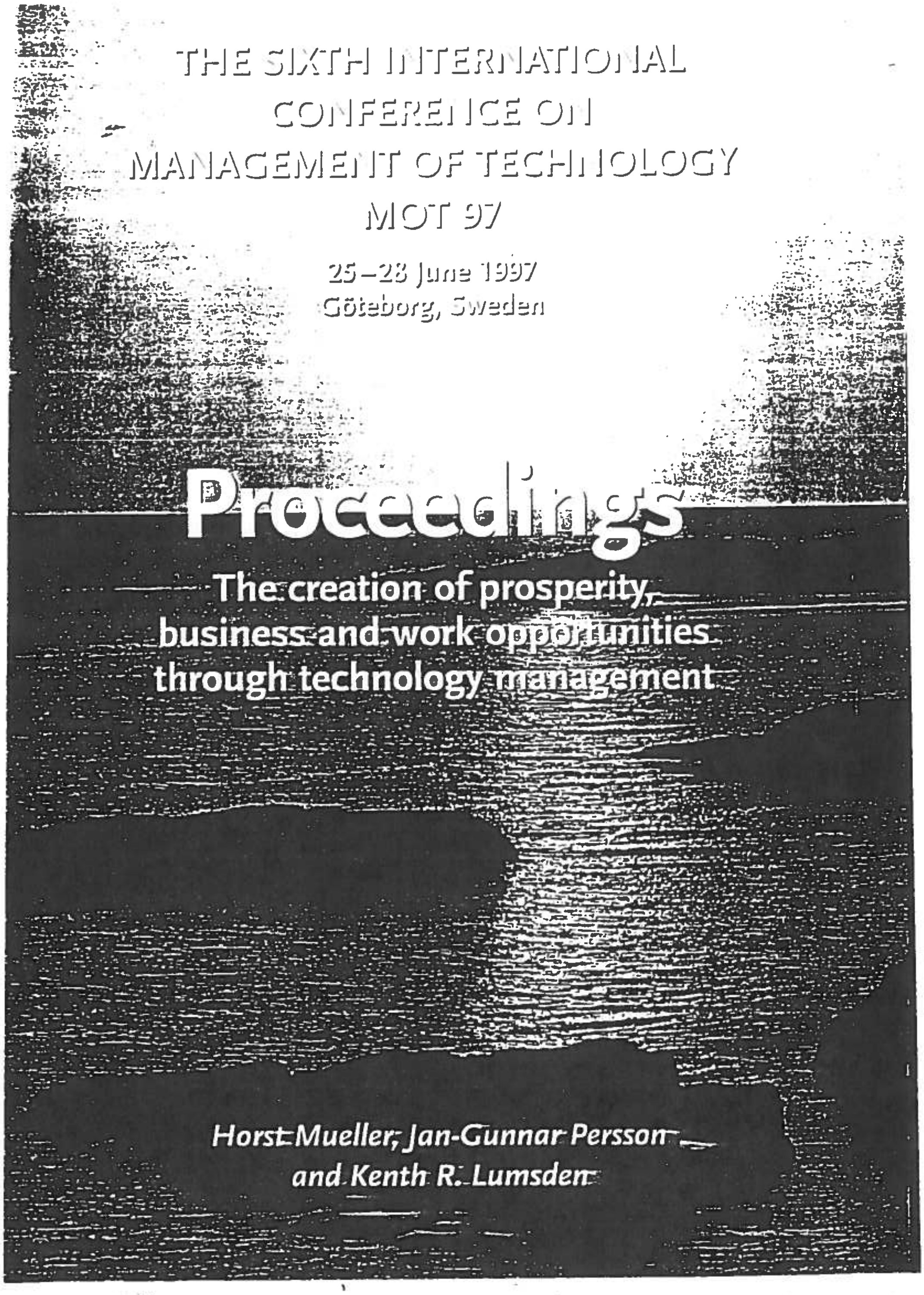

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The creation of prosperity, business and work opportunities through technology management

Horst Mueller, Jan-Gunnar Persson
and Kenth R. Lumsden

Successive Assembly System Design Based on Disassembly of Products

Tomas Engström[a], Dan Jonsson[b] and Lars Medbo[a]
[a] Department of Transportation and Logistics, Chalmers University of Technology, S-412 96 Gothenburg, Sweden.
[b] Department of Sociology, Göteborg University, S-411 22 Gothenburg, Sweden.

