6th

"ACHIEVING COMPETITIVE EDGE"

GETTING AHEAD THROUGH TECHNOLOGY AND PEOPLE

JUNE 25-26 1991

Aston University, Birmingham, England

SIXTH INTERNATIONAL CONFERENCE

OPERATIONS MANAGEMENT ASSOCIATION UK

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6.1.21

CONSEQUENCES FOR FINAL ASSEMBLY, PRE-PRODUCTION AND DESIGN OF NATURAL GROUPED ASSEMBLY WORK AND MATERIALS HANDLING - METHODS AND EXPERIENCE

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ABSTRACT

We shall here summarize some experience and methods from the development of long cycle time assembly systems. This paper reports general questions valid for the person or the company intending to both make assembly work more efficient and humanize it, and also illustrates these questions with specific "delimited" examples. Our results are based on several years´ collaboration characterized as action research between researchers and practitioners mainly within the Volvo Car and Volvo Truck Corporations. This work has led to real implementation of research results in the industrial environments.

Our research has shown, that in order to be able to develop and maintain a spectrum of different final assembly concepts and to further develop industrial work, the introduction of new product and process structures is a necessity.

But it is possible at the same time to find resistant relationships as a basis for orientation among the precise work of the design department, central pre-production and the various final assembly processes, since automobiles and trucks display certain generic characteristics. The consequence is that the information systems in use today and the company's transfer surfaces within the internal organisation must be changed when the new assembly work is realized.

We will begin by introducing, in a broad sense, our field of research in designing alternative production systems to traditional line-assembly and go on to discuss in detail our method and the more defined problem area of developing descriptive structures adapted to final assembly for the assembly plants of tomorrow. This work illustrates the importance of principles of differentiation between causal and taxonomic descriptions and of using stereometric models containing product and local assembly processes as well as central design and pre-production departments.

The empiric support for our reasoning is clear from the practical examples we have chosen to report, which in turn have necessitated modification of the original basic stereometric model on a number of points. This modification is also based on practical experience which we do not explicitly report in this paper.

INTRODUCTION

The development within final assembly of automobiles and trucks is in Sweden shifting from production systems with short, repetitive tasks, controlled from outside the real work process, towards more connected and many-facetted tasks. In these new tasks the workers make important decisions together with their colleagues in such matters as pace and how the work is to be done. To realize this, for example in Volvo´s Uddevalla plant, a radical re-creation of different technical and administrative sub-systems was required. These results have then spread throughout the Volvo Corporation in different ways.

Our research clearly indicates that in order to be able to create and maintain a system of concepts related to final assembly it is necessary to create new product and process structures. These will be a pre-condition, partly because of the need to reform the work on the factory floor itself, but also necessitated by the fact that different assembly plants today have specifically different production systems (as long as line assembly was all-dominating, the central pre-production work was more supportive and more easily accessible to the local process).

For automobiles and trucks of the degree of design (how easy the product is to assemble) and production volume corresponding to that of Swedish automobiles larger gains in efficiency are achieved by increasing the degree of process (the ability of the production system to compensate for "bad design"), than by increasing the degree of design [1]. The new long cycle time assembly systems brings to the fore the question of how designs with a "relatively low" degree of design. can be assembled with small system, balancing and handling losses. Compared to the final assembly systems that have existed up to the present time, production systems with high productivity can be achieved [2].

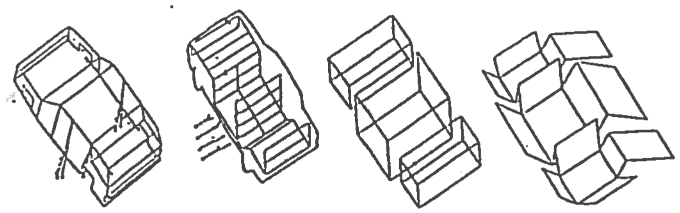
Characteristic for the radical new production systems of the future is that they are based on occupational-educational knowledge for increased learning linked with a reorganisation of existing technical and administrative pre-conditions. A changed work organisation does not in itself necessarily result in qualified jobs. For the majority of the assembly tasks it is necessary to change the work content itself. This is possible by re-casting the work itself which, in turn, assumes changed technical and administrative pre-conditions. These changes are strongly linked to material flow analyses and principles for naturally grouped work.

