Product and Process Information for Motor Vehicle Assembly: Some Cognitive Engineering Aspects

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ABSTRACT:

This paper explains critical details for understanding proposed work structuring principles and tools applied in various Swedish automotive plants with unorthodox assembly systems. Especially so by relating the principles to theoretical frames of references of Gestalt psychology which comprise the concept of so-called "dual vision" but also by relating to semantics and vocational training knowledge. However, this paper focuses on the former field of knowledge.

Specifically the paper report on (1) the state of the art regarding the overarching design-oriented product structure and (2) six generic relationships exhibited by large motor vehicles. This in turn leads to explaining the (3) abstract principles underlying the design of a so-called assembly atlas based on (4) specific criteria's for grouping the components in the product.

Finally, (5) an industrial application is explained, namely how the assembly-oriented product structure interacted with the detailed assembly sequences at the Volvo Uddevalla plant.

1 INTRODUCTION

Within the context of collaboration between Osaka University of Economics and the School of Economics and Commercial Law at Göteborg University, a number of 2 – 3 days seminars, named "Seminars on Comparisons of Management Practices between Japan and Sweden", have been carried trough. These seminars have earlier been arranged in September 1999 at Göteborg, and in October 2000 at Osaka. This paper is written for the September 2001 seminar in Göteborg.

In-between the seminars there have been study tours by delegations of Japanese researchers in the Göteborg area for visiting of industrial premises, such as that in March 2001 arranged by Chalmers University of Technology, specifically for studying Swedish automotive plants. During seminars and study tours, unorthodox assembly systems have caught the interest of Japanese research colleagues and process designs have thus been discussed from several points of view. However, during these discussions, which have to a large extent concerned the underlying principles and practises of these unorthodox assembly systems, it has become evident that some unclearness exists in the authors' publications.

This paper will focus on the design of product and process information rather than process design in the sense of e.g. choice of product flow pattern, choice of buffer positions and buffer functions, the choice of materials feeding techniques, selection manufacturing equipments and tools, etc., i.e. what is considered as synonymous with assembly system design.

Therefore this paper will specifically clarify the state of art concerning the overarching design-oriented product structure and explain how to reform the product and process information for long cycle time assembly work condensed into in one publication in order to elucidate some of the questions brought up by Japanese researchers. These are questions that, in most aspects, bring forward a relevant constructive criticism, originating from the fact that the research and development work has been published successively during the last two decades in various scientific journals and books, giving a somewhat scattered content. This is especially evident for the work structuring principles advocated, which are connected to, or based on, vocational training and psychology.

Though these results are spread on both an international level by means of traditional academic channels and also shared locally between a limited number of practitioners and researchers actually involved in the experiences referred to, it is fair to say that the detailed core knowledge has proved intriguing to comprehend for outsiders since, among other thing, specific manufacturing engineering knowledge of the automotive industry practices, and other types of frames of references are required. In addition to this, there is a need for rare in depth insights about the idiosyncrasies of product and process information used in the automotive industry, calling for specific approaches and methods for penetrating and analysing such information as outlined below (see also e.g. Engström and Medbo 1994; Engström, Jonsson and Medbo 2000 for a detailed explanation of the actual design procedure).

2 THE STATE OF THE ART REGARDING THE OVERARCHING DESIGN-ORIENTED PRODUCT STRUCTURE

The standardised so-called product structure used within the Swedish automotive industry for describing motor vehicles, known as the ”function group register”, is intended for motor vehicles in general, ranging from automobiles to dumpers and trucks (see e.g. Volvo 1989). This is a design-oriented product description, i.e. it describes a motor vehicle from the central design department's point of view in a traditional way by e.g. separating electrical components from mechanical components, despite the fact that many product functions are in fact combinations of e.g. electrical and mechanical components.

The main function groups for an automobile like Volvo are: 2 000, engine and equipment; 3 000, electric power supply and instruments; 4 000, power transmission; 5 000, brakes; 6 000, wheel suspension and steering; 7 000, frame, springs, damping and wheels; 8 000, body, cab and upholstery. Note that for reasons discussed below most of the components of an automobile are concentrated in main group 8 000.

In an international manufacturing corporation like Volvo, the core information emanating from the central design department is used for specifying the product and comprises e.g. original drawings/CAD-models, data on torque, tolerances, etc. as well as bill of materials data guiding the materials in the industrial network. This core information, which constitutes the overarching design-oriented product structure organised in accordance to the function group register, is the reference for the manufacturing of the product in various local plants but also for interaction with suppliers and customers.

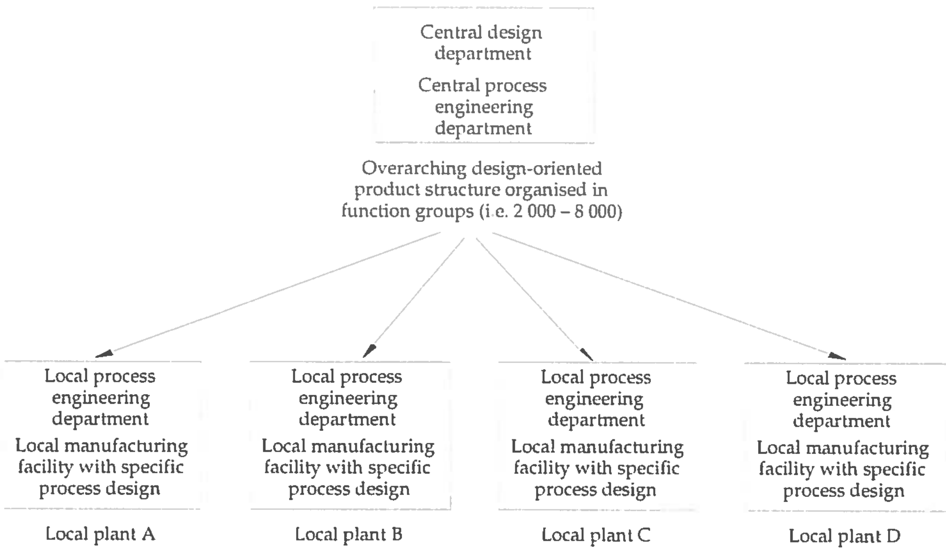

Figure 0. In an international manufacturing corporation, the core information emanates from the central design. In the case of Volvo, this data is organised according to the so-called function group register, which is general for al motor vehicles.

Since the function group register is general, it will cause parts of the hierarchy to disappear when applied to e.g. an automobile. Accordingly, the complete overarching design-oriented product structure describing a product will contain "implicit holes". It will thus not be obviously how to hierarchically divide or unite products.[1]

It must also be noted that motor vehicles have changed during the last decades. This is particularly true for an automobile with a welded body, while the structural content of a bus or a truck has changed less since they have, from a motor vehicle point of view, a more conventional product architecture comprising e.g. a separate frame. Today, for example, the complete interior of an automobile is upholstered with panels of plastic or cloth, which is why most of the components are to be found in the last of the seven main groups (i.e. 8 000 body, cab and upholstery) in the overarching design-oriented product structure. Another reason for this distortion is that this main function group contains components not possible to obviously belonging to any other function group. The increased combinability in-between subassemblies are the result of changes in market, product architecture, choice of materials and external suppliers. This has influenced the content of the overarching design-oriented product structure more for the automobile than on the bus or truck.

