left there is a mock-up of a truck frame for fixation of leads removed during the disassembly. Four different mock-ups were required, one for each system of leads and to the right there is an illustration of leads normalised against the transparent outline. The 'transparent' components (air hoses for suspension, various tanks, etc.) shown only in form of contours are expressing that these components are omitted.

See Figure 5 for example of labels containing product information used during disassembly generated from the analysis date base. These labels complemented the small cards shown in Figure 4, by having all information necessary to relate the label to the design-oriented product structure. This meant information such as e.g. manufacturing engineering data, materials feeding information and in some cases even selected data from other plants as reference.

Consequently it becomes possible to decompose e.g. one single product using its components as representative of all product variants. In practice the component, e.g. one seat, was removed from the automobile body according to the small card, and the labels for all variants of seats were placed on or fitted to this specific seat. Thus, as has been the case in the Autonova plant design, the product information in the form of labels and small cards could be up-to-date, while the product decomposed could even be old.

5. DISASSEMBLY AND CHECKING THROUGH ASSEMBLY (WORK STRUCTURING PHASE C):

This work structuring phase mainly includes:

C.1. Successively disassembling the product guided by the suggested assembly sequence and the preliminary work modules represented by the grouping of the small cards. The cards are positioned on tables, sometimes divided by wooden laths, in order to overview the component and allowing work modules to be redefined by regrouping small cards.

C.2. Successively positioning the components on the floor dividing suggested work modules by the wooden laths, including positioning the correct labels on or beside the respective component including correcting the analysis data base as the work goes on. Thus giving input to for example the design of the materials feeding technique.

C.3. Rechecking the disassembly and the analysis data base by guiding selected expertise through the disassembled components.

C.4. Final rechecking by assembling the product.

The small cards ought to be positioned on tables near the corresponding components. Any questions and assumptions must be noted on the small cards or on white boards as the work goes on in order to systematically decompose the product. This makes it possible to have extra personnel assist in guiding the work structuring phases, thus speeding up the work, or as has been the case in the Autonova plant design, to let operators who were going to be responsible for specific work on the product perform the disassembly.

During this process each component was marked with the labels (see Figure 5). The authors also sewed all small components together with the appropriate illustrations onto 21 large (220 x 120 centimetres) white sheets of paper[10]. This allowed the practitioners and reserchers to

[10] These paper sheets were also used by the new operators to learn the assembly work in the training workshop, as well as for the initial identification of the small components suited for packing in plastic bags, a unique materials feeding technique especially developed for the Volvo Uddevalla plant (Johansson and Johansson, 1990).

Finally, in the Autonova case, the disassembled products are also assembled and the analysis data base was used in order to mirror other product variants which were assembled to verify the hierarchical product structuring scheme and a corresponding assembly work structuring scheme. The principle of mirroring product information was performed for the design of the Autonova plant where the analysis data base was first developed and refined during the manufacturing of the Volvo 850-model and later mirrored in and used for the manufacturing of the C70-model. Thereby the manufacturing of the new model was extensively facilitated, since a preliminary assembly-oriented product structure was available before the materials for the new product arrived at the plant according to the generic characteristics of automotive vehicles, e.g. the plus/minus relationships (Engström, 1993).

Note that the purpose of the design procedure could differ. For example, in the Volvo Uddevalla case it was initially a question of finding a logical grouping of the components, which in fact proved possible by some thinking and moving around of the components of a disassembled automobile on the shop floor of the experimental workshop.

As a result of this procedure, and by the aid of photos of the components taken in the experimental workshop, it was possible to recognise an assembly-oriented product structure. The main groups in this structure were for the automobile: (0) Doors; (1) Leads for electrics, air and water; (2) Drive line, (3) Sealing and decor and (4) Interior. The first group being sub-assembly work, while the other four were work on the automobile body. These main groups of components imply not only a general classification applicable to automobiles but also, importantly, a classification based on five generic characteristics always present in all vehicles (see also example 1).

The detailed assembly work is then derived from the assembly-oriented product structure according to specific levels, where the highest level, depending on the specific assembly system designs, is work modules. Accordingly, an overall taxonomy, in the form of the assembly-oriented product structure was first stipulated, and different levels of the detailed assembly sequence, depending on specific shop floor preconditions (work group size, competence overlap within the group, ergonomic preferences, etc.) are later derived from this classification. This procedure allows, among other things, an implicit defined interrelation between materials and tools, work descriptions and other types of production documents in accordance with the work hypothesis for design of parallel product flow, long cycle time assembly systems.

