CHALMERS

Alternative Product Structures Including Alternative Product Variant Codification: Experiences from reforming the assembly line

–

Possibilities for physical and administrative modularisation

Tomas Engström and Lars Medbo

Department of Transportation and Logistics, Chalmers University of Technology,
S-412 96 Gothenburg, Sweden (toen@mot.chalmers.se and lmed@mot.chalmers.se)

Submitted to the work shop in Lyon, France 15 – 16 March 2001 within the international network: Competencies and Knowledge in the European Automobile system´ (CoCKEAS)

CHALMERS UNIVERSITY OF TECHNOLOGY
Department of Transportation and Logistics
SE-412 96 Göteborg, Sweden
Visiting address: Hörsalsvägen 7
Telephone: +46(0)31-772 10 00 Fax: +46(0)31-772 13 37
E-mail: transport@mot.chalmers.se
Chalmers tekniska högskola AB. Reg. No. 556479-5598. VAT No. SE556479559801

Alternative Product Structures Including Alternative Product Variant Codification: Experiences from reforming the assembly line
–
Possibilities for physical and administrative modularisation

Tomas Engström and Lars Medbo

Department of Transportation and Logistics, Chalmers University of Technology,
S-412 96 Gothenburg, Sweden (toen@mot.chalmers.se and lmed@mot.chalmers.se)

ABSTRACT

This paper reports on structuring principles originally used for introducing unorthodox, parallel product flow, long cycle time, assembly systems within the automotive industry. The structuring principle comprise alternative product structures including product variant codification, which in turn are essential ingredients for the design of materials feedings techniques, intra-group work patterns (i.e. division of labour within a work group) and various information systems and operator interfaces (i.e. design of variant specifications[1], assembly instructions, picking lists etc.). The development of these ingredients has required an assembly-oriented product structure, from which essential ingredients like product variation, assembly sequences and intra-group work patterns, are derived.

The assembly-oriented product structure is an alternative or complement to the product data available in the traditional design-oriented product structure, which within the Swedish automotive industry is available by means of various, not always integrated, information systems formalising the product development work which in turn generates the base for bills-of-materials which are used for materials planning and control purposes.

Obviously such an assembly-oriented product structure calls for measures to consider product variation. Consequently a product variation implying numerous product variants complicates both assembly work and administration of product data. This has in fact proved to generate a much too fictitious flora of product variants, combined with various anomalies emanating from the traditional design-oriented product structure. It has also proved to influence e.g. the operators' learning negatively, thus complicating the creation of appropriate work instructions, aggravating the introduction of design change orders as well as decreasing the information quality. This, in turn, complicates the striving for assembly of the product in accordance with the specification.

This specific paper illustrates and epitomises some selected aspects of the structuring principles used during joint-venture co-operation between practitioners and researchers by bringing forward some methods and results used for considering product variation for complex products like automobiles, buses and trucks. However, the understanding of the physical products, product functions as well as anomalies created by the traditional design-oriented product structure is also necessary. These are aspects that are exemplified as well.

However, since introduction of unorthodox assembly systems implies a radical reformation, including way of organising the information handling, which from a traditionalist's point of view might seem risky, it is less hazardous to continue using traditional procedures than inventing something new. The orthodox assembly systems are obviously producing products one way or another. Even though the quality of the information supporting the assembly work along the orthodox assembly line (i.e. serial product flow, long cycle time, assembly systems) in general is worth discussing, it is only touched upon in this paper.

The paper comprises the following examples: (1) detecting an assembly-oriented product structure for diesel engines by means of disassembly, i.e. defining discriminating groups of components; (2) results from detection of so-called variant tracks for diesel engines, i.e. defining product characteristics, organised according to how explicitly these are due to the materials (components) already fitted or planned to be fitted, i.e. generativity, meaning that one component fitted will define another, which in turn generates long tracks, chains, of interrelated components. The examples (1) and (2) aim at

[1] That is the paper, or papers, following the product during assembly specifying product variation.

surveying the product and the true product variations from an assembly point of view, striving to achieve e.g. holistic learning (i.e. what the pedagogues denote as hierarchical integration of knowledge).

The paper also comprises (3) how to track down product functions in trucks by means of alphabetical registers and specially designed illustrations. This example is based on the fact that discrimination and generativity as well as functions are characteristics that are present in complex products with high product variation. Therefore the principles and methods advocated are possible for other automotive manufacturers to use.

To summarise, the product design depends on defined product characteristics, product variation, and product functions which in turn might lead to some sort of (physical) product modularisation (dividing the product into modules i.e. "toy bricks"), which in fact exists on a scale of extremes, from the exchangeable nut, screw or clip to complete aggregates. In this context it also ought to be noted that there is in fact a difference between administrative and physical product modularisation.

Finally, the experiences and insights concerning the design of unorthodox assembly systems reported here are generalised, by hinting at the possible consequences for the industry on a higher level by transferring the insights to the supply chains and thereby have an impact on the supply chain design, thus creating two contrasting scenarios: (a) homogeneous high-volume standardised assembly plants versus low-volume heterogeneous plant designs, using unorthodox assembly systems designs; represented by the trend of (physical) product modularisation and outsourcing by means of engaging e.g. so-called system suppliers resulting in reduced manpower requirements in each production system (node) at a delimited number of high-volume OEM assembly plants; or, (b) differentiated supplier systems due to product development engagement (such as systems suppliers) versus differentiation of the supply chains for other reasons.

In all, this implies that the supply chain of the future is more concerned with various "virtual artefacts" and not only considers physical products and physical modules.

1 INTRODUCTION

Generally speaking the automotive industry is in many respects viewed upon as taking the front line of industrial development. This means that large industrial conglomerates are turning out complex products with high product variation, like e.g. automobiles, buses and trucks en masse. These procedures represent a sophisticated human artefact successively refined during the last century. Therefore it might seem astonishing to imply that somewhere, during this evolution, the internal logic of the information handling procedures and manufacturing principles applied has in fact destroyed the logic of the products beyond human understanding (Engström and Medbo, 1992).

This fact has become evident during the design, running-in and full-scale production of unorthodox, parallel product flow, long cycle time, assembly systems with cycle time of 90 – 300 minutes instead of orthodox serial product flow, short cycle time, assembly systems (the traditional assembly line) with some minutes' cycle time).

These unorthodox assembly systems designs have inevitably called for a holistic product perception, firstly in order to extend the work content substantially and secondly to develop essential ingredients such as appropriate materials feedings techniques and intra-group work patterns (i.e. division of labour within a work group) and various information systems and operator interfaces (i.e. design of variant specifications, assembly instructions, picking lists etc.).