ABSTRACT

This paper presents and illustrates some previously unpublished information about the design procedure of the defunct Volvo Uddevalla plant by highlighting some specific aspects of general interest. Namely our design procedure used in the form of work structuring principles and work structuring methods using disassembly of products combined with product information in order to, among other things, gain a holistic perception of product and work. The existence, as well as the application, of these methods within the Swedish automotive industry during the last decade underlines the engineering aspects of the actual design procedure.

The paper will report on experiences made in assembly system design through describing the design procedure used for work structuring using disassembly of products and taking advantage of the product information available. The experiences reported formed the platform for the design of e.g. the new Autonova plant ten years later, which has recently started operations in the same building as the Uddevalla plant.

1 INTRODUCTION

Since parallel flow assembly systems have more degrees of freedom than conventional line assembly systems, the design of parallel flow assembly systems is more demanding and requires a more elaborate theoretical foundation; a foundation not yet fully crystallised and communicated.

An important principle involved in the design of parallel flow assembly systems with long cycle time assembly work is that of structural congruence. 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; (b) a hierarchical assembly structuring scheme used to describe the assembly work as a structured aggregate of assembly operations; (c) the intra-group work pattern, i.e. the allocation of assembly operations to operators within each work group responsible for the assembly of a complete product and (d) the layout and product flow pattern within each work-station system responsible for the assembly of a complete product.

Due precisely to the requirement for structural congruence, the design of one structure has to take restrictions on other structures into account simultaneously, and the total design procedure is an iterative process 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 assembly-oriented product structuring scheme (a).

Though an ideal design procedure of parallel flow assembly systems ought to be based on total congruence between (a), (b), (c) and (d), this paper will mainly report experiences on (a) and (b). Thus we only briefly sketch on (c) and (d) since these have been reported elsewhere (see Engström and Medbo 1994a; Engström et al. 1995). The methods we have developed and used to design the product and assembly structures will be discussed below, and will be illustrated mainly by data from the Volvo Uddevalla final assembly plant.

We shall be considering work in autonomous work groups, sometimes denoted "collective working" 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.

The generality of the design procedure described below is underlined by the fact that the design procedures for final assembly reported here have been refined and used later by two of the authors for e.g. redesigning the Volvo Torslanda automobile plant in 1989 (a redesign which was never implemented; see Engström and Medbo 1994b), the Volvo truck plant Tuve in 1990, and the Autonova automobile plant in 1996. All these three cases used, or use, long cycle time parallel flow assembly systems. The last case is the reopened Volvo Uddevalla automobile plant operated as a joint venture between Volvo and Tom Walkingshaw Racing (TWR) denoted Autonova. This company has at the moment (end of 1996) just started production of exclusive coupés and convertibles by using some carry-over components from Volvo. A plant which for about one and a half year until this moment has manufactured the Volvo 850-model partly for training and running-in purposes.

2 USING PRODUCT DISASSEMBLY TO DESIGN AN ASSEMBLY-ORIENTED PRODUCT STRUCTURING SCHEME AND A CORRESPONDING ASSEMBLY WORK STRUCTURING SCHEME

2.1 Overview

To support long cycle time assembly work, there is a need for a reformed product perception using the product information already available in the form of the existing overall product structure. This product structure is mainly design and market oriented and based on the so-called function group register as described in e.g. Engström and Medbo (1993) and Engström, Jonsson and Medbo (1993), as well as on information available from the central product and process department as discussed below. This is an essential requirement since it facilitates the design procedure (i.e. reforming information already available) and promotes the introduction of e.g. new unorthodox materials feeding techniques (i.e. it is necessary for the function of the new assembly system to communicate with the overall product structure).