Though this paper has deliberately, to restrict the scope, omitted to explain how to consider product variation and product variant codification, it might be added that the existing method of describing variations in the product is principally intended for materials control. It is therefore extremely difficult to understand the product variation from the function group register (see e.g. Engström et al. 1995 for a more detailed description of how the advocated principles and tools are linked to product variation and product variant codification).

All this means e.g. that manufacturing engineering at the local manufacturing facility requires extensive work to restore the information into a form suitable for the particular assembly system involved in order to get the quality data needed for effective manufacturing beyond materials control purposes. Besides resulting in fragmented information, the overarching design-oriented product structure also obstructs feedback concerning assembly work to the central design department due to the reasons explained above.

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[1] The general classification register used within the Swedish vehicle industry by the Volvo Group consists of seven main groups divided into sub-groups. On the third level of the hierarchy the structure consists of 271 groups and 245 "holes" (the register here contains no car components). When this register is applied to a chosen type of automobile 122 of these groups are used, and the number of "holes" thus increases to 394. For a representative truck the corresponding figures are 90 groups and 426 "holes".

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The overarching design-oriented product structure described here has thus proved not only to inflict the actual work of the operator on the shop floor but also obstruct the development of this work. The introduction of parallel product flow assembly systems with long work cycle time assembly work calls for not only an advanced materials feeding technique, since the materials obviously cannot be feed by traditional line stocking[2], but also specific measures to facilitate the long work cycle time. The latter has proved to require a congruence between (1) operators' perception of the assembly work; (2) the materials display on the workstation; and (3) product and process information used on the shop floor (see Medbo 1999, Engström and Medbo 1992 for a more comprehensive presentation).

The main task to be performed when designing parallel product flow assembly systems with long work cycle time assembly work is to ensure this congruence. Such congruence cannot be achieved by means of the traditional design-oriented product structure, but requires certain common structuring principles and tools, notably (a) six generic relationships exhibited by all large motor vehicles with multiple product variants, (b) criteria for grouping components together, (c) a structured semantic network reflecting (a) and (b), thereby forming what in an abstract sense is denoted an assembly atlas (originally Engström and Medbo 1992). These common structuring principles and tools will be described in the following sections.

3 SIX GENERIC RELATIONSHIPS EXHIBITED BY LARGE MOTOR VEHICLES

During the disassembly of automobiles undertaken by two of the present authors in connection with e.g. the design of the Volvo Uddevalla Plant, several generic relationships (the product's inner logic) exhibited by all large motor vehicles with multiple product variants were identified (originally Engström 1991). Considering a single product, the following generic relationships appear:

(1) <u>Part-whole relationships</u>. This means that motor vehicles contain several components, sub-components and so on.

(2) <u>Intra-system synergies</u>. Specific components interact and form systems of components that serve particular product functions (see e.g. Hubka and Edler 1988, who discuss complex technical systems as consisting of numerous components which could be divided into sub-systems embracing product functions). For example the function of braking calls for a brake system, which is composed of a brake pedal which manoeuvres the servo/booster for pressurising the brake fluid, with help from the vacuum from the engine, thus the brake fluid is conducted by the brake lines to the callipers. These callipers grab the discs on each wheel in order to stop the motor vehicle.

(3) <u>Bilateral intra-product symmetries</u>. Some components are positioned bi-symmetrically, i.e. appearing in pairs positioned around the product's assumed mid-axis, while others appear only on one side of the axle. This is an "organic" symmetry, analogous to that of the human body, which has e.g. two arms and legs but only one heart and liver.

[2] See Engström (1983) for explaining how to organise the materials feeding in parallel product flow assembly systems.

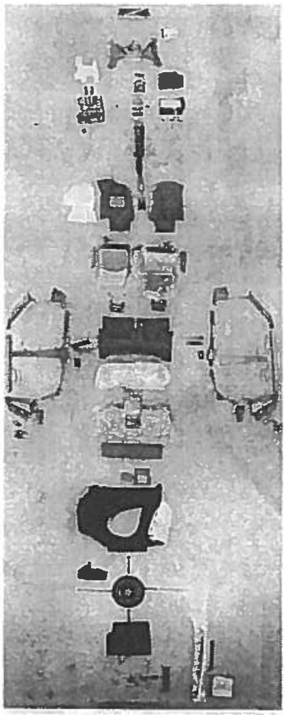

Figure 1. Photo of 1/4 of an automobile laid out on the floor of the authors' experimental workshop in 1985. In this case, some of the generic characteristics of this motor vehicle are evident. Note e.g. that the automobile has an "organic" symmetry, i.e. the components are organised around an assumed symmetrical axle running in the middle of the product from back to front in analogue to a living organism.

Comparing different products the following generic relationships appear:

(4) Contingent inclusion relationships. When comparing selected products by considering them as each other's mirror images, it becomes obvious that a component may be present in one product and absent in another, and that components may be substituted for one another. For example, an automatic gearbox may replace a manual one – or an air-conditioner may or may not be included.

(5) Genealogical links. A specific component included in a particular product goes along with another specific component, thus forming long chains of interrelated components. Such relationships may be based on intra-system synergies and product functions, but not necessarily so. Thus, e.g. a specific product function with a corresponding component system may generate a long chain of components to be fitted, but similarly one chromed trim detail usually requires the rest of the trimming to be chromed, in opposition to being surface dressed in black. Also, similar colour and materials of the product interior components may generate such links.

(6) Bilateral inter-product symmetries. When comparing selected products, some components may appear to the left of an assumed mid-axis in one product and to the right of this axis in another one. For example if a left hand drive automobile is compared with a right hand drive, the drivers controls in form of pedals, steering column and steering wheel, combination instrument and instrument nacelle are found at opposite sides of the mid-axis, while the location of some components or component systems functions are independent of if the motor vehicle if e.g. left or right hand driven.

These six types of relationships are themselves conceptually related as shown in table 1.

	Relationships involving a single product:	Relationships involving multiple products:
Composition:	- Part-whole relationships	- Contingent inclusion relationships
Association:	- Intra-system synergies	- Genealogical links
Symmetry:	- Bilateral intra-product symmetries	- Bilateral inter-product symmetries

Table 1. These six types of relationships are themselves conceptually related as shown.