THE PROBLEM AREA AND OUR METHOD

To try to reorganize the technical and administrative pre-conditions in today's serial production systems, with the aim of changing the content of the assembly work itself , assumes research based on thorough empirical data, which although starting in something that exists, will finish in "something new".

It was quite obvious from the outset that such a reorganisation was necessary. We dismantled a number of products along the lines of the production documents and assembly instructions that were available and found that, in spite of support from the company's experts, it was not possible for us to find any simple way of understanding in advance how this dismantling was to be carried out. Nor was it in a holistically possible to relate existing descriptions of assembly work to the finished, assembled product or to the product descriptions used by dealers, repair workshops and service stations.

Today we realize that the assertions of practitioners with regard to the complex products and the assembly work that was consequentially very difficult to learn, which during the 1970´s and up to the mid-80's were axiomatic for research and development work, were no real restriction. The product later proved to be less complex than was generally believed. It was, instead, the way of describing it that was misleading. Our approach was to use real products as a starting point for finding logical descriptions, suited to their purpose, of the product and assembly work, in order to allow these later to lead to computer-based formalization and a basis for the dimensioning of factory layouts in a number of plants.



1 Reference diagram of the body to normalize pictures of individual components.

2 Reference diagram of the body to illustrate the position of various leads.

3 Schematized automobile, in the form of boxes, which has been used for analyses of the need for equipment to turn, rise and lower the body to provide satisfactory ergonomics in relation to the investment in equipment.

4 Schematized automobile in the form of folded-out planes, used to achive a system of views for individual assembly areas.

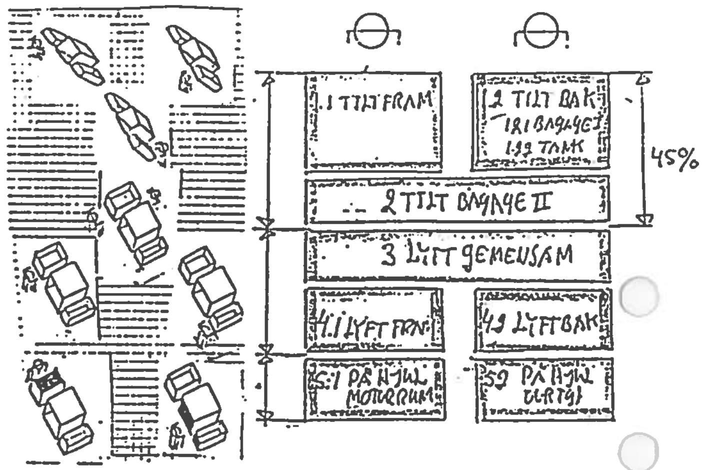


Figure 1. *One of the methods we applied was to design equipment and work in different final assembly plants using newly developed illustrations of the product as a basis.To accomplish this we have since 1986 employed an architectural research student specializing in visualization techniques. The companies have kindly made premises, products and administrative information available to us.*

Examples of illustrations showing the need for equipment to turn, raise and lower the body to achieve satisfactory ergonomics in relation to the investment in equipment. On the left is shown the operator's assembly position in relation to the position of the automobile body. On the right is shown how two operators cooperate during assembly of the drive line. The work content here corresponds to the final assembly of approx. 1/4 automobile. This figure is the collective overview in a set of cards that we produced in collaboration with the training workshop during the projection of the Volvo Uddevalla plant. The set of cards was one of the methods we used to formalize assembly work.