To design a hierarchical assembly-oriented product structuring scheme and a corresponding hierarchical assembly work structuring scheme we have during the last decade disassembled 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.[1] This was in almost all respects a tedious manual process making notes by hand during the disassembly, using photocopy machines, basing different types of analysis on insufficient and often incomplete data printouts from the Volvo expertise, etc., as well as a search process for the right information and personal contacts within Volvo.

Though the process was time-consuming, it certainly resulted in the building-up of our own knowledge, as well as serving as a method for formalising practitioners knowledge. e.g. by having Volvo expertise continuously check our work by e.g. cross reading our registers 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 assembly-oriented product structuring scheme and a corresponding assembly work structuring involved a constant change between the components from the disassembled products placed on the floor of an experimental workshop, production documents and data print-outs placed on large tables. The development work was practically performed by moving the physical components around, modifying photographs and drawings using scissors and glue to compose new documents including different types of product information, data print outs, etc. until we achieved a logical coherence between physical and logical descriptions verbally, as well as by illustrations of structuring principles successively crystallised during this process.

These structuring principles have proved to be generally applicable to most vehicles (as illustrated by photos in figure 4 and reported by Engström 1991). These structuring principles are based on five characteristics generic to all vehicles. As illustrated by the photos there is at least one obviously generic characteristic implying the existence of general structuring principles, i.e. the components 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 human body as mentioned above, (2) functions, (3) plus/minus relationships, (4) generativity and (5) diagonal symmetry.

The disassembled products laid out for long periods of time on our shop floor in our experimental workshop also served as illustrations of the production principles developed including the design of the materials feeding techniques, e.g. kitting fixtures, design of sub-system for kitting of small components in plastic bags, etc. The experimental workshop also served as a vital source of

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[1] This procedure has later been speeded up considerably and further refined by the use of e.g. database programs, personal contacts with expertise within Volvo for the supply of product information on diskettes, printouts of specially required labels (see figure 3), 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.

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. A procedure which of course can have different scopes according to e.g. vehicle model and the course of product variants.

Figure 1. Disassembled automobile used for design of an assembly system. The photograph is from the authors´ development work for the Autonova plant in 1995. This work essentially repeated the work done for the design of the Volvo Uddevalla plant ten years earlier.

2.2 Collecting information used in later stages (phase A)

This design phase mainly includes:

A.1 "collecting" the relevant product information in the form of Volvo product including e.g. so-called materials control codes complemented with information about suppliers, materials supply methods and quantities, weight, the need for or use of special packaging, etc.
A.2 "collecting" the correct translation of so-called variant codes into true product characteristics.
A.3 "collecting" correct component names and descriptions of product systems function including synonyms and homonyms.
A.4 "getting hold" of data files stating the assembly times for each detailed assembly task.
A.5 "getting hold" of an assembly sequence from specific 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 practitioners knowledge.

"Collecting" the relevant product information in the case of Volvo automobiles requires among other things; (1) to have a diskette of the existing overall product structure containing components name, components position on the product, variant code, etc. and (2) to get hold of the detailed assembly instruction from the central product and process department, so-called process- and control instruction[2], as well as other types of relevant information.

Collecting the correct translation of variant codes and turning these codes into e.g. true real product characteristics, component names and product 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 chaise 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 product and product information is necessary to decode this information. The overall knowledge 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 lexicons themselves based on workshop manuals, service instruction material, information process and control instructions, interviews, etc. Consequently, the term "collecting" certainly merits a separate paper.

Work in this phase, in the Uddevalla case, proved to be time-consuming since the product perception on the shop floor, as well as from the production engineering's point of view, proved far

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

too fragmented to even allow systematic disassembly of an automobile. Still less so while at the same time understanding which components were interconnected or related to other components due to product functions or true product variant characteristics. The knowledge is obviously present in the company mainly in the design department, but during the transformation of product information from the design department to the shop floor, both logic and information are deformed or lost (see Engström and Medbo 1993; Medbo 1994).