4 ABSTRACT PRINCIPLES UNDERLYING THE DESIGN OF AN ASSEMBLY ATLAS

In order to achieve coherence between (1) operators' perception of the assembly work, (2) the materials display on the workstation and (3) product and process information used on the shop floor the components to be fitted must be overviewed and grouped together according to criteria described in the next section. That is, the components to be fitted to an automobile body or the frame of a bus or truck must form a coherent hierarchical structure, from top to bottom, based on the characteristics of the components (such as form, functions, size, materials) as well as other criteria. This means that the component groups consist of components, which together and separately constitute subgroups of components forming a hierarchy described by means of meaningful names. In analogy to an atlas ("the assembly atlas") comprising continents, countries, districts, etc. described with different grades of resolution, by exact names as well as schematised maps. Various routes in this atlas will then be analogous with chosen assembly sequences, i.e. the process is usually unique for each specific process design, but also for products that are assembled.

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Three interrelated abstract principles may be cited as providing the theoretical foundation for the design of assembly atlases.

Firstly, an assembly atlas may be regarded as product information that reflects the assembly point of view, in contrast to the design-oriented product structure explained above, that is it may be regarded as a so-called assembly-oriented product description. On the other hand, an assembly atlas may also, conversely, be regarded as assembly process information that takes the structure of the product into account.

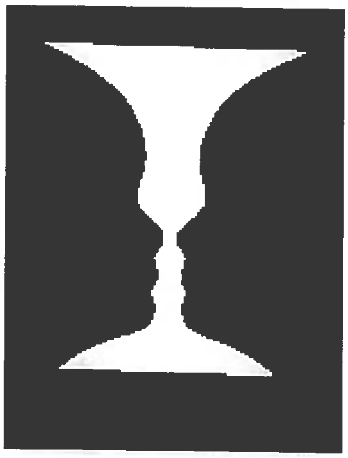


Figure 2. Dual perception illustrated by using the Peter-Paul goblet used to illustrate the "figure-ground effect" (Berelson and Steiner 1964).

This phenomenon is analogous to the so-called "figure-ground" effect explored in Gestalt psychology. Briefly, one region of the perceptual field tends to stand out as "figure", while the complementary region is perceived as "ground" (Berelson and Steiner 1964). The roles of "figure" and "ground" can however be reversed (cf. figure 2).

Thus, the first principle concerns product – process duality. The assembly atlas is in reality a product information which is coupled to the process information. From an assembly process design and assembly work point of view, the assembly process will be the ”figure” while the product will be ”ground”, while from a product architecture and materials supply point of view the product will be the ”figure” while the assembly process will be the ”ground”.

Secondly, both the physical product, the assembly process and information about them consists of a number of elements (Dahl 1982). These elements interact to form structures in which two phenomena may consist of different kinds of elements yet have the same structure. Another way of expressing this is to distinguish between shape and substance as illustrated in figure 3.

As discussed above, one conclusion concerning the Swedish automotive industry is that the overarching design-oriented product structure and process designs practised has figuratively “destroyed” the product’s inner logic, with the consequence that the elements of the structure on the shop floor, and also in the manufacturing engineering department of the local assembly plant are perceived as fragmented. To remedy this situation, and create structural similarity between the physical product, the assembly process and information about them, an assembly-oriented product structure, where components are given meaningful names and arranged in a hierarchy as described below, is required.

Figure 3. Similar shapes structures but different substance.

To explain the third principle, an analogy with a linguistic concept may be useful. Chomsky (1957; 1975), who created the theory of transformational-generative grammar, argues that human beings have an innate facility for understanding the formal principles underlying the grammatical structures of a language. Chomsky distinguished between two levels of structure in a language; “surface structures” which are the actual words and sounds used; and “deep structures” which carry a sentence's underlying meaning. According to Chomsky, humans can create and interpret sentences by generating the words of “surface structures” from “deep structures” according to a set of abstract rules. The same rules are present in all languages and, though limited in number, they allow for an unlimited variation. Figure 4 illustrates the distinction between surface structures and deep structures.

The assembly sequence is analogous to the surface structure of a sentence, and according to the deep structure transformation principle, the assembly sequence should be derived from a ”deep structure” to make assembly work (cognitively) meaningful, just as the underlying ”deep structure” makes a sentence (semantically) meaningful. Also, according to the principles of product process duality and structural similarity this deep structure will be closely related to the inner logic of the product to be assembled.

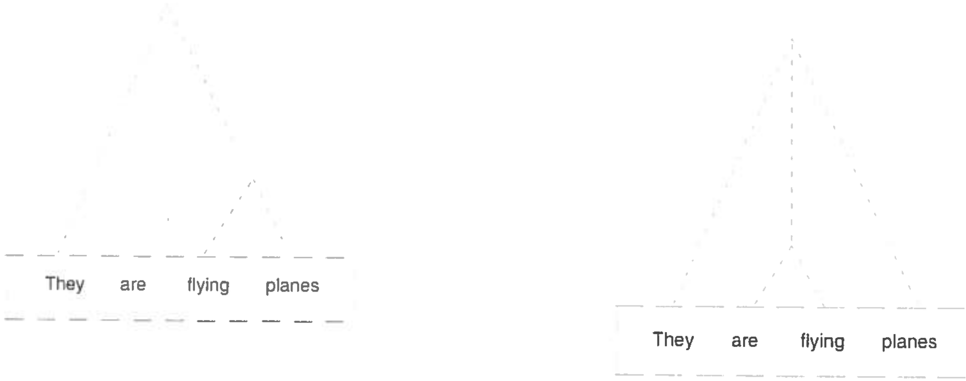


Figure 4. Same surface structure – different deep structures.

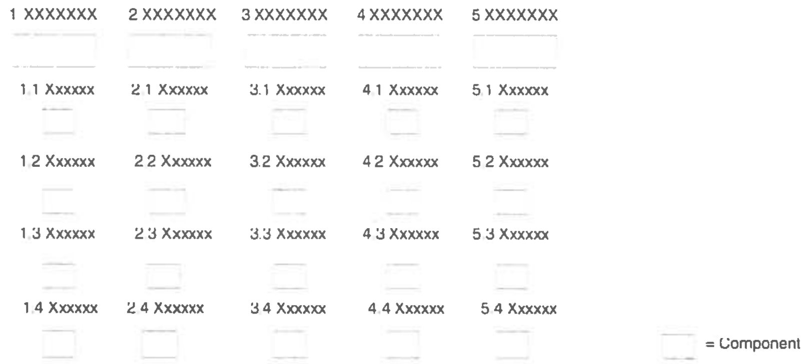
Other important influences on the results presented in this paper are Marton (1970) and his disciples who stress the importance for the human being of creating an internal, mental representation – a structure – to facilitate learning. Complex knowledge cannot be composed out of small pieces. It is especially important to construct a mental structure ("building up an internal representation") in the initial phase of the learning, leading to higher performance in later phases. In this connection (see Nilsson 1994) speaks about from two qualitatively different perspectives, the mechanistic contra the organic perspective. However, these influences are not explained here – they certainly merit a separate paper.