When dealing with complex products, like automobiles, buses and trucks, which are characterised by high product variation and numerous components, there is a call for special measures for structuring the physical materials and the product data. These measures are based on the possibilities to survey and understand the products in detail, based on insights of the idiosyncrasies of the traditional way of organising the product data emanating from the design department and delivered, modified and complemented when used for describing the actual assembly work on the shop floor.

The introduction of the assembly line at the beginning of the twentieth century is commonly viewed as a breakthrough for efficient mass production. Less publicly recognised but just as important was the concomitant introduction of standardised, exchangeable components. This meant e.g. that any XYZ-screw fitted any XYZ-nut. This possibility to exchange components is today a matter of course, but was at the turn of the century a great step forward. In a closer analysis it becomes evident that the possibility to exchange components, as well as products, is somewhat limited even today but the perspective is different since standardisation of single components is already a norm. This possibility to exchange components is in some respects even diminishing due to the accelerating number of product variants, which calls for more different variants on the component level.

Product design (architecture) is closely related to product complexity which has been treated by Hubka and Eder (1988), who discuss complex technical systems as consisting of numerous components which could be divided into subsystems embracing product functions. MacDuffie et al. (1996) connect product and component variation to complexity in production. Ulrich and Eppinger (1995) focus on complexity in the product architecture, i.e. the relationship between physical components and product functions.

Modular product architecture, i.e. modularisation meaning dividing the product into modules (i.e. "toy bricks"), of vehicles and so-called platform concepts have in this context also been brought forward as a method for future product designs and assembly systems, especially in order to manage production with high variation (Muffato, 1999; Ulrich and Eppinger, 1995). However, it is not always possible to divide a product into a number of discrete (physical) modules that can be finalised and tested before being fitted together. In practice, the product functions impose vital restrictions on the possibility to introduce modular product architecture.

2 THE METHOD OF "SUCCESSIVE ASSEMBLY SYSTEM DESIGN"

This paper is based on the authors' experiences of assembly systems design applied at several Swedish assembly plants during the last 15 years.[2] This analytical procedure has been denoted as "successive assembly system design" and takes advantage of existing product data (see Engström, Jonsson and Medbo, 1997). This is information that in Sweden is formalised by means of the traditional design-oriented product structure, which is restructured and supplemented by e.g. information gained through disassembly of physical products, a work resulting in a so-called assembly-oriented product structure.

However, in most cases additional product data are required regarding packages, assembly position on the product, components characteristics (i.e. weight, volume, fragility etc.) but also complementary information such as assembly time calculations, based on e.g. predetermined motion time systems.

Briefly explained the method of "successive assembly system design" comprises a number of interrelated measures that, among other things, clarifies the true product variation by decomposing a physical product of a selected product variant.

The result from this disassembly is put into relation to other product variants by comparing product data from various sources complemented by interviews with e.g. designers and assembly operators as well as inventories of the physical materials along the work stations. Other examples of measures used for this analytical procedure are small cards, labels, grouping of physical components, disassembly of products and construction of an analysis database. All these measures are successively cross-referred.

---

[2] These five cases are (1) The Volvo Uddevalla plant 1984 – 93, (2) The Volvo Torslanda plant 1989 – 89, (3) The Volvo Truck plant 1989 – 90, (4) The Autonova plant 1995 – 97 and (5) The Scania assembly line 1998 – 99. The design procedure was initiated and used for the Volvo Uddevalla plant design and was revised in the redesign of the Volvo Torslanda main plant, a redesign which was never implemented, and for the Volvo truck plant in Tuve, as well as for the Autonova plant. All these four cases used or use parallel product flow, long cycle time assembly systems. The last case is the reopening of the Volvo Uddevalla plant, operating as a joint venture between Volvo and Tom Walkinshaw Racing (TWR), denoted Autonova. This company manufactures exclusive coupés and convertibles for Volvo. Finally, restructuring of the information system at the Scania diesel engine assembly at the main Södertälje plant utilises the same design procedure, but with the aim to improve the quality of data supplied to the operators at the work stations along the existing assembly line.

Generally speaking, the true product variation is considered by means of: (1) successively detailed information within an analysis database specially constructed for formalising the product data and assembly work. Thereby (2) it becomes possible to generalise the so-called hierarchical product structuring and the hierarchical assembly structuring schemes to include all product variants through the identification of so-called variant tracks. The (3) identification of the variant tracks corresponds to characteristics more or less obvious due to the choice of assembly-oriented product structure (see figure 1).

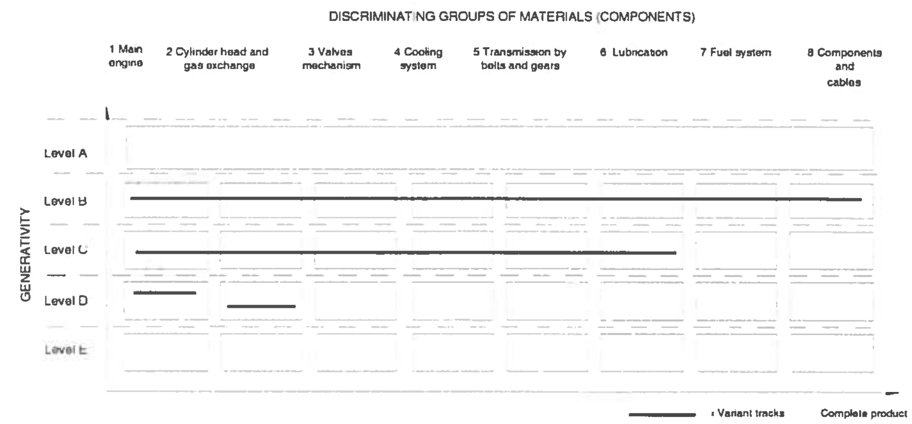
These procedures are illustrated more in detail below. However, the term assembly-oriented product structure refers to a hierarchy of discriminative groups of components while the variant tracks are thus the characteristics which form patterns (i.e. tracks) across the defined groups of components.

Or, in other words, the true product variation will, by recognising the assembly–oriented product structure, give rise to tracks perpendicular to assembly-oriented product structure. These tracks are organising themselves into levels, which are: (1) either explicitly obvious for e.g. the operator fitting physical components to the respective products, (2) or when it is impossible to detect if the materials, about to be fitted or that have been fitted, are correct. Between these two extremes, i.e. (1) and (2), depending on the knowledge of product and product variation, a spectrum of variant tracks are emanating due to <u>generativity</u>, i.e. to what degree physical components are more or less obviously related to each other by means of various characteristics.