Note that the different engineering documents 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 about product and manufacturing processes, which in fact has proved necessary in both the Volvo automobile and truck companies.

2.3 Preparing for disassembly (phase B)

This design phase mainly includes;

B.1 creating small cards describing the detailed assembly work (see figure 2).

B.2 creating labels comprising information from the product overall product structure, (see figure 5). These labels also contain information concerning the components suggested to belong to other types or groupings, i.e. the so-called final assembly functional groups (see section 2.4) or information, as to whether the same materials control code is used for one or more components fitted in different positions on the vehicle, as is the case for Volvo automobiles and trucks.

B.3 excluding all the small cards that are non-assembly relevant due to the scope 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, etc.).

B.4 grouping the small cards according to the suggested assembly sequence into suggested work modules, i.e. different levels of the detailed assembly sequence, depending on specific shop floor preconditions (se 2.4), forming the suggested intra-group work pattern.

During our design work in the case of the Autonova plant we were supported by having the Volvo overall product structure available on line, as was also the case in our work for the Volvo truck company, and we also used a database programs to support our work. An analysis data base composed of different Volvo data files including information such as size of materials containers, weight, suppliers, etc. was created for the Autonova plant design. This was unfortunately not the case during the early Uddevalla experiences.

Thus we could easily document the successive results from the disassembly work, as well as transfer the results for the total design of an assembly system, regarding among other things, material 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.[3]

2.4 Disassembly and checking through assembly (phase C):

This design 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

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[3] There are at least three explanations for the extremely time-consuming work to create a database related to the Volvo overall product structure based on disassembly, i.e. to designate the correct physical component to the "right administrative position" in the overall product structure. This is a reversed process to the ongoing work in a running plant to use the bills-of-materials (derived from the overall product structure) to trigger the materials to be delivered.

One reason is that in the original overall Volvo product structure the smallest identifiable unit (the so-called 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 for steering a complex, constantly changing organisation there work moves around between manufacturing facilities, subassembly and final assembly stations, etc.

Finally, the product information and the product specifications are constantly changing (i.e. change orders) and the different files containing different product information are not synchronised. Therefore each existing local assembly plant transforms the overall Volvo product structure according to the specific assembly system design and the product variants manufactured (see e.g. Engström and Medbo 1993).

positioned on tables, sometimes divided by wooden lathes, 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 lathes, including positioning the correct labels on or beside the respective component including correcting the analysis data base as the work goes on.
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 card ought to be positioned on tables near the corresponding components. Any questions and assumptions must be noted on the small card 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 the researchers by guiding the design phases described in this paper, thus speeding up the work. Or, as has been the case in Autonova, to let operators who were going to be responsible for specific work on the product perform the disassembly work.

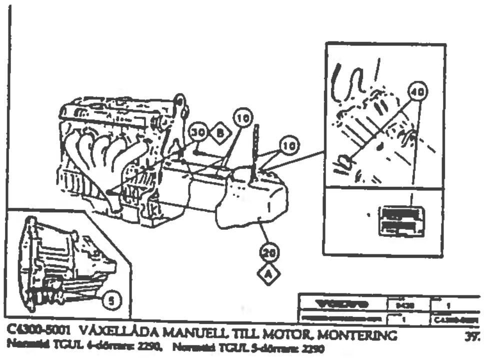

Figure 2. Small cards (approximately 14 x 10 centimetres) used for guiding the disassembly, as well as the subsequent assembly work. Illustrations of detailed work tasks on the cards were derived from the Volvo process and control instructions. These instructions contain illustrations of the work, name of the operations, etc. The cards have been composed by us to include assembly time required for a specific product variant and name of the work since the original document is quite extensive. The cards has also been complemented by us with sequence number in this case from 1 to 997 in order to be able to find the original card since some were prone to get lost during the design procedure, and since the result of the procedure might need to be updated later due to change orders. The method used to create these cards requires shrinking of the illustrations, transferring the name and function group codification (coded into the groups of components (coded 2 000 – 8 000) to the front page of the card since the original document contains front illustrations (1 – 10 pages), as well as a standardised form (1 – 40 pages in A4 format) comprising assembly sequence and materials required (component number, component name, variant codification, tools, torque, quality demand, etc.). The card shown above is from our work for the Autonova plant.