5 CRITERIA FOR GROUPING COMPONENTS IN AN ASSEMBLY ATLAS/ASSEMBLY-ORIENTED PRODUCT STRUCTURE

To develop an assembly-oriented product structure for an automobile type, e.g. the Volvo 700 series, one or more automobiles are disassembled, their components are laid out on a suitable large surface, e.g. a floor, and the components are then iteratively rearranged to represent the allocation of components into a hierarchy of groups and subgroups. At the same time, a hierarchy of terms corresponding to the components and groups of components is developed – a hierarchy that constitutes the core of an assembly-oriented product structure. These two hierarchies should exhibit structural similarity as illustrated in figure 5. The hierarchy of terms can be used as an "assembly atlas" to navigate among physical components and groups of components as well photographs or illustrations of components and groups of components.

Hierarchy of physical components
(substance = physical components).

Verbal hierarchy of terms
(substance = terms).



Congruence showed by similar forms

Congruence showed by different formed hierarchies using/utilising various substances.

Figure 5. Illustration of structural similarity between hierarchy of physical components and verbal hierarchy of terms (i.e. a verbal network).

There are several types of criteria for grouping components when designing assembly oriented product structures. Firstly, components are grouped according to characteristics such as form, size, weight, materials (e.g. metal or plastics), location in the product, product architecture (e.g. physical modules) and product functions. This means that components are grouped in order to form hierarchies according to similarity, proximity and complementarity or synergy (i.e., contribution to a common product function).

Secondly, since we are dealing with an assembly-oriented product structure, a rough assembly sequence, dictated by the design of the product, has to be taken into account, meaning that groups of components should be ordered in a way that reflects a logical rough assembly sequence determined by the product architecture. For example, most of the plugs in the automotive body must be fitted early and could accordingly be placed in the first subgroup of the first main group, while hubcaps, the triangular warning sign, etc. would be put into the rear trunk towards the end of the assembly sequence and could be placed the last sub-group of the last main group.

Thirdly, again because of the fact that we are dealing with an assembly-oriented product structure, the assembly time represented by components in each group must be taken into account for purposes of balancing the range of each group, that is to facilitate an even division of labour among operators. Specifically, the criteria of even division is facilitated if the components in each main group represent approximately the same assembly time, i.e. approximately the same amount of components or fittings points (e.g. fasteners).

Rules of thumb can be used to estimate the assembly time represented by components in a particular group. For example, wiring harnesses can, for an extremely rough estimation of the assembly time, be assumed to correspond to the same number of small components as the number of time these where fixated (by clips, clamps, etc.) plus the number of lead-troughs in the automobile body panels. For example a wiring harness with twelve fixations and three lead-throughs was assumed to require the same assembly time as fifteen small components.

Based on the above considerations, the main groups defined for the Volvo 700 series during the authors' involvement in 1986 (Volvo Uddevalla plant process design) were (0) Doors; (1) Leads for electrics, air and water; (2) Drive line; (3) Sealing and decor and (4) Interior. These main groups were to some extent obvious. However, the sub-groups were trickier to define and to designate correctly in order to establish a meaningful correspondence between the physical components and their positions in the automobile (forming a spatial network) and in the hierarchy of terms (forming a verbal network). It is fair to state that so far the main groups in the assembly-oriented product structure have proved to be general for Volvo automobiles (the rear driven 200 and 700-models as well as the front wheel driven 800 and C70-models), while the sub-groups has varied dependent on product architecture.

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Note that the three types of considerations listed above are based exclusively on the product to be assembled, that is they are dependent on the product's "inner logic" but independent of the specific facility (or, more generally, the assembly system) where the product is assembled. This generic assembly-oriented product structure is utilised in the design of a specific process design. As a result this assembly-oriented product structure is adapted and amended to the specific process.

Finally, the specific assembly-oriented product structure is used, in accordance with the principle of deep structure transformation, to generate a recommended assembly sequence. Or to formulate it in another way, "the assembly-oriented product structure is an taxonomic product information from which the detailed assembly sequences are derived". These sequences may, on a higher level, depend on the process design or due the choice of the local work groups constrain due to absent operators, competence overlap, product variant manufactured, etc. A process design for a number of parallel work groups should also stipulate how the components are organised in e.g. the materials kits. In this connection it should be noted that the interaction of product architecture and process design imposes process restrictions. For the 700 series assembled in the Uddevalla plant, for example, the assembly sequence was influenced by the fact that the sub-frame, comprising engine and gearbox assembly, was inserted from below of the automobile body, as was also the case for the rear axle arrangement.

It might be added that, in the Volvo Uddevalla case, quality demands on the product did also influence how the assembly work was derived from the specific assembly-oriented product structure mentioned above. This was the reason for combining (1) Leads for electrics, air and water with (2) Drive line to be assembled on one workstation, since these main groups were focused on correct torque on the nuts and bults used for fitting of components, which also called for a tilting device. On the other hand, (3) Sealing and decor and (4) Interior were combined and allocated to a workstation featuring a lifting table, because these components called for quality in form of correct tolerances between components. The work at this workstation involved adjusting mostly "cosmetic components" like panels and other interior components against each other and in relation to an automobile body recognized as having a dimensional inaccuracy. In addition, when fitting components from groups (1) and (2) the operators hands were usually somewhat soiled, while fitting of components from group (3) and (4) called for cleaner hands due to e.g, interior related components.

6 THE INDUSTRIAL APPLICATION REGARDING LONG WORK CYCLE TIME ASSEMBLY WORK

As mentioned above, the successive rearrangement of components on the shop floor in the experimental workshop during 1985 – 1993 led to an assembly-oriented product structure for the Volvo 700-model comprising five main groups of components. This work was carried out in stages over a number of years. During this period, empirical manual explorative studies were made with pens, scissors, glue, paper, copying machines, and a word processor in order to gain insights in product and process information as well as a detailed understanding of the product architecture and product variation.

Even though all Volvo documentation in form of e.g. service manuals, spare part catalogues, assembly instructions from various Volvo plants, process controls instructions from the central process engineering department, etc. was available, and valuable help was also received from various Volvo manufacturing engineers and other specialists from the Volvo Torslanda assembly plant, it proved almost impossible to understand the automobile as a whole by means of the Volvo documentation alone. For example it was not possible to use the documentation for disassembly of a complete new automobile, neither was it possible to order the specific materials included in a complete automobile.[3]

It proved more practical to apply a "reverse engineering" approach, i.e. to disassemble an automobile to improve the understanding of both the product and its documentation.[4] It was first necessary to understand a single product, which was a product variant stripped of most options. Identical to the first fifty automobiles assembled in the training workshop at the Volvo Uddevalla plant. Then followed the dismantling of a number of extensively equipped product variants.