In the case of the design of the Autonova plant ten years later, these main groups were known, as well as the general work structuring principles and methods. Thereby the work was primarily concentrated on a search for intra-group work patterns based on work modules as well as a search for the design of materials feeding techniques and focused on the creation of an analysis database to support the design and running-in of the plant as well. The analysis data base was also used for the unpacking and sorting of the materials for the first automobiles.

6. CONSIDERING THE EFFECT OF PRODUCT VARIANTS (WORK STRUCTURING PHASE D)

This work structuring phase mainly includes:

D.1. Detailing the assembly information gained according to variance introduced by different product variants, that are not necessary to disassemble since they could be grasped intellectually by the analysis data base and work performed in phase A. Thereby it became possible to generalise the hierarchical product structuring scheme and the hierarchical assembly structuring scheme to include all product variants through the identification of the so-called *variant tracks* (see Figure 6).

D.2. Identification of variant tracks corresponding to characteristics more or less obvious due to the choice of the assembly-oriented product structure. These tracks correspond to the need for e.g. overlapping competence between operators within or between work station systems, i.e. these tracks may or may not call for extra work, as is evident from Table 2.[11]

D.3. Grasping the differences in assembly work stipulated by a decomposed reference product variant. This could be either by rough estimations or by taking advantage of the existing product and manufacturing process data.

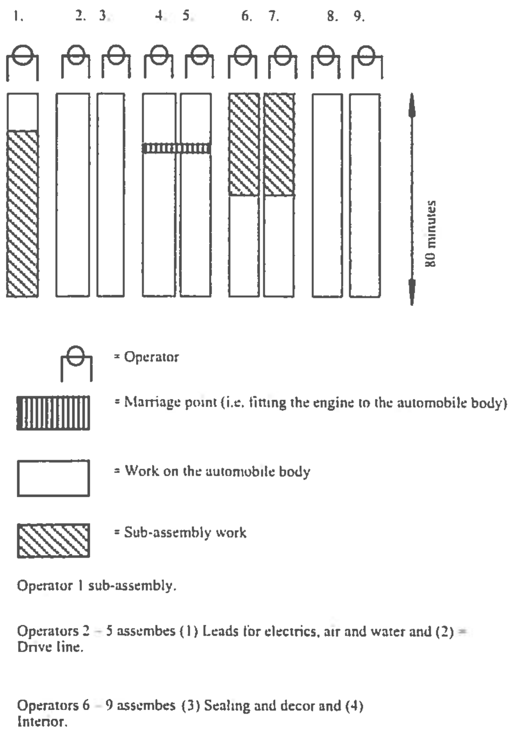
Table 2
Time spread in per cent of assembly work on the automobile body in comparison to a disassembled reference product variant according to the design procedure performed for the Volvo Uddevalla plant design in 1987.

	Reference variant [%]:	Variant 1 [%]:	Variant 2 [%]:	Variant 3 [%]:	Variant 4 [%]:	Variant 5 [%)]	Variant 6 [%]:
Type of variant:*	B230FS, 4D,	B230FS, 4D, ABS-brakes	B230FS, 4D, Aircondition	B230FS, 4D, Sunroof	B230FS. 4D	B230FT, 4D	B230FT, 4D, ABS-brakes Aircondition Sunroof
Operator 1:	25	0	12	0	0	0	17
Operator 2:	25	0	0	20	14	0	31
Operator 3:	25	0	1	16	0	0	21
Operator 4:	25	2	0	16	0	3	20
Operator 5:	20**	3	13	0	1	1	55

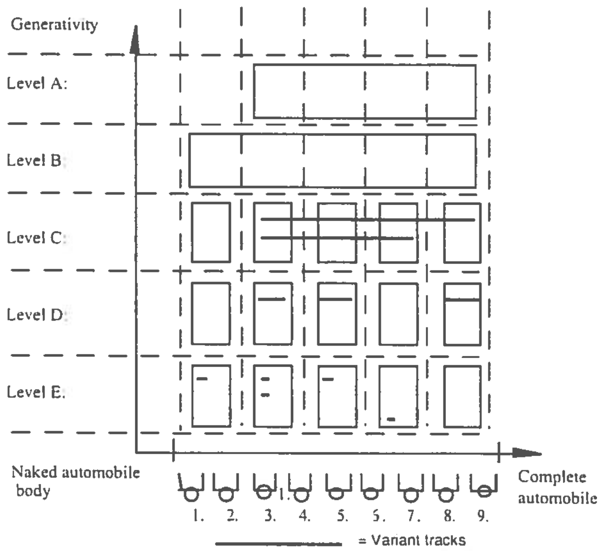
* Extremely brief description B230FS = 2.3 litre suction engine with injection, B230FT = 2.3 litre turbo engine with injection. 4D = four doors and 5D = five doors.
** This operator performed only sub-assembly work corresponding to 20% extra in relation to the 100% work on the automobile body.