During this process we marked each component with the labels containing complete information from the existing overall product structure (see figure 5). We also sewed all small components together with the appropriate illustrations onto 21 large (220 x 120 cm) white sheets of paper[4]. This allowed the authors to acquire in-depth learning of the product, as well as to establish the interrelationship between the components and the existing overall product structure. We used illustrations reduced in size from those provided by the central product and process department (see figure 2), and we also constructed a new illustrations system as a contextual visual aid. This illustrations system 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).

Finally, the disassembled products are assembled or the analysis data base is used for mirroring yet another product which is assembled in order to verify the assembly-oriented product structuring scheme and a corresponding assembly work structuring scheme. The latter approach was performed for the design of the Autonova plant where the analyse data base was developed and refined during

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[4] 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 Uddevalla plant.

the manufacturing of the Volvo 850-model and later mirrored in and used for the manufacturing of the C70-model.

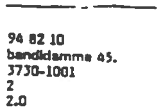
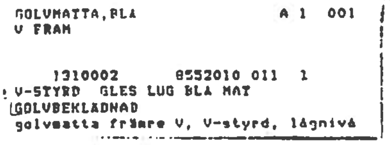
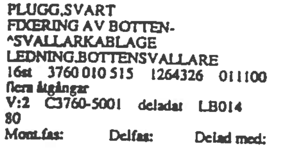
 94 82 10 bandklamme 45. 3730-1001 2 2.0	 GOLVMATTA,BLA A 1 001 V FRAM 1310002 8552010 011 1 V-STYRD GLES LUG BLA MAT GOLVBEKLADNAD golvmatta främre V, V-styrd, lågnivå	 PLUGG,SVART FIXERING AV BOTTEN- ^SVALLARKABLAGE LEDNING,BOTTENSVALLARE 16st 3760 010 515 1264326 011100 flera ingångar V:2 C3760-5001 deladat LB014 80 Mont.fas: Delfas: Delad med:
Label used in 1987 for disassembly used for the design of Volvo Uddevalla plant[5]	Label used in 1989 for disassembly used for the design of Volvo Torslanda plant[6]	Label used in 1995 for disassembly used for the design of Autonova plant[7]

Figure 3. Example of different labels containing product information used for disassembly. These labels complement the small cards shown in figure 2, by having all information necessary to relate the label, which represents one component in the existing overall Volvo product structure, process engineering instructions, material supply information and selected reference plant processes. Thus it becomes possible to decompose e.g. one single product using its components as representative of all product variants. Practically 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 somewhat old. The planned rebuilding of the Volvo Torslanda plant referred to above was never implemented (see Engström and Medbo 1994b).

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Note that the purpose of the design procedure could differ. For example in the 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 work to puzzle together the components on the shop floor, and by the aid of photos of the components taken in the experimental workshop, we recognised five final assembly functional groups. These groups were: (0) Doors; (1) Leads for electrics, air and water; (2) Drive line; (3) Sealing and decor and (4) Interior. The first group being subassembly work, while the other four were work on the automobile body. These groups of components imply not only a general classification applicable for automobiles – but also, and this is important, a classification based on five generic characteristics always present in all vehicles.

The detailed assembly work is then derived from this classification according to levels, where the highest level, depending on the specific assembly system designs is work modules. [8] That is, an

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[5] These labels were used for our first work structuring. i.e. the disassembly was aimed at identifying a taxonomy, i.e. the final assembly functional groups, as well as the suggested detailed assembly sequence for the first automobiles assembled in Uddevalla. In this case a delimited number of specific product variants. Our knowledge of the merits of using existing product and process information was quite insufficient.

[6] 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. This dissembly helped us conform the final assembly functional groups and their "variant tracks".