For three years all the components remained on the floor of the experimental workshop for regrouping, marked with information to enable the authors to check when we felt uncertain and to illustrate the principles for numerous visitors. Another reason for keeping the components for so long was that during this period we also produced specially designed visual illustrations, which described the assembly-oriented product structure (see figure 7). To help us with the illustrations we employed an architectural research student specializing in visualization techniques.

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To recapitulate the assembly-oriented product structure comprised: (0) Doors; (1) Leads for electrics, air and water; (2) Drive line; (3) Sealing and decor and (4) Interior. The first group thus comprised subassembly work on the doors, while the other four main groups were work on the automobile body.

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[3] Given the insights reported in section 2 it might have been a successful course of action to engage specialists from design department. However, the state of the art concerning the Volvo information was of course puzzling for the authors. How was it possible, for example, that no one were able to specify the assembly sequences, materials volumes, etc, and why was it so complex to understand the available information when comparing with physical products?

[4] This was not a new experience for some of the authors who had earlier been involved in e.g. design of the so-called mini-line at Saab Scania in Trollhättan, a Toyota Tahara plant look alike built approximately fourteen years earlier. There it proved necessary to make a special inventory of all materials contained in an automobile to grasp materials volumes, number of components, etc.

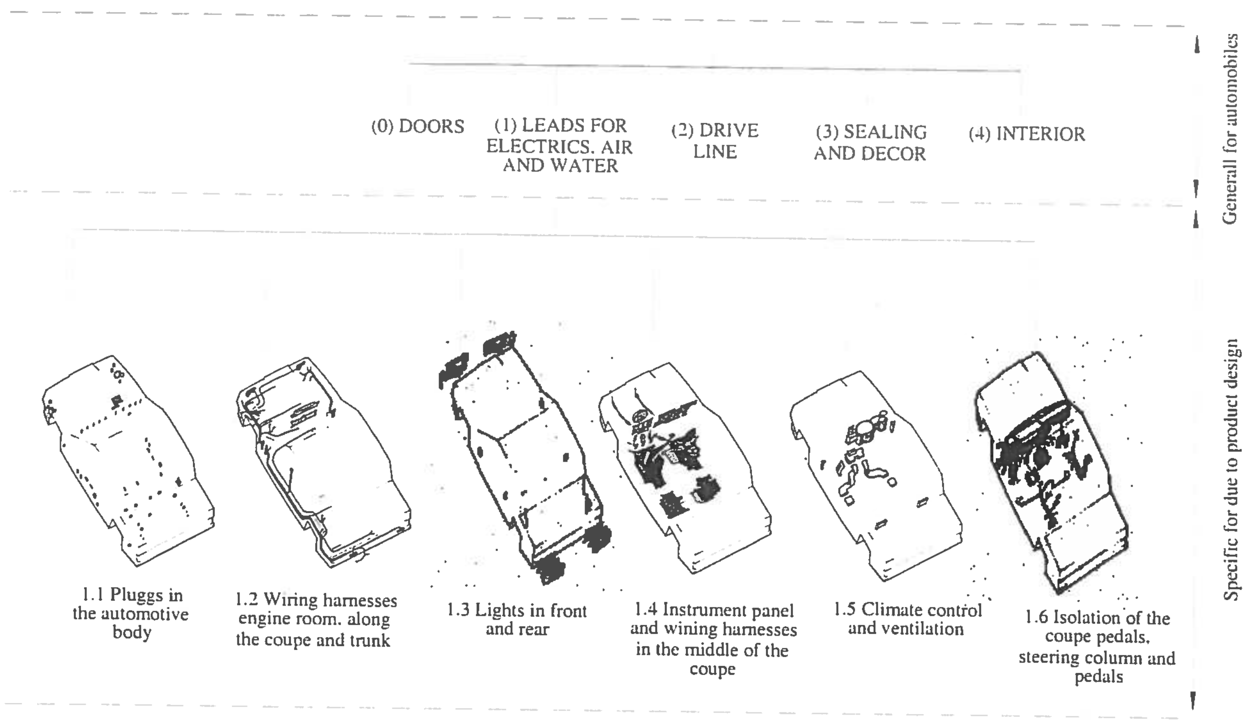


Figure 7. The assembly-oriented product structure as applied for automobiles (i.e. Volvo 200, 700, 800, 900 and C70 models). The lower part of the hierarchy is dependent on the product architecture, while the upper part has proved general. Note the specially designed illustrations normalised against a transparent outline as discussed by Engström, Hedin and Medbo (1992).

How to adapt the generic assembly-oriented product structure for a specific process design (such as a specific assembly system with a specific process design in the form of product flow pattern, specific buffer positions and buffer functions, etc. is explained here by recapitulating some of the experiences and work from the Volvo Uddevalla plant process design.

The point of departure was (a) the generic assembly-oriented product structure, but there were also three process-dependent restrictions, the first of which was (b) the choice of one tilting device and one lifting table for each complete automobile built. [5] The tilting device was designed to allow the automobile to be continuously adjusted up to a 90° sideways tilted position whenever required. It also allowed continuous height adjustment during the assembly. The tilting device was comprised of two pillars mounted on the floor of the workshop with adapters for the automobile body. Thus the body could be raised and lowered as well as rotated round a horizontal axis longitudinally along the centre of the automobile body. The adapters fitted the automobile body at the bumper attachments

Furthermore, (c) the sub-assembly workstations were for several reasons integrated in the work group. These reasons where to increase the number of work positions for the operators in a work group and to reduce the number of unique complete subassemblies under transportation to the work group. Thus only the most time consuming subassemblies were integrated into the work groups, i.e. the doors requiring four subassembly stations, and sun-roof, engine dressing and torpedo panel. The latter subassemblies called for one workstation each. The subassemblies requiring expensive investments (like cutting and bending the brake lines) and the subassemblies which where it was rational to assemble many at one time (like fitting door locking knobs on the lock-mechanics linkage by means of a fixture) were designated to the materials workshop. These subassemblies were contained in the materials kits.

[5] The ambition to reduce the total number of tilting devices during the Volvo process plant design meant that as much assembly work as proved possible without impairing the ergonomics was transferred to a workstation equipped with a lifting table workstations in order to avoid under-up work (no operator should be working with his or her hands above shoulder height).

Finally, the original experiences from the Volvo Uddevalla training workshop, predating the actual starting-up and full scale running, where the automobile was assembled by four separate work groups according to the assembly-oriented product structure showed that (d) the feasible operator concentration varied between the main groups in this product structure. The following variation of recommended operator concentration without operators disturbing each other, has been noted: (1) Leads for electrics air and water and the (2) Drive line had a recommended operator concentration of two operators per product. On the other hand, on the (3) Sealing and decor and (4) Interior it was possible to work three operators at the same time without creating unnecessary waiting times due blocked work positions along the automobile body, waiting for tools and materials, etc.