The principle is that appropriate descriptions of the true product variation are in fact a consequence of product characteristics, which are more or less obvious from an assembly point of view, while the discrimination between groups of components means that the individual characteristics of the product are organised in order to survey the product. These possibilities to survey the product is usually, for complex products with high product variation like automobiles, buses and trucks, achieved according to a multitude of clusters of characteristics, such as component size and form, position within the products, functions due to component interrelations, colour and surface treatment etc.

*

The general aim to construct an assembly-oriented product structure is to organise the materials at the work station to support learning of an extended work content by emphasising product perception and group work. The variant tracks correspond to the need for, e.g., overlapping competencies between operators within the work group. Accordingly, such an assembly-oriented product structure divides the product into groups of components, corresponding to the total assembly work content of the product. Then, e.g., various operators' assembly sequences for a specific product are derived from this structure, which is viewed upon as a taxonomic description of the product instead of being seen as a stipulated, fixed overall assembly sequence as is generally the case in most assembly systems.



<u>Figure 1</u>. Principal schematisation of an assembly-oriented product structure (in this case Scania diesel engines which is discussed more in detail below in sections 2 and 3), i.e. discriminative groups of components. It is thus possible to define variant tracks, describing the true product variation, which are appearing in levels (A – E) according to the concept generativity, i.e. how explicitly these tracks are due to the components already fitted or planned to be fitted. This implies that some physical components form 'tracks' of components according to the generative characteristics of the product. It thereby becomes obvious which is the correct physical component to be fitted – while in other cases there is no possibility at all to know exactly which component to fit without consulting for example the variant specification.

The traditional design-oriented product structure versus the assembly-oriented product structure

The traditional design-oriented product structure used by the Swedish automotive manufacturers, i.e. the so-called function group registers, is applicable to all types of vehicles. This generality has the consequence that applied to an automobile, for example, and causes parts of the hierarchic structure to disappear (Engström and Medbo, 1992). Thus will not series of numbers that refer to physical components of e.g. an automobile form coherent series of figures, referring to the digits in the function group register, since parts of the hierarchy will disappear. This phenomenon is due to the fact that components in the function group register are not applicable to an automobile.

Neither will various discrete functions in the vehicle be understood since some components included are to be found in different functions groups. For example, by referring to a vehicle fitted with an ABS-system, used for automatic monitoring of the brake force in order to avoid locked up brakes during the driving, this phenomenon becomes evident. Some components like cables with the function to link the electrical signals are found in the main function group "3 000: Electric power supply and instruments" while the sensors fitted on the wheel spindles with the function of detecting the speed of the wheel are included in the main function group "6 000: Wheel suspension and steering". On the other hand is the hydraulic aggregate with the function to regulate and distribute the brake power between the four wheels during braking included in the main function group "8 000: Body, cab and upholstery" (Volvo, 1987). That is why, for example, components that are specific to an automobile are not specific to a truck. Therefore two products like an automobile and a truck fill the design-oriented product structure in specifically distinct ways.[3]

It must also be noted that the product design of some vehicles has changed substantially during the last decades. This is particularly true for the automobile, which has changed in structural content. Today, for example, the whole interior is upholstered with panels of plastic or cloth, which is why most of the components are to be found in the main function group "8 000: Body, cab and upholstery". Today's substantially increased combination of subassemblies is the result of changes in market, design technology, choice of material and external suppliers leading to a vast number of components and modules.

Briefly explained, the assembly-oriented product structure containing product data from the design department, utilised by the Swedish automotive manufacturers, consists of a computer-oriented ("digital") core of alphanumeric codes supplemented by descriptive names for components according to the function group register.

Product variation in the existing information system, comprising the assembly-oriented product structure, is defined by means of so-called variant designations of each so-called structure (i.e. lines of data in the tables in information systems comprising the design-oriented product structure). The variant designations are for example "MAIRBAG" (with air bag), and combinations of such codes, can be seen as arbitrary alphanumerical codes used for material selection or in some cases as meaningful names of certain product functions appropriate for design purposes. The materials selection is done by so-called materials control codes which specify a part number at the lowest level of the design-oriented product structure by using variant designations.

---

[3] The function group register, as used by Volvo, for an automobile comprises 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 and; 8 000: Body, cab and upholstery. One the other hand, the assembly-oriented product structure for a complete automobile, as developed by the authors contain, apart from doors; (1) leads for electrics, air and water, (2) drive line, (3) sealing and decor and (4) interior (Engström and Medbo 1993). The general function groups register applied by Volvo for automobiles 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 automobile 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".

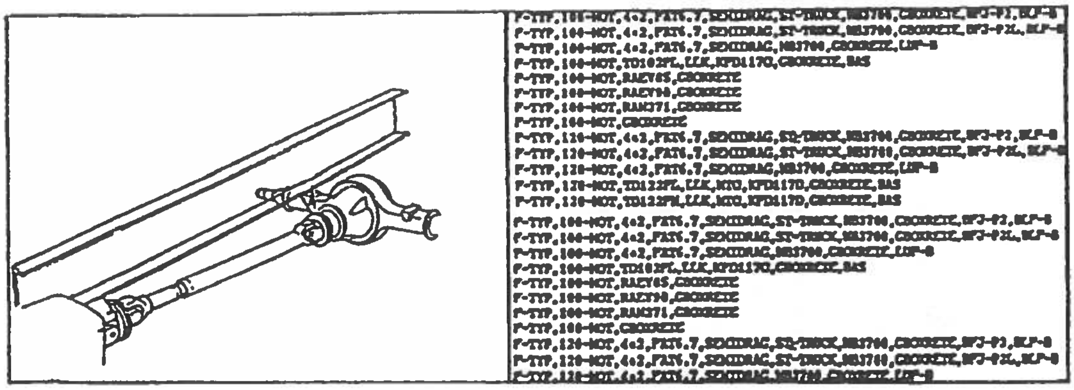


Figure 2. Example of how a propeller shaft in a truck is described today by Volvo by coding the shaft with variant designations ("RAEV91", "TOOLB-L", "UKOB" in the figure) using the design-oriented product structure. In reality there are 200 different physical propeller shafts for a certain type of vehicle, which are all assembled essentially in the same way. The existing information system, comprising the assembly-oriented product structure, gives in the case of Volvo trucks rise to 1 300 material control codes. This makes it unreasonable, in fact almost unrealisable, to perceive the true product variations as well as to define assembly work on the shop floor. However, this has proved possible, if the product design and product data are perceived through an assembly-oriented product structure, a mechanism, an instrument, for transforming the existing product data in order to design and run unorthodox assembly systems. Such a structure has also proved to be one key factor for updating of product data reaching the shop floor. This is a labour-intensive and complicated work, necessary due to introduction of new product variants, the continuous introduction of design change orders etc. Accordingly, this leads to that in some observed cases it is difficult, in point of fact impossible, to assure that the assembled product corresponds to the specifications.