Among the reasons for this misconceived complexity were:

-The existing basic descriptive structures (the so-called Function Group Register) are designed for vehicles in general. When, for example, they are adapted for an automobile, they cause parts of the hierarchy to disappear. This is why the groups of numbers that refer to the components in the product do not form coherent series of figures or connected descriptions, since the components that are not automobile components disappear. That which is specific to an automobile is not specific to a truck. These two products therefore fill the constituent groups in the existing descriptive structures in specifically distinct ways. [1]

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1 The classification registers used within the Swedish vehicle industry consist of seven main groups divided into sub-groups. On the third level of the hiearchy the structure consists of 271 groups and 245 "holes". 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".

-The products have been changed. This is particularly true for the automobile, which has changed with regard to its structural contents over the last ten years. 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 last of the seven main groups in the existing descriptive structure. The combinability of subassemblies has increased through changes in design technology, choice of material and external suppliers.

-The existing method of describing variations in the product is principally intended for material control. It is therefore extremely difficult to understand the variation in the product from the assembly point of view.

-Previously, before the assembly of complete automobiles by work groups had been proved to be a realistic production concept and before this assembly work had been formalized, the flow of information from the design department to the workshop floor had been mainly one-way. This state of affairs meant that assembly work along the line was fragmented and it was neither "worth the trouble" nor possible to formalize by feeding back upwards in the organisation. Describing the product in small disjointed units has been regarded as natural in the organisations that have existed up to the present; the need for wholes has not seemed obvious.

-The universally prevailing production concept "line" meant that the "smallest unit" in the description of the product and the consequential assembly work, expressed simply , was synonymous with material address along the line, which means that when a number of essentially different production layouts are to be supplied with material and information from central design and pre-production departments, this takes place in the form of "smallest units" (material codes) for these material addresses. This must be taken into account when designing product and assembly instructions; when a shared pre-production department, on the basis of the work of the design department supplies factories with production information, this information must in fact be structurally different depending on local production concepts.

These were conditions which had not been generally recognized before the projection of the Uddevalla factory, but which successively became all the clearer in a tangible way.

MODELS FOR MULTIDIMENSIONAL REORGANIZATION - FROM ASSEMBLY REALITY TO DESIGN REALITY

The point of departure for our argument is that our view of reality is based on a number of stereometric models where certain of these models are regarded as superior. Pertinent information is assigned pre-defined planes in the model, hereby making it possible for different interpreters to approach different questions from different knowledge-wise pre-conditions.[2]

These stereometric models exist for both local and product process and organisation. The product description is, however, as suggested above, superior to local process and organisation since a central product description must be able to be used no matter what final assembly method the local assembly plant chooses. We refer here to a basic, generally applicable product description.

Systematically working in this way by categorizing different descriptions so that the information is brought together and expanded in a known possibility sphere, as shown in the figure above, results in a generally applicable method of describing product and process. The method of reorganizing perception of product, process and organisation is thus mainly taxonomic and classification-oriented with the components of the product as the basis in practice. Causal and genealogical relationships will form "surfaces", "lines" and "points" in these taxonomic descriptions. An example of this is the formation of the systems in the product through a causal combination of parts in the taxonomic "map". An infinite number of causal descriptions can, in principle, be created depending on the needs of different users. These descriptions will be linked by the fact that the common product is taxonomically, clearly defined by its components.