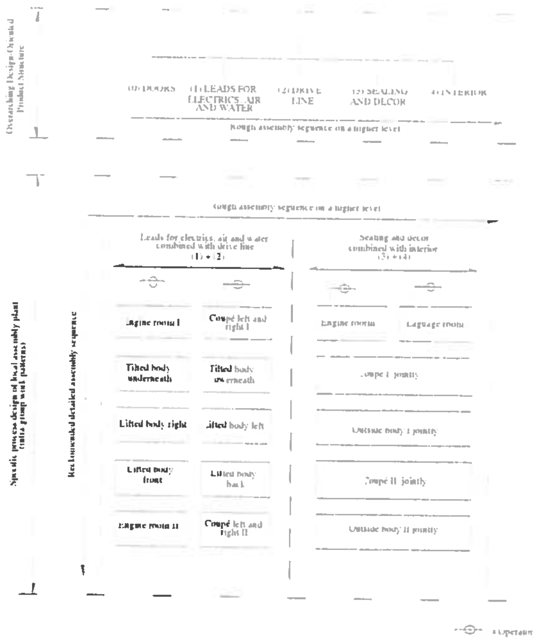
In addition to (a), (b), (c) and (d) the organisation of the assembly work in the Uddevalla plant was influenced by the following to introduce an internal buffer capacity:

> A For the work performed directly on the automobile body, the mean operator concentration was decreased. That is, to deliberately chose to allocate to each work group a number of automobiles that represented more work positions than the number of group members, thus causing some work positions on the automobile bodies to be non-occupied. These free work positions, which were equivalent to one free automobile out of four products available for each work group, enabled operators performing assembly on an automobile body to e.g. switch tasks and help their co-operators when they had finished their own tasks. Specifically, one or both of the two operators normally working with the first half of the total work on the automobile body (i.e. "1 Leads for electrics air and water" and 2 Drive line could help their co-operators on the second half of the work on the automobile body (i.e. "3 Sealing and decor" and "4 Interior"), since three operators could work without disturbing each other on the second half.
>
> B The assembly work not performed on the automobile body was also used to introduce an internal buffer capacity. This became possible because the sub-assembly workstations were not fully utilised and there was a possibility for buffering subassemblies within the workgroup. Thus operators who during certain periods performed sub-assembly tasks could also help their co-operators.

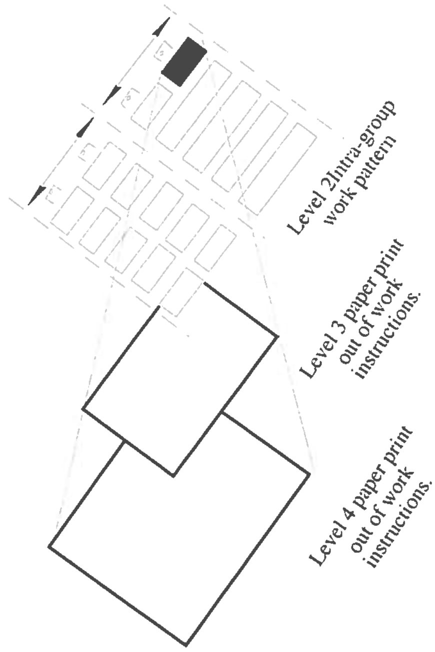
As a result of the considerations described above, the work was organised into work modules derived from the assembly-oriented product structure and the fact that a tilting device and a lifting table were used, thereby forming a matrix defining an intra-group work pattern as shown in figure 9. These work modules, were related to the work positions on the automobile and were consequently given names related to the operator and these work positions.

For example, "tilted body left" meant assembly work on a tilted automobile body on the left side performed by an individual operator. Also, "outside body I jointly" referred to the first time (coded by the roman number I) assembly work was performed on an automobile body at the "ordinary" height (i.e. lowered tilt device corresponding to the automobile body standing on the floor) was performed by two operators jointly, where the one first completed the previous work module starts directly on the oncoming work module. Finally, "coupe left and right II" described that this was the second time assembly work on a automobile body as positioned on the shop floor was performed by operators solely but from both the left and right side of the automobile body.

The construction of these work modules was both facilitated by, and expressed for the engineers and operators, by a schematised automobile body, where the body is sketched as three boxes as shown in figure 9.



So-called intra-work group pattern, a matrix which is a consequence of intersection a homogenous assembly-oriented product structure with specific characteristics/restrictions of a local process design.



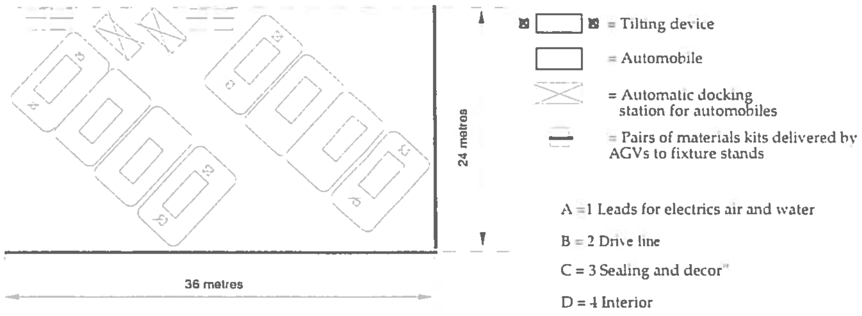
Blow up of work modules on level 2 into levels 3 and 4.

Figure 8. To the left a so-called intra-group work pattern, defined by a matrix using both product and process dimensions. Note that some of the work modules were assigned to pairs of operators, since the product architecture either called for or allowed co-operation where the first operator "reaching" the common module (denoted "jointly" in the intra-group work pattern) starts with this work. To the right is illustrated the fact that each work module in an intra-group work pattern is described with various degree of resolution from schematisations down to details.

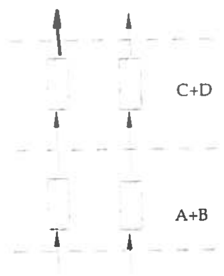
*

The assembly work in the Volvo Uddevalla plant was performed within some 40 workstation systems and there was a detailed, predetermined time and motion study based, division of labour (assignment of work tasks to operators) within each workstation system. The complete assembly work was organised into 50 work modules representing about 15 minutes work each. These modules were combined to form the task of each operator. The work modules consisted of work elements, totally 1 100, which in turn consisted of sub-elements, totally 2 100. These sub-elements were defined and time-studied through a MTM-based time measurement method denoted SAM (Viklund 1990), similar to the so-called MOST system (Zandin 1980). The average time of each sub-element was 27 seconds.[6]

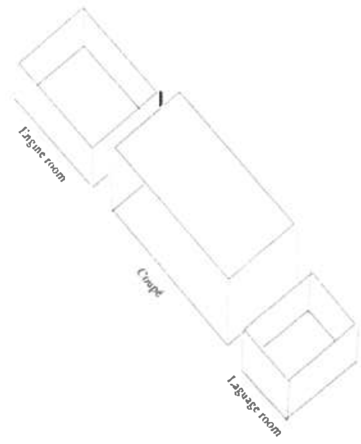
[6] Note there is some general misunderstanding concerning the practical application of this work structuring methods. In some cases (e.g. Moestam Ahlström 1997), it has been implied that individual operators completed product functions. This is not the case. It is in fact impossible to designate specific product function within a automotive product like an automobile, buss or truck to individual operators due to the product design, and if it were possible at all it would result into an enormous plant due to the decreased number of operators per product.