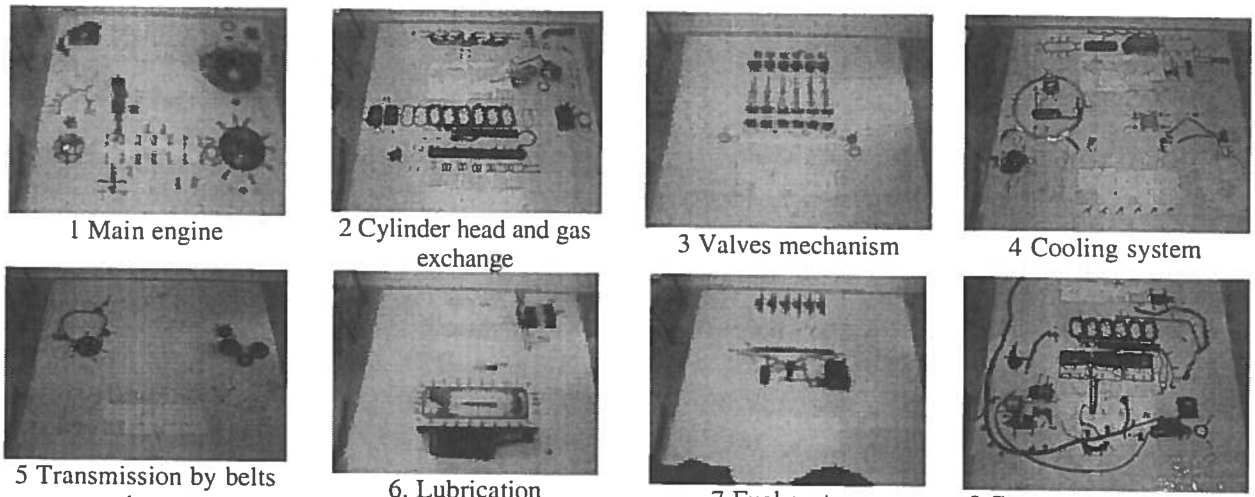
3 DETECTING AN ASSEMBLY-ORIENTED PRODUCT STRUCTURE FOR SCANIA DIESEL ENGINES ASSEMBLY LINE

The results presented in this section are based on a co-operation project between the company and the university, carried out during 1998 – 00. Basically, this co-operation was aimed at improving the quality of the data supplied to the operators along the assembly line, i.e. an orthodox assembly system with approximately 4 – 8 minutes' cycle time comprising in total 43 work stations along a serial product flow. This specific aim has earlier not been the case since designing assembly systems used to be in focus.

In short, the required restructuring of the existing information system at Scania was first a matter of understanding the assembly system and various information systems. These information systems mainly use data derived from the traditional design-oriented product structure. This refers to the initial product data emanating from the design department, which at Scania is adapted to an assembly information system generating shop-floor assembly information. This shop-floor information is represented by a so-called work order, which is a document, following each engine, and specifies all the physical components (with their respective auxiliary information, i.e. tasks, tools and torque, position in the work station, etc.). See Portolomeos and Schoonderwal (1998) for a more detailed description.

The restructuring procedure was guided by measures such as small cards, labels, grouping of physical components and disassembly of a diesel engine. It also required cross-referring of the removed physical components arranged on the floor in an experimental workshop, including marking on the appropriate materials resulting in an understanding of the physical product design, the orthodox assembly system design and various information systems in use. The arrangement of the physical components on the floor was first in accordance with the work station along the assembly line, i.e. in reversed assembly sequence, and later in accordance with the proposed assembly-oriented product structure.

The restructuring procedure also provided a basis for the refinement of an analysis database. This refinement was achieved by first focusing on the large components (pistons, connecting rods, crankshaft, water pump etc.) and later on the small ones (screws, nuts, O-rings etc.) and by assuming that the large components required were associated with the small ones. This underlined various anomalies in various information systems. In figure 3 the resulting assembly-oriented product structure for the Scania diesel engine is shown, giving an overview/a survey/a general view that did not exist earlier.



1 Main engine; 2 Cylinder head and gas exchange; 3 Valves mechanism; 4 Cooling system; 5 Transmission by belts and gears; 6. Lubrication; 7 Fuel system; 8 Components and cables

Figure 3. Disassembled diesel engine at Scania in 1998 expressing an assembly-oriented product structure. The physical components were positioned on the floor according to their position on the engine. The paper silhouettes illustrate various views of the engine (Portolomeos and Schoonderwall, 1998).

4 VARIANT TRACKS AT THE SCANIA DIESEL ENGINE ASSEMBLY

The detected true product variation at Scania was checked by interviews with e.g. designers and assembly operators as well as *through inventories of the physical materials along the assembly line. Figure 4 shows variant tracks describing the true product variation of a Scania diesel engine as they spread in the assembly-oriented product structure. Basically most of the product variants proved to be possible to be described by; (1) the type of fuel injection system, (2) if the engine is to be used in a truck or a bus and (3) if the vehicle is to be equipped with front wheel drive or not and by (4) type of cab.

	Main engine	Cylinder head and gas exchange	Valve mechanism	Cooling system	Transmission by belts and gears	Lubrication	Fuel system	Components and cables
PDE	Svänghjulkåpa Svänghjul	Cylinderhuvud Ventilkåpa Ventilkåpa oljepåfyllning Ventilkåpa över	Kamaxel Axel med lyftare Vipparmaxel Stötstång	Styrenhetskylare Flänsrör	Transmissionsplåt Kamaxelkugghjul		Bränslelist Överströmningsventil Pumpinsprutare Matarpump	Rör luft IN Rör luft UT Styrenhet Luftkompresor PDE
RAD-PUMP	Svänghjulskåpa Svänghjul	Cylinder huvud Ventilkåpa Ventilkåpa oljepåfyll Ventilkåpa över	Kamaxel Axel med lyftare Vipparmaxel	Flänsrör Rör kylvätska IN Rör vatten UT	Transmissionsplåt Kamaxelkugghjul		Bränslelist Insprutare	Värmesköld Luftrör
TRUCK	Frontkåpa Lock			Fäste Rör kylslinga		Sugledning Oljesump		Jordfläta
BUS	Frontkåpa Lagerhus	Laddluftrör Laddluftrör				Sugledning Oljesump	Fäste Handpump	Remskiva AC
D11	Vevaxel Kolv och Vevstake							
D12	Vevaxel Kolv och Vevstake							
FRAM-HJULS-DRIFT: JA		Avgasbroms Rör Fäste		Webastorör				
FRAM-HJULS-DRIFT: NEJ		Avgasbroms Rör Fäste						
Radpump 01				Lufttemperaturgivare Motortemperaturgivare			Insprutningspump	
Radpump 02							Insprutningspump	