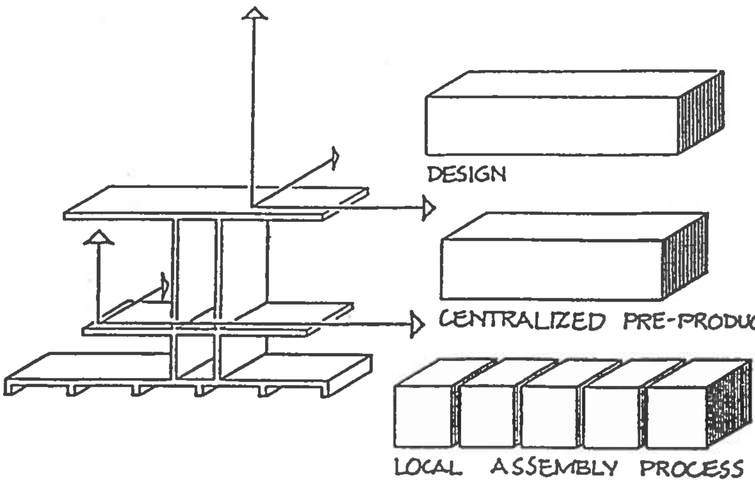

Figure 2. *The 3-dimensional model of process and organisation where the new product structure gives a visual and verbal network which provides orientation [3]. The different parts of the organisation are separated in the illustration from the transfer surfaces. The arrows in the figure show how the product is described in different parts of the organisation, i.e. how the product description changes according to who is using it. Suitable units must be found for the axes in the transfer surfaces between the different parts of the organisation. It is not least important to find common surfaces, lines and points of reference for the whole organisation, in order to allow the various users to be able to move between general and specific product and process structures without losing their mental orientation. We shall later see that this model requires modification and detail.*

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2 An example of the technique of assigning data to pre-defined planes are the assembly instructions that link the new groupings with separate assembly sequences developed for Volvo´s Uddevalla plant, where assembly, for example carries on a dialogue with ancillary activities via these instructions. The local quality, material and production engineering activities with times and central variant control have received their own projections of the final assembly activities.

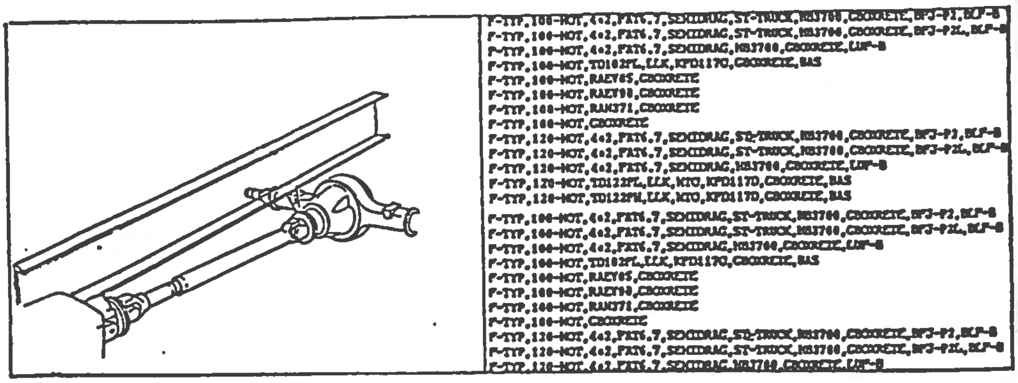

Figure 3. *Example of how a propeller shaft is described today by coding it with variant designations (RAEV91, TOOLB-L, UKOB). In reality there exist 200 different propeller shafts for a certain type of vehicle, which are all assembled essentially in the same way. Through this method of describing them there arise 1.300 administrative units. This makes it unreasonable to describe the assembly work and its variation, using the existing structure as a starting point. Uppdating of production information is made difficult to the point of absurdity, as the assembly of the product to the correct specification.*

The consequence is that the products can be perceived from several different points of departure (projections), which means, for instance, that production engineers, pre-production planners or workers approach the product description from their respective frames of reference, which hitherto has been impossible.

The models are taxonomic, and can therefore be adapted as experience is gained and organically "grow into" each other. It becomes successively possible to establish transfer surfaces suited to their purpose between product, process and organisation. It is not necessary therefore to replace immediately the current method of describing the products, but this can be done gradually in a controlled way, by crossing the descriptive structures of today with those of tomorrow (the information technology of today admit new possibilities). This means that the product descriptions will consist of the differences and similarities between the products, described simultaneously in today's Function Group Register and in the new taxonomic descriptions.