The actual layout at theVolvo Uddevalla plant.



Schematised layout at the Volvo Uddevalla plant.



Schematised automobile body sketched as three boxes.

Figure 9. To the left the actual and schematised layouts used for two work groups in the Volvo Uddevalla plant. To the right, a schematised automobile body where the body is sketched as three boxes. One box represents the engine room, which is open from underneath as well as from the top, one box represents the coupe which open from the left and right side and one box represents the luggage room/trunk which is open from the top only. This schematisation was used to determine how to relate the automotive body to the operators to minimise operators' interference during assembly work as well as optimising the ergonomics by means of equipment like tilting devices and lifting tables. The surfaces and edges on the three boxes were marked on a number of schematisations based on the original experiences from the Volvo plant training workshop, predating the actual starting-up and full scale running (see Engström and Medbo 1994 for a more detailed explanation). Thereby is was possible to identify so-called work modules by names such as "tilted body left", meaning assembly work on the left side of a tilted automobile body performed by an individual operator.

The work modules were arranged into an intra-group work pattern according to the impact of e.g. the product variation on the assembly work. Totally 170 variant designators were used to specify the product variation with regard to the tasks. A number of standardised intra-group work patterns were available (two standardised patters were most common in the Volvo Uddevalla plant, for seven and nine operators respectively).

A print out of all work instructions totalled into approximately 100 pages. This should be compared with the documents from the central Volvo Process Engineering Department, which consists out of 25 binders totally including illustrations, albeit not used for the same purpose This illustrates a dramatic reduction of information required to specify products and assembly work, which contributed to a better overview than that available within Volvo at that time, leading in turn to a superior flexibility manifested in the Volvo Uddevalla plant by lower costs in connection with annual model changes. As shown by comparisons of the Volvo Uddevalla plant parallel product flow assembly system with the serial product flow assembly system of the main Volvo Torslanda plant.

3.1 Lifted body - Leadings for electrics, air and water

	Work sequence	Turque	Socket size	Tools
	Hjulhus fram			
1	1 Fjäderben, höger- och vänster utförande	48±8	17	Vinkelmaskin+hylsa 17 mm
2	1 Tätningslister hjulhus, höger sida			
3	1 Propar och plugg			
	2 Sprutskydd höger- och vänsterutförande	3,5±0,5	10	Batterimaskin+magnethylsa 10 mm
	3 Fästen bromsrör främre hjulhus			
	4 Bromsslangar till rör	14±2	11	Spärrnyckel, öppen momentnyckel och U-ringsnyckel 14 mm (mothåll)
	- Momentdrag fäste bromsrör ("konsol")	14±0,5	12	Spärrhandtag+magnethylsa 12 mm
	- Tryck bromsrör i clips			
	- Fixtur till fjäderben			
	Hjulhus bak			
4	1 Slanghållare /bromsrör)	48±8	11	Spärrnyckel, öppen momentnyckel och U-ringsnyckel 14 mm (mothåll)
	2 Propp och plugg			
	Kontroll och justring			
	- Bromsrör frigång, minst 2 mm mellan rör och kaross			

Level 3 of paper print out of work instructions used in the Volvo Uddevalla plant.

3.1 Lifted body - Leadings for electrics, air and water

	Work sequence:	Materials position:	PKI-nummer:
	Hjulhus fram:		
1 1	2 st FJÄDERBEN 4 st brickor 10,5 x 26 x 2 4 st flänslåsmutter M10		6110-1001 6110-1006
2 1	1 st TÄTNINGSLIST HJULHUS INRE 2 st TÄTNINGSLIST HJULHUS YTTRE	Låda "Tätningslister höger" Låda "Tätningslister höger"	8450-1008
3 1	1 st plugg (fjäderbenstorn) 2 st plugg (små) 1 st plugg (stor). 1 st plugg (avlång sidobalk)		8995-1008 8995-1031 8995-1020 8995-1024
2	1 st SPRUTSKYDD 3 st sems skruv 14 x 22		8631-1001
3	1 st fästen bromsrör främre hjulhus 1 st låsskruv 8 x 12 för fästen bromsrör		5220-1003
4	2 st SLANGHÅLLARE		5220-1003
	- Momentdrag fäste bromsrör ("konsol") *- Tryck bromsrör i clips* *- Fixtur till fjäderben*		6110-1007
	Hjulhus bak:		
4 1	1 st slanghållare (bromsrör).		5220-1002
2	3 st gummipropp /stora). 3 st tätningsplugg (stel bakaxel). 1 st plastplugg (avlång). 2 st gummipluggar (hjulhusbalja) 1 st gummipluggar (hjulhusbalja)		8995-1024 8110-1023 8995-1020 8610-1013
	Kontroll och justring		
	- Bromsrör frigång, minst 2 mm mellan rör och kaross		

Level 4 of paper print out of work instructions used in the Volvo Uddevalla plant.

Figure 10. Print out and blow up of the work instruction system used in the Volvo Uddevalla plant (i.e. the right part of figure 7) on level 3 and 4 in this case of the work module "luggage room".

Figure 10 shows a print out of the Volvo Uddevalla plant assembly instructions. Note the use of typography: large components are written with upper-case letters, small components use lower-case letters, nicknames are given within parenthesis with citation mark, assembly work requiring no materials (e.g. connecting wires from an harness already fitted, checking, adjusting) are set in italics. The detailed assembly sequence was available for two levels of detail, denoted level 3 and 4 in this figure. The typography was congruent on both levels, and the work task belonging together due to various reasons (e.g. the same tool, position along the product, etc.) were demarcated by lines.

The correct component names were derived from the general Volvo design-oriented product structure. This work instruction system was not fully developed during the plant's life. For example, the number of ways to search for information was extensively restricted (in fact only one way of scrolling was possible) and illustrations were never integrated into the system. Thus unfortunately, in many respects this information system successively turned into the manufacturing engineers "notebook" for product and work specification not fully utilised by the assembly operators.