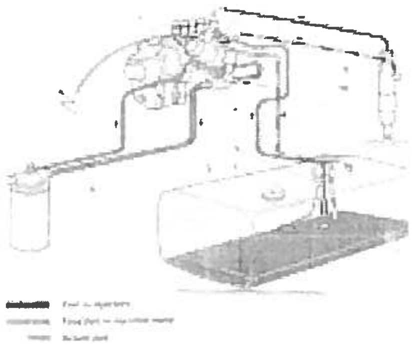
Figure 4. Example of variant tracks of Scania diesel engines defined by starting from the assembly-oriented product structure, which in turn settles the variant tracks. These tracks are organised due to generativity in accordance with figure 1. In fact the variant tracks at Scania were; (1) type of fuel injection system (in-line or unit injection), (2) if the engine is to be used in a truck or a bus, (3) if the vehicle is to be equipped with front wheel drive or not and (4) type of cab. Type of cab means normally built with hood and driver situated behind the front axle and low built with driver situated above the front axle. This last type of cab is available in two different heights. The three types of cabs are coded by the variant designations "CT", "CR", and "CP" respectively (Portolomeos and Schoonderwall, 1998).

The variant tracks in figure 4 are described by selected large components distributed along the assembly-oriented product structure starting with the naked engine block to the left in figure 4 and ending with the complete assembled engine to the right. These selected components were initially chosen based on available information, disassembly of a diesel engine and discussions with operators in order to describe all product variants. Omitted components in figure 4 means that no such components exist.

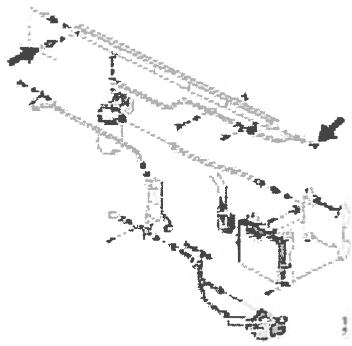
*

To exemplify how the understanding of the product and product functions will be defined by the true product variation, let us focus on the fuel injection system whose components are spread over numerous work stations. The type of fuel injection system defines variant tracks with the highest degree of generativity. At the Scania diesel engines assembled there are two main fuel injection systems. First there is an in-line injection system designated "RADPUMP" ("i rad pump" in

Swedish) The other fuel injection system is the unit injection system designated "PDE" which is an abbreviation for pump diesel "einspritzen". See figure 5.
The in-line injection system with a separate high-pressure in-line injection pump is situated on the left side of the engine, fitted to the flywheel house cover. This injection pump is driven by the gear transmission from the rear side (clutch side) of the engine. The injection pump pressurises and delivers fuel to six fuel injectors located in the cylinder heads. This injection pump delivers the correct amount of high-pressure fuel to each individual injector. The unit injection system (PDE), on the other hand, uses a combined pump and injector that is located in the cylinder head, for high pressurising and injecting the appropriate amount fuel into the combustion chamber. The fuel is monitored electrically by a solenoid-controlled valve integrated into the unit injector. The need for a separate in-line pump for delivering the correct amount of fuel is eliminated. This unit injector is manoeuvred by an extra rocker located in the cylinder head controlled by a third push rod through an extra cam lobe on the camshaft.



In-line injection system



Unit injection system

Figure 5. The type of fuel injection system defines variant tracks with the highest degree of generativity, i.e. many components are spread over numerous work stations, thus forming a variant tracks. Scania utilises two fuel injection systems (in-line injection and unit injection systems). Illustrations from Scania service manuals.

*

By using the detected information concerning variant tracks (fuel injection system, type of vehicle and engine cylinders displacements) it proved possible to foresee most of the physical components to be assembled at 28 of 43 work stations. This is according to an analysis based on information contained in the work orders, which also was confirmed through interviews and inventories. As a result of this work described here, the work orders were possible to reduce from 43 pages down to one, containing correct information for specifying product variation. This way of specifying the product variants is now used at Scania, thus eliminating some of the former inconvenience and risk of the product not meeting the specifications.

In fact the information needed for estimating the assembly work along the line proved to be available weekly through a list used for production scheduling, which comprised the sequence of engines manufactured defining every single product variant by means of various variant designations. Still, this possibility has not previously been recognised since it has not been possible to interpret the product variant codification.

However, this possibility to in advance understand the true product variation has strong implications on, for example, the potential usage of engines as buffers along the assembly line and the choice of sequence of engines for acquiring a more smooth flow. By interpreting the information on the list, the technical autonomy (i.e. freedom from being machine-paced) could be increased for the work groups along the assembly line, since they are, in fact, able to plan their work. In the Scania case the number of operators along the line was less than the number of engines accessible for assembly. It is thus possible to formalise intermediate buffers between work groups. Such formalised intermediate buffers will be a result of combining the information mentioned above with the work groups' planning, by defining of buffer areas on the floor of the workshop. This suggested procedure, not exploited by the company, has strong similarities with the concepts of administrative and physical exchangeability between products discussed in section 7.

5 TRACKING DOWN PRODUCT FUNCTIONS THAT SUCCESSIVELY ARISE DURING THE ASSEMBLY OF VOLVO TRUCKS BY MEANS OF ALPHABETICAL REGISTERS AND SPECIALLY CONSTRUCTED DRAWINGS

The results presented in this section are based on a co-operation project between the Volvo Truck Company and Chalmers University of Technology, carried out during 1989 – 90. Basically, this co-operation was aimed at restructuring the product in accordance with the principles presented above. This work led to, among other things, introduction of unorthodox assembly systems.