[11] In e.g. the Uddevalla case information from the central Volvo product and process department, information in the form of motion-and-time studies, specifying assembly times for specific detailed work tasks, was available for all product variants. Thus we did not e.g. need to disassemble more than two product variants in the case of Uddevalla and one in the case of the Autonova plant design.

In this case it was an assumption of a distribution of the assembly work into four equal parts of work on the automobile body (i.e. 25%) which of course would not be possible to achieve in practice. The time given in Table 2, stipulating additional time for six product variants in relation to the reference variant, was used for the design of different intra-group work patterns, thereby assuming an ideal balancing of the work for the reference variant. The estimation of relevant assembly times for different product variants was a tedious work based on work mapping in the training workshop at the Volvo Uddevalla plant (see Engström and Medbo, 1994) by coding every component according to the product variant codification, as well as by composing and decomposing detailed work tasks organised according to the design-oriented product structure.



Intra-group work pattern at the Volvo Uddevalla plant.



Variant tracks at the Volvo Uddevalla plant.

Figure 7. A schematic outline of how the product variation during assembly is described with the aid of the assembly-oriented product structure. To the left there is the intra-group work pattern for one complete automobile comprised out of work modules, while to the right the variant tracks organised according to generativity are shown, i.e. the product characteristics forms so-called variant tracks through the assembly-oriented product structure. On the basis of this generative distribution the characteristics are grouped on levels from A to E, where level A represents 'obvious' (e.g. 4 or 5 doors, sunroof or not, etc.) and level E 'unpredictable' characteristics from the operator's point of view.

7. CONCLUSIONS

To summarise, the results from the work structuring phases briefly described above are a hierarchical product structuring scheme and a corresponding hierarchical assembly work structuring scheme. These schemes are necessary e.g. as inputs when calculating production capacity considering assembly time constraints. Continued assembly system design is discussed elsewhere, e.g. in Engström and Medbo (1994); the complete design procedure involves design of intra-group work patterns, the detailed work station system layout, the product flow pattern, the materials feeding techniques, definitions of sub-assembly work tasks suitable for integration into the work station system, etc.

The work structuring phases in the design procedure reported above underlines that both an overview and detailed information are required to mould the work to achieve the structural congruence needed for efficient and flexible parallel product flow, long cycle time assembly systems. This requires a combined design procedure amalgamating 'analogous' physical products and an assembly-oriented product structure gained through reforming of existing product and manufacturing process data. Thus it is possible to interrelate the 'shop floor reality' of existing product and manufacturing process data to the future 'shop floor reality', i.e. the assembly systems not yet designed.

From the authors' point of view the cases reported here are not pure examples of participative design procedures as has sometimes been the international perception of unorthodox Swedish assembly system design (Grotingen, Gustavsen and Héthy, 1989). Instead some of these design procedures include an engineering approach, supported by established knowledge from social science (e.g. Karlsson, 1978; Nilsson, 1981, 1995). Accordingly, the true core of the cases reported have been internationally misunderstood as a human relations approach, dimmed by terms like participation and humanisation.

Generally speaking, the experience from and involvement in the design of the Volvo Uddevalla plant and the Autonova plant ten years later, emphasises the importance of transferring design procedures and design experiences between large industrial development projects. In the cases reported above, due to various circumstances, this responsibility has gradually become the role of the researchers; see e.g. Ellegård (1989) and Granath (1991). This has in some respects meant avoiding reliance solely on consultants or internal expertise in these matters, which has influenced large organisations not to fabricate carbon copies of other plants. How much of this knowledge that has in fact been assimilated by the organisations is however debatable.

The experiences reported are consistent with the concept of agile manufacturing which emphasises methodologies of implementation of advanced manufacturing systems and concepts (see for example Kidd, 1994). This can be interpreted as stressing the technical dimensions of the socio-technical design paradigm, which for long time has influenced Scandinavian manufacturing systems designs (van Eijnatten, 1993) and specifically the assembly systems designs within the Swedish automotive industry, including the cases reported here; a design paradigm which has been criticised for neglecting operationalising of technical dimensions (Lindér, 1990). This discourse may, however, basically be due to an assumed contradiction between social and technical sciences. Being an engineering scientist is often an advantage, though, since the manufacturing industry can, more or less directly, access and apply the research results into engineering designs.

However, if the research, as was case for the Volvo Uddevalla plant design, included not only practitioners and engineering scientists, but also researchers in architecture, as well as social scientists within the areas of pedagogy, human geography and psychology, it proved feasible to satisfy various critical restrictions, resulting in a substantial broadening of the set of designs of assembly systems.

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