[7] 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 guid the unpacking and sorting of components delivered for the first 40 product variants manufactured in Autonova. The unpacking refined the analysis data base still further. Note that in this case the taxonomy was already known. We also directly during the disassembly, 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.

[8] The final assembly functional groups are intersected with work modules forming the intra-group work pattern for the "collective working" 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 fitted in a so-called tilting device, which enabled the automobile body to be altered (e.g. the modules were denoted "tilt over" corresponding to assembly work on the upside of the vehicle as well as on a tilted automobile body)

overall taxonomy, in the form of the so-called final assembly functional groups 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 and instructions on how to perform the assembly work in practice. Thus the technical and administrative preconditions on the shop floor facilitate the long cycle time work in order to reduce the individual learning time. In fact this prestructuring of information and materials is vital for long cycle time work.

In the case of the design of the Autonova plant ten years later, these groups were known, as well as the general structuring principles. Thereby work was primarily concentrated on a search for intra-group work patterns based on work modules and the creation of an analysis database to support the design and running in of the plant by serving as an instruction both for organising the materials for the first automobiles built and for the building of all other products manufactured until today.

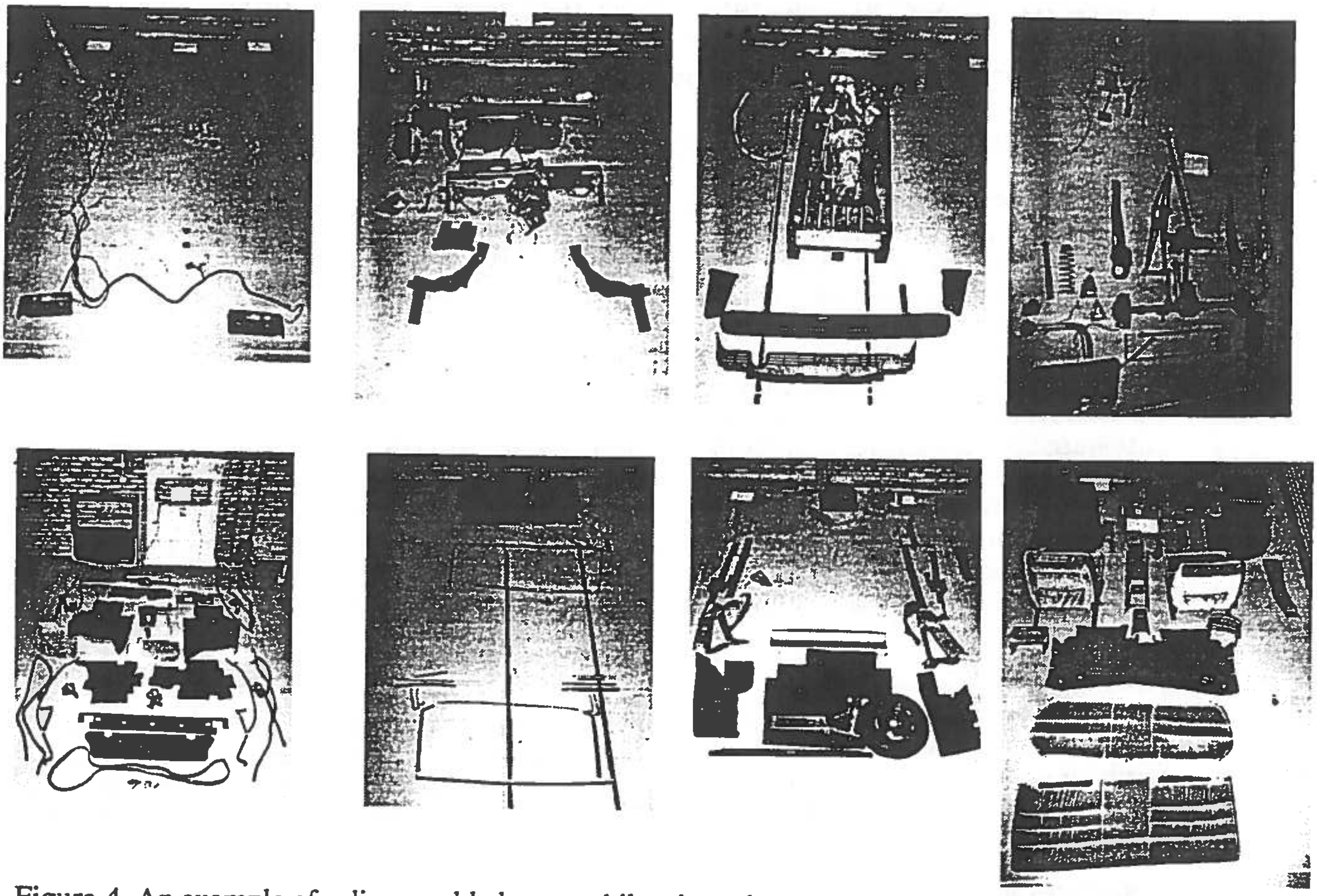

Figure 4. An example of a disassembled automobile where the components are positioned on the floor according to their position in the automobile body. Photographs from the Uddevalla experiences dated 1986 showing a Volvo 740-model. In this case the photographs correspond to 1/8 of an automobile, i.e. approximately 20 minutes cycle time where three operators were responsible for the assembly work. These photographs proved to be valuable for us when formulating and communicating work structuring principles as described above. Placing all eight photos of the disassembled automobile made it evident that a plant layout where 1/8 of an automobile was assembled in eight separate workshops in series would require enormous buffer volumes between assembly workshops or a constant shifting of operators according to time differences between product variants with different product designs. In fact, no congruence between the product structuring scheme and the assembly structuring scheme was possible to achieve until at least 1/4 of the automobile was overviewed.