One important, critical knowledge advocated, included in the structuring principles, is to link various product functions, which are created by composing various components. In order to achieve this the authors constructed a number of alphabetical registers. These registers consisted of a short description of the component, source of data, the appropriate illustration, positions on the vehicle, etc. Increasing the quality of data in these registers was in many respects an iterative process, which successively refined the information by cross-referring various sources of data. The sources were, during that period of time, all possible material describing the Volvo trucks, i.e. service manuals, assembly instructions, instructions defining the product quality, after market materials like brochures and sales specifications, variant specifications etc. One important aspect was to compare various physical components and aggregates with each other as well as gain an insight into which variant designations that had or had not physical correspondences. This was an extensive work, performed during two years, also including decomposition of a complete truck in accordance with the method of "successive assembly system design.

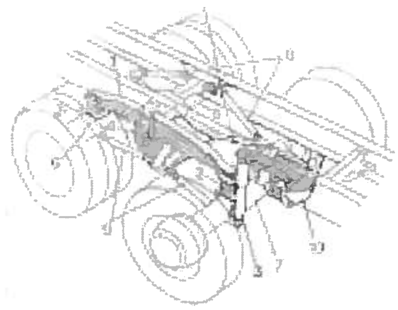
In detail this meant, for example, that the completed alphabetical registers compared and described the functions of various physical components and aggregates like e.g. power take-offs that might be fitted to a truck for the reader of the registers. In this case he or she also needed to understand that there were in fact six such power take-offs, all situated on different positions of the gearbox and looking distinctively different. For example, the variant designation "BKU 1073" was a low-speed unit for propeller shaft drive, the variant designation "BKU 1123" referred to a high-speed unit for propeller shaft drive etc. All these power take-offs needed to be illustrated on the same drawing in order to gain the required general view. It proved possible to find such an illustration in the Volvo materials. [4]

This was, however, not the case for the bogies which called for construction of specially designed drawings (see figures 6 and 7). In fact a system of drawings, normalised against a number of transparent outlines, was constructed according to the principles used earlier by the authors (Engström, Hedin and Medbo, 1992). These drawings were constructed by utilising the decomposed truck. To create these drawings the physical components were placed on the shop floor, positioned/oriented to facilitate the drawing, while all leads were positioned and fixed at a number of wood mock-up frames. Four different mock-ups were required for the leads, one for each system of leads, and to the right there is an illustration of leads normalised against the transparent outline. Thus a number of systematic, normalised illustrations was created.

The alphabetical registers, finally concentrated contain a selected number of representative components needed as well as aggregates, necessary to understand product functions and product variation, proved to consist of in total 190 terms. This concentrated register also stated existing synonyms and corresponding variant designations, i.e. if a specific variant designation was synonymous with specific components and aggregates.

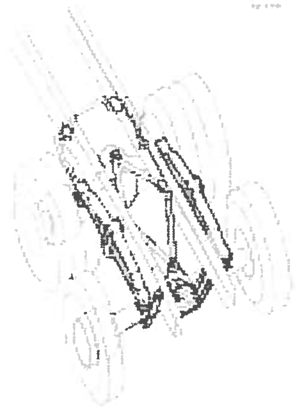
[4] If a product variant is specified by the existing product data it is not obvious, or even possible to track down, what the complementary occurrence is. If for example the variant designations for a truck stipulate that the vehicle is supposed to be fitted with some sort of extra equipment there is a number of variant designations that specifies this and the various alternatives of this specific equipment. However, if this equipment, for some reasons, no longer is fitted with the vehicle (i.e. the alternative designations are no longer valid), variant designations defining that a vehicle should not have this equipment might still be used within various information systems. For example "BKU 1073" and "BKU 1123" referees to alternative power take-offs, while "UKOB" means without power take-off ("U" = "utan" = "without" in Swedish). Therefore it is not always correct to assume that the complementary occurrence automatically exists if a variant designation defines that the vehicle is not fitted with this specific equipment.

Note that no such registers existed, or exist today, within the company. The product data are still today fragmented and not revised in accordance with e.g. synonyms and homonyms. Therefore it is still not possible to recognise if there actually is a connection between specific physical components and aggregates and product data in the form of e.g. variant designations. A similar state of affairs goes for e.g. Scania which to some extent has acknowledged this discrepancy but refers to the substantial investments in various existing information systems as a severe restriction towards restructuring. Of course both companies carry on comprehensive ongoing development work concerning Product Data Management (PDM) systems, but these initiatives are not along the lines briefly expressed in this paper.



1 = Leaf spring package, 2 = rubber spring, 3 = shock absorber, 4 = cradle, 5 = balance arms and balance axle, 6 = drive axle, 7 = tow axle, 8 = V-bar, 9 = Reaction bars, 10 = air bellows

Traditional illustration of the so-called S-ride bogie



Normalised illustration of the so-called S-ride bogie

Figure 6. To the right a traditional illustration found in Volvo materials showing a bogie. These illustrations are usually drawn as the components or aggregates are viewed when the vehicle and observer are positioned on the ground; to the left normalised illustrations which were constructed by means of disassembly and grouping of the physical components of a Volvo truck from the authors' experimental workshop in 1988 – 89 (Danhäll et al., 1990).

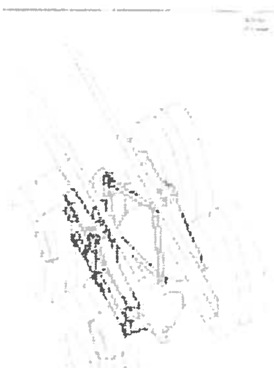
"A-RIDE"
A bogie comprising two, "correctly turned" leaf spring packages which always have parable leaf springs and a stabilising bar fitted. The last axle on this bogie is a tow axle while the foremost axle is driven. There are double tyres on both axles. This bogie is fitted to a (6x2)* truck.

"LUFT-RIDE"
"BGT18", "6x2", "LUF-B"
A bogie fitted to 4x2 and 6x2 trucks (the 4x2 truck has the bogie aggregate turned around compared to the 6x2, i.e. facing the other way around). The suspension uses air bellows (no leaf springs). Stabilising bars are always fitted (one for 4x2 and two four 6X2).

"S-RIDE"
A bogie comprising two "upside down" leaf spring packages as is also the case for "T-RIDE". The last axle is a tow axle that is possible to lift. Double tyres are fitted the driven axle which is positioned before the tow axle which has single tyres.

"BGT16PA"
pusher axle
A bogie comprising two, "correctly turned" leaf spring packages. The bogie has a fixed, self-piloting, air suspension axle fitted before the driven axle in the rear. Double tyres are filled on the driven rear axle and single tyres on the front tow axle.

"PARFORCED"
rear steer axle
A bogie comprising "two correctly turned" leaf spring packages. A swivel rod is force- steering the foremost air-suspended axle. This axle is fitted before the driven rear axle along the similar lines as "BGT16PA".