*

To summarise the proposed work structuring principles and tools: (1) The general characteristics of all products constitutes a generic assembly-oriented product structure which are general for e.g. automobiles on a high level but product specific on the lower levels. Pre-structuring of external information and materials before the assembly work within a plant is initiated manifests this structure. (2) This structure contains work modules, which are combined according to specific internal preconditions of a assembly. (3) The detailed assembly sequence is hierarchically divided into work modules, which have a varying assembly time depending on product architecture and product variation. (4) The work modules are combined into a number of alternative intra-group work patters in order to gain an internal flexibility within a work group or as was the case in the Volvo Uddevalla plant, to suit two principally different layouts in the assembly workshops. This state of affairs was due to experiences from the extended running-in process, which were successively taken into account. Some of the work shops had tilting devices and lifting tables between which the automobile body was transferred, while others used only tilting devices in which the body was fixed during the total assembly process.

Generally speaking, this internal flexibility of the work groups has two benefits, i.e. to reduce production losses and to allow different intra-group work patterns. This work structuring method may lead to a efficient, flexible process design (see Engström, Jonsson and Medbo 1996 for an evolution of performance aspects). This design also reduced the need for "standardised human beings" as is the case on the traditional assembly line.

7 FINAL COMMENTS

This paper explains some critical details concerning work structuring principles and tools used for unorthodox Swedish automotive plants. Specifically, the authors attempt to clarify some selected aspects brought forward in the context of Japanese and Swedish collaboration mentioned above, thus clarifying some "hidden assumptions" brought forward by our Japanese research colleagues when reading some of the authors publications.

This paper includes a summarisation of the state of the art and idiosyncrasies regarding the so-called overarching design-oriented product structure, which is general for all local assembly plants within the Swedish automotive industry, emanating from the central design departments work. This recapitulation is required in order to explain for the reader the actual difficulties in perceiving both products and work in the design department as well as on the shop floor. In addition, this paper also explains work structuring principles and tools used to remedy this situation, complementing the authors' earlier work, to make it easier to grasp some of the core knowledge behind introducing long cycle time assembly work for large scale manufacturing.

Note that the present state of the art concerning the core knowledge of short work cycle time on the traditional assembly line has specific unfortunate effects, like extensive requirements of white and blue-collar resources for distributing information to the shop floor regarding organising the introduction of product change orders, updating of work instructions and product variant specifications used on the shop floor, ensuring the deliveries of correct materials to the workstation in the local assembly plant, etc. Even with the use of these additional resources, the quality of the information actually reaching the operator on the shop floor has proved to questionable. This quality might not be considered especially critical for the restricted work content (short work cycle time) for the operator work along the traditional assembly line, but these facts certainly also have other consequences touched upon.

The proposed work structuring principles and tools have lately proved applicable for improving the quality of information at a traditional assembly line at the Scania diesel engine plant in Södertälje (Portolomeos and Schoonderwal (1998). Thus, the Volvo Uddevalla plant experiences are of general interest even though this specific plant is closed down.

REFERENCES:

Berelson B, Steiner G A (1964). "Human Behavior – an Inventory of Scientific Findings". Harcourt, Brace & World Inc. New York.

Chomsky, N. (1957). "Syntactic Structure", Mouton, The Hague.

Chomsky, N. (1975). "The Logical Structure of Linguistic Theory". Plenum Press, New York.

Dahl Ö (1982). "Grammatik". Studentlitteratur, Lund (in Swedish).

Engström, T. (1983). "Materialflödessystem och serieproduktion". Departement of Transportation and Logistics, Chalmers University of Technology, Gothenburg (Ph.D. thesis in Swedish).

Engström, T. (1991). "Future Assembly Work – Natural Grouping". Design for Everyone, Proceedings of the 11th Congress of the International Ergonomics Association, Paris, 1991, Vol. 2, Queinnec, Y. and Daniellou, F., eds., Taylor & Francis Ltd, London, pp. 1 317–1 319.

Engström, T. and Medbo, L. (1992). "Preconditions for Long Cycle Time Assembly and Its Management – Some Findings". International Journal of Operations & Production Management, Vol. 12, No. 7/8, pp. 134–146.

Engström, T. and Medbo, L. (1994). "Intra–group Work Patterns in Final Assembly of Motor Vehicles", International Journal of Operations & Production Management, Vol. 14, No. 3, pp. 101–113.

Engström, T., Hedin, H. and Medbo, L. (1992). "Design Analysis by means of Axonometric Hand–drawn Illustrations". Proceedings of International Product Development Management Conference on New Approach to Development and Engineering, the European Institute for Advanced Studies in Management (EIASM), the Gothenburg Centre for Work Science and International Center for Research on the Management of Technology and the Massachusetts Institute of Technology, Brussels.

Engström, T., Jonsson, D. and Medbo, L. (2000). "The Method of Successive Assembly System Design: Six cases studies within the Swedish automotive industri". Agile Manufacturing: 21st Century Manufacturing Strategy, Gunarsekaran A. (ed.), Elsevier Science Publishers (in press).

Engström, T., Jonsson, D., Medbo, P. and Medbo, L. (1995). "Inter-Relation Between Product Variant Codification and Assembly Work for Flexible Manufacturing in Autonomous Groups". Journal of Materials Processing Technology, Vol. 52, pp. 133–140.

Engström, T., Jonsson, D., Medbo. L. (1996). "The Volvo Uddevalla Plant: Production Principles, Work Organization, Human Resources and Performance Aspects – Some Results from a Decade´s Efforts towards Reformation of Assembly Work". Department of Transportation and Logistics, Chalmers University of Technology, Gothenburg (report on Work Environment Fund Projects No 93-0217 and 94-0516).

Hubka, V. and Eder, W. E. (1988). "Theory of Technical Systems". Springer-Verlag, Berlin.

Marton, F. (1970). "Structural dynamics of learning". Gothenburg Studies in Educational Sciences 5, Almqvist & Wiksell Publishers, Stockholm (Ph.D. thesis).

Medbo, L. (1999). "Materials Supply and Product Descriptions for Assembly System – Design and Operation". Department of Transportation and Logistics, Chalmers University of Technology, Gothenburg (Ph.D. thesis).

Moestam Ahlström, L. (1997). "På väg mot den lärande organisationen. En studie av monteringsfabriken Torslanda, Volvo Personvangar". Institutionen för produktionssystem, Kungliga Tekniska Högskolan, Stockholm (in Swedish).

Nilsson, L. (1994). "Intentions and some Consequences of the Volvo Uddevalla plant". The Second GERPISA International Colloquium "The New Industrial Models of Automobile Firms", Paris.

Portolomeos, A., Schoonderwal, P. (1998). "Restructuring the Information Technology and Communication Systems at Scania Engine Plant". School of Technology Management and Economics, Chalmers University of Technology, Göteborg. (MOP thesis).

Viklund, A. (1990). "SAM Sekvensbaserad aktivitiets- och metod analys. Sveriges Rationalseringsförbund, Stockholm (in Swedish).

Volvo (1989). "Funtionsgruppsregistret och positionsnummmer I KDP". Volvo Personvagnar, (internal document in Swedish).

Zandin, K. B. (1980). "MOST Work Measurement System".Dekker, New York.