2.5 Considering the effect of product variants (phase D)

This design phase mainly includes:

D.1 detailing the assembly information gained according to variance introduced by different product variants, 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 making it 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.

D.2 identification of variant tracks corresponding to characteristics more or less obvious due to the choice of the final assembly functional groups. 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 the table shown in figure 7. [9]

D.3 grasping the differences in assembly work stipulated by a decomposed reference product variant in relation to product variants. This could be either by rough estimations or by taking advantage of available manufacturing process information. [10]

This assembly time analysis according to D3 and illustrated in figure 5 also made use of the delimited time-and-motion studies performed in Uddevalla. During this period only a restricted number of product variants were manufactured. i.e. the delimited assembly times from the Uddevalla plant were compared to the assembly time gained through information from the central Volvo product and process department in order to check the reliability of the information. [11]

2.6 Continued assembly system design

To summarise, the results from the analysis phases briefly described above are an assembly-oriented product structuring scheme and a corresponding assembly work structuring scheme necessary as an input for calculating production capacity considering e.g. assembly time constraints, i.e. the choice of capacity for the work-station system design in relation to the total assembly time stipulated by the product design and the targeted production capacity for the total plant.

The last procedures have been reported elsewhere in Engström and Medbo (1994a) and Engström et al. (1995). Briefly sketched, they contain design of the intra-group work pattern, the work-station system layout, the product flow pattern, the design materials feeding techniques, defining subassembly work tasks suitable for integration into the work-station system, etc. Thereby including, for example, the design of the overall layout of a specific assembly system, is quite an elaborate procedure. We have therefore delimited this specific paper to explaining some vital work structuring phases in the design procedure of assembly systems which we have utilised during the last decade. The assembly system design must of course include e.g. the choice of product flow pattern such as serial or parallel flow assembly systems, adapted to production capacity and assembly time