"B-RIDE"
A bogie comprising two, "correctly turned" leaf spring packages. Both axles are driven. None of the axles are possible to lift. Double tyres are fitted on both axles.

"L-RIDE"
A bogie comprising four, correctly turned leaf spring packages fitted by means of four reaction bars into the frame. Each leaf spring package has ten leaves each. Both axles are driven (8x4 and 6x4). Non of the axles are possible to lift. Double tyres are fitted on both axles. The bogie lacks stabilising bar and shock absorbers. It is not possible, as is the case for "T-RIDE", to adjust this bogie.

"T-RIDE"
A bogie comprising two "upside down" leaf spring packages, as is also the case for "S-RIDE". The bogie is fitted by means of two V-bars into the frame. Therefore is it possible to (unlike the "L-RIDE") to adjust this bogie.

* Refers to the total number of a wheels on the vehicle in relation to the number of driven wheels. For example 6x4 means totally six wheels of which two are driven.
Codification: Capital letters = Variant designations, Capital letter and lower case letters = Colloquial language

Figure 7. Normalised illustrations of all bogies for Volvo trucks where the vehicle is viewed from above, slightly from the left and with the front facing up into the left corner (i.e. as a hypothetical driver has to enter a series of trucks and as an architect might view a city from above).

The bogie fitted to Volvo trucks comprises a number of obvious characteristics like: (1) type of suspensions, e.g. air or leaf springs, and in the case of leaf springs – type of spring; (2) type of brake system e.g. so-called SRB-system, i.e. the Swedish brake system, ERB-system, i.e. the English brake system, KRB-system, i.e. the Continental brake system and (3) number of driven wheels in relation to the total number of wheels on the vehicle (4x2, 6x2, 6x4, 8x2 and 8x4, where the last digit explains the number of driven wheels). These normalised illustrations were especially constructed in the authors´ experimental work shop in 1990 in order to be included in an alphabetical register comprising all components and aggregates.

No such drawings were available within Volvo which made it impossible to understand various product functions as generated by various bogies. Drawings, and other illustrations, available within the company were not normalised and since all types of bogies were not summarised in a delimited number of drawings it was difficult to achieve the required survey. The product data proved to be far too fragmented to make it possible to use this data as the only source for perceiving the variation of bogies. For example, to specify the components in a bogie each component included in the bogies required up to twelve different variant designations for each included component. These variant designations were used for materials planning and control purposes.

7 CONCLUSIONS

To summarise some conclusions and statements from the reported experiences from Swedish automotive industry concerning the state of art of product data:

> 1 The traditional design-oriented product structure has, for various reasons, conveyed fragmented product data. This fragmentation becomes especially evident when comparing the physical products components with the content in various existing/traditional information systems used for generating product data supporting the shop floor assembly work.
>
> 2 The accuracy and logic of the content in various existing/traditional information systems, as well as in all available materials from other sources describing the products, are somewhat insufficient. The product data consist of a confusing mix of terms, codes and abbreviations contaminated by company-specific nomenclature and a colloquial language muddled by a blend of Swedish and English terms.
>
> 3 The traditional design-oriented product structure and the variant designations are animate beings. They are constantly shifting due to reformed product variants, introduction of new models or on account of design change orders, i.e. branches in the structure trees and materials control codes (the leaves of the tree) are constantly changing in a way that is in fact intriguing. The information is perishable; the time window is movable, leading to difficulties in securing the correct information to a specific product.

Especially intriguing is the state of art of product data, if e.g. the planned production sequence is not strictly followed; here the parallel product flow assembly system will turn out to be bewildering to the traditional manufacturing engineers. On the other hand, however, the restructuring principles presented in this paper imply potentials, as is evident by the Scania example, concerning buffer functions along the assembly line described above.

To summarise, the enigma of structuring complex products with high product variation has earlier proved vital for understanding the anomalies of the existing product data and information systems, which has became evident for the authors when designing assembly systems. As has been hinted above, the state of art within Swedish automobile industry, underlines the need for a radical reformation of product data in itself as well as ways of organising the information handling in order to change the product perception.

As is described in this paper, an appropriate product perception within the automotive industry ought to, e.g., link various product functions, which successively arise during the assembly, to verbal and spatial networks, which will create and support both holistic and detailed perception of a product,

product variation and work. Either this work is related to assembly or to administration of the product data. This calls for recreation of the logic of the product, a logic that is available at the design department and apparently evident for the complete products, but not for various reasons appropriately formalised in various existing information systems. This logic has been lost during the total manufacturing processes, which is especially prominent during assembly of vehicles as is evident by the five examples reported above.

*

The international trend towards product designs involving external subassemblies and predefined interfaces (i.e. modular product architecture), in some cases represented by component manufacturers or special companies, has in many cases increased the number of component types assembled. For combinatorial reasons, the number of product variants tends to increase with the size of the subassembly. In order to remedy this situation the subassemblies are often treated as administratively non-exchangeable though they are in fact physically possible to substitute for one another.

A representative example showing that administrative exchangeability is usually more restricted than the physical is the sequence-bound components delivered to a final assembly plant. Sequence-bound deliveries mean that the supplier assigns product individuals (i.e. components or physical modules) to specific product individuals. Two different components, which are physically identical and thereby physically exchangeable, but from the production scheduling point of view designated for different product individuals, will therefore be treated as non-exchangeable. For a more detailed description of these aspects, see Engström, Jonsson and Medbo (2000)

In fact, an alternative product variant codification, along the lines explained above, implies the need of reformed codification, in a narrow sense, this might be seen as a matter of complementing the existing information system to comprise the assembly-oriented product structure, which today organises the production scheduling based on component numbers and alphanumerical characters. Such a procedure, though, will actually conserve the present state of art since the fundamental principles are questionable.

According to the authors´ experiences, it has proved necessary to introduce a nomenclature to recreate the logic of the product on the shop floor. Thus, a "semantic and spatial network" is formed, giving a holistic perception of product and work, closely coupled to product characteristics, product variation, product functions which in turn might, or might not, lead to some sort of (physical) product modularisation. This is a "semantic and spatial network" that in fact has proved to be possible to derive from the designers' nomenclature. Thereby high quality nuance product data are actually available but the existing mechanisms within the automotive industry (the information systems) are based on the fundamentally questionable assumptions.

The creation, and computer formalisation, of an appropriate "semantic and spatial network", requires quite another approach. This new approach has not been fully recognised, but will*, if correctly implemented, lead to various effects. These effects include increased operators competencies that enable operators to control their work and perform administrative work, such as creating work instructions and dealing with design change orders, earlier inevitably done by white-collar personnel. This is opposed to traditional fragmentation of product data generated from a distant design department, which inevitably causes excessive administrative work at the local plant.