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[9] Regarding product variants these ought to be described in terms of characteristics which are always present in all product variants. Two such characteristics exist for all vehicles, (1) distinguishing groups of components, which is possible since a vehicle does not consist of one part alone (final assembly will of necessity always need to be described in terms of groups of material) and (2) generativity (gender), i.e. those components which have been assembled or are to be assembled imply characteristics of a specific vehicle. Therefore product variants may be described according to variant tracks at different levels A – E. Level A showing characteristics having their origin outside final assembly work, which becomes obvious when viewing e.g. the naked automobile body or the complete vehicle (i.e. colour, 4/5 doors, with or without sunroof etc.). Level B showing characteristics having their origin in large, synchronous sub-assemblies (i.e. power plant with fuel system, facia etc.). Level C showing characteristics which have their origin in a specific functional group but which overlap more than one group (i.e. ABS and ETC-systems). Level C showing characteristics which have their origin within a functional group but do not belong to any others (i.e. upholstery colour). Level D characteristics which are not generative at all (i.e. wheel embellishments). See Engström (1991).

[10] In e.g. the Uddevalla case information from the central Volvo product and process department. Information in the form of time-and-motion studies specifying assembly times for specific detailed work tasks 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.

[11] Put diffently, there was a coherence between (1) the central times gained stipulating net assembly times (i.e. the minimum time required for one worker to assemble the complete product at full pace if tools and materials materialised in his hands at the precise moment required based on time-and-motion studies) gained through our work mapping and (2) the Uddevalla times gained locally through the Uddevalla engineers´ time-and-motion studies based on the restricted number of product variants manufactured during this period.

constraints, that is production capacity targets and required assembly times for the product and product design considered.

	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, 5D = five doors.

** This operator performed only subassembly work corresponding to 20 per cent extra in relation to the 100 per cent work on the automobile body, i.e. he was not fully balanced if the five operators performed "collective working".

Figure 5. Time spread in per cent of assembly work on the automobile body in comparison to disassembled reference product variant according to our design procedure performed for the Volvo Uddevalla plant design in 1987. In this case we assumed a distribution of the assembly work into four equal parts of an automobile which of course would not be possible to achieve in practice. The time given in the table was used for the design of different intra-group work patterns thereby assuming an ideal balancing of the work for the reference variant (Engström, Medbo and Tuhnberg 1987). The estimation of relevant assembly times for different product variants was a tedious work performed in the experimental workshop in Gothenburg by two of the authors of this paper based on our work mapping in the training workshop in Uddevalla (see Engström and Medbo 1994a) by coding every component according to variant code, as well as composing and decomposing detailed work tasks organised according to the function group register (coded into the groups of components 2 000 – 8 000).

3 CONCLUSIONS

This paper highlights some specific aspects of general interest of the story about the design and development of assembly system design within the Swedish automotive industry, namely the design procedure including work structuring principles used for several assembly system design cases. Thereby we will emphasise the importance of the technical aspects mostly neglected in the international debate concerning the socio-technical design approach where design processes tend to be regarded as mainly participative in nature.

In practice the work structuring phases in the design procedure reported above underline that the overview and detailed information required to structure the work in order to achieve an efficient assembly work, using parallel flow assembly systems with long cycle time assembly work, according to the need of the structural congruence required, is not possible to obtain from present "digitised" information about the product and work available within the automotive industry. It requires a combined design approach amalgamating "analogous" physical products and their components, as well as data from the overall product structure. By using the procedure described, it is possible to interrelate "shop floor reality", the present descriptions of the shop floor reality of both products and manufacturing processes and the future "shop floor reality" i.e. the assembly systems not yet designed.

From our point of view the design cases reported are not pure cultivation of participation as has been the international public profile of non-traditional Swedish assembly plants. Instead the plant design does include a true engineering approach, supported by established knowledge from social science (e.g. Karlsson 1978; Nilsson 1981). However, the true core of the plants might have been internationally misunderstood as a human relation approach further dimmed by terms like participation and humanisation - since the true engineering approach, certainly has been present in some cases, as described above.

Generally speaking, our experience from and involvement in the design of the Volvo Uddevalla plant in 1985 – 1988 and the Autonova plant ten years later, as well as several other assembly facilities, underlines the importance of transferring design procedures and design experiences between large industrial development projects. A responsibility which in the case concerning assembly system design, due to various circumstances, has come to be the role of the researchers.

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