In the first case the training and learning is constituted by the technical preconditions for work, i.e. the implicit technical dimension promotes and demands qualified operators (for materials handling, assembly, administrative work, etc.). In fact, the training and learning can be performed in the direction from a whole to the details and not the opposite. The learning can therefore be regarded as holistic (hierarchical integration of knowledge) instead of atomistic (focusing on details) (see e.g. Marton and Both, 1997). This leads to a work that utilises the specific human capabilities as a valuable complement to the technology of the future.

*

To conclude, the unorthodox assembly system designs result in efficiency and flexibility implying low-scale manufacturing premises by means of extremely competent operators, i.e. in the most extreme case, including only one work group of operators (see e.g. Engström, Jonson and Medbo, 1996 for proofs of these statements). This is in contrast with high-volume manufacturing utilising an extreme division of labour among operators (i.e. short cycle time), who today in the western world are either low or multi-purposely qualified. This way of manufacturing implies a need for a so-called high design degree, i.e. substantial product development work is required in order to achieve an appropriate product design. On the other hand, the alternative product variant codification described above implies a flexibility, making it e.g. possible to prioritise the internal work of materials handlers and operators involved in the direct manufacturing – in contrast to the demand for total synchronisation of materials handling and direct manufacturing.

These effects could be transferred to the external materials flow systems and thereby affect the supply chain, creating two contrasting scenarios:

> A Homogeneous high-volume standardised assembly plants versus heterogeneous plant designs, represented by the trend of (physical) product modularisation and outsourcing by engaging e.g. so-called system suppliers resulting in reduced manpower requirements at a delimited number of high-volume OEM assembly plants. If this trend continues, the plants will ultimately consist of a selected amount of a highly mechanised equipment which automatically unites some modules into a complete vehicle (so-called marriage-points), which are either fully automated or prepared for increased automation; all in coherence with the trend of standardising the local plants' assembly process, forming supply chains of carbon copy plants. This stands in contrast to a heterogeneous network of plant designs adapted to the local preconditions, custom barriers, local suppliers specialities etc., forming supply chains composed of a larger number of low-volume plants establishing an alternative industrial network. Such an industrial network would be "monitored" by an alternative product structure including alternative product variant codification, which both are examples of important "virtual artefacts", and thus would the shop floor work and supply chain design be a direct result of the product design, fully in coherence with the product data.

> B Differentiated supplier systems due to product development engagement (such as system suppliers) versus differentiation of the supply chains for other reasons. There is today a trend within the automotive industry to differentiate the suppliers according to level of responsibility in respect of product development. Thus, a national as well as an international network of high volume (i.e. specialised, independent system suppliers) has arisen, while at the same time the dependent suppliers are categorised (class A, B and C etc.) – This may be in contrast to supply chains where the nodes have other, from the automotive industry's point of view, non-traditional criteria. These criteria could be e.g. flexibility of mixing product variants and models in the same plant (manufacturing products not only for the mother company), possibility of prototype and full-scale manufacturing simultaneously in the same plant, adapting to the future work force requirements for combining work and leisure-time activities, comprising e.g. flexible work time scheduling. These are important considerations to avoid exporting the work to countries with substantially lower wages etc. This implies that the industrial network cannot be perceived as a number of predefined, rectilinear supply chains, starting upstream at the suppliers and ending downstream at the customer. Instead the industrial network turns into a multi-dimensional matrix comprising a number of materials and information handling processes.

In all, this implies that the supply chains of the future are more concerned with the "virtual artefacts" than with the physical product, i.e. the means are to achieve an appropriate content (both regarding information quality as well as the appropriate content) in the information systems backed up by various software methods, supporting this information handling and manual work. This has proved not to be the case in the Swedish automotive industry where the existing "virtual artefacts" (such as product structures including product variant codification) are mirroring an old product design combined with preservation of an out-of-date assumption regarding human learning. The later aspects are not elaborated in this paper.

The product design's (architecture) relation to "virtual artefacts" and the human perception of these artefacts is, according to the authors' experiences, a critical key factor for the automotive industry of the future which probably successively will replace the physical economy and increase flexibility and performance of the supply chain of the future. This might, however, be seen as inevitable for the young generations of human beings while the old "fogies" are adducing the investments as the sole arguments for the present state of art.

References:

Danhäll D, Engström T, Hedin M, Kristensson B, Medbo L, Thunberg K (1990). "Naturligt grupperat arbete vid Volvo Lastvagnar AB – Slutrapport". Institutionen för Transportteknik, Chalmers Tekniska Högskola, Göteborg.

Engström T, Hedin H, 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,, Brussels.

Engström T, Jonsson D, Medbo L (1997). "Successive Assembly System Design Based on Disassembly of Products". The Sixth International Conference on Management of Technology – MOT 97, "The Creation of Prosperity, Business and Work Opportunities Trough Technology Management", Mueller H, Persson J-G, Lumsden K R (eds.), Göteborg, pp 264 – 273.

Engström T, Jonsson D, Medbo L. (1996). "Production Model Discourse and Experiences from the Swedish Automotive Industry", International Journal of Operations and Production Management, Vol. 16, No. 2, pp. 141 – 158.

Engström T, Medbo L (1992). "Material Flow Analysis, Sociotechnology and Natural Grouped Assembly Work for Automobiles and Trucks". Research and Development in Work and Technology, Porsnschlegel H (eds.), Physica Verlag, Heidelberg, pp 220 – 242.

Engström T, Medbo L (1992). "Naturally Grouped Assembly Work and New Product Structures". International Journal of Technology Management, Vol. 7, No 4/5, pp 302 – 313.

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

MacDuffie J P, Sethuraman K, Fisher M L (1996). "Product Variety and Manufacturing Performance: Evidence from the international automotive assembly plant study". Management Science, Vol 42, No 3, pp 350 – 369.

Marton F, Booth S (1997). "Learning and Awareness". Erlbaum, Mahwah, New Jersey.

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

Muffatto M (1999). "Platform Strategies in International New Product Development". International Journal of Operations & Production Management, Vol 19, No 5/6, pp 449 – 459.

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, Gothenburg (MOP-thesis).

Ulrich K T, Eppinger S D (1995). "Product Design and Development". McGraw-Hill, New York.

Volvo (1987). "Fuktionsgruppförteckning. Function Group Register". Volvo, Novum Grafiska AB, 1:87, Göteborg.