It is hereby possible to find resistant relationships as a basis for orientation between the precise work of the design department, central pre-production and various final assembly processes (for known differences between product families and variants), since automobiles and trucks display certain characteristics that could be termed generic. There are certain, built-in "hereditary" characteristics that can be predicted [4].

These generic characteristics have made possible the taxonomic description and together with it formed the basis of the re-organisation that was a pre-condition for creating, in Uddevalla´s assembly reality, a permanent relationship between the way of working, the material display and the way of describing the work. This work was a regrouping at the base of a particular local assembly process in our model in figure 2. We here refer to the "Assembly Geographical Atlas", which consists of the so-called Final

Assembly Functional Groups with their so-called Variant Tracks. [3] In the same way that customer and market demands have been translated into design work and real product there is a need to create a network of concepts and images from the assembly reality of different local processes up to the work of the design departments [4].

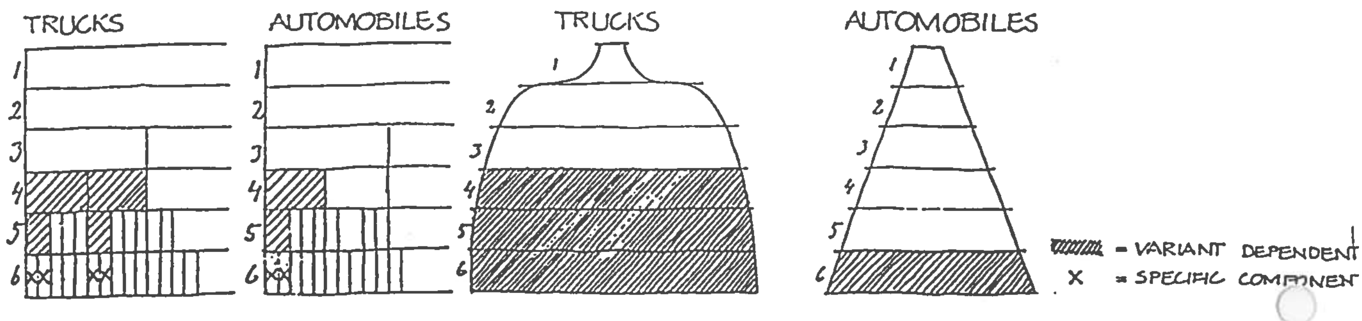

Figure 4. *Above is illustrated the essential difference between two existing overall automobile and truck structures, i.e. common to more than one company. It is clear that variants have been treated in two different ways. In both cases there are six levels in the product structure to determine the structure details of individual components (with regard to part number, part name, position, variant etc). In the case of the automobile descriptionhas been made on the five highest levels only with regard to the relationship of the components to the product, and possible variation between the product's variants has not been taken into account. Variant coding is done on the 6:th level. In the case of the truck the structure is variant-dependent on levels 4-6, resulting in considerably more structure details at the lowest level (6), in spite of the fact that the total number of variant designations that give a real difference between variants is approximately the same in both cases. In the two illustrations on the right we have normalized with regard to the total number of components. It is clear from the example that it is a matter of differentiating clearly between product description and organisation description. If, as is the case with the truck, they are formally mixed, which occurs on level 4, there is no possibility to move mentally between and within the hierarchies of the company, with the result that the product is perceived as unnecessarily complicated.*

To summarize, a "hierarchical set of maps" will be needed, ranging from a central generally applicable product description, down to the individual assembly sequences of local processes. The new generally applicable basic product description is a stereometric model of the product, from which different users can derive their adapted descriptions of product and process. We have designed such product descriptions for both automobiles and trucks. We wish to point out that the "higher" common areas, for the different parts of the organisation, in the product hierarchy, are changed considerably less often than the "lower" ones. The principle can be compared to a set of maps where the reader "mentally takes along" the perception of the spherical earth as he or she reads specific maps of countries, counties, towns and the routes that correspond to particular assembly sequences.

These new product and process structures, if correctly designed, involve the paradox that variants are an asset in final assembly. This is never the case in conventional production systems. The different variants of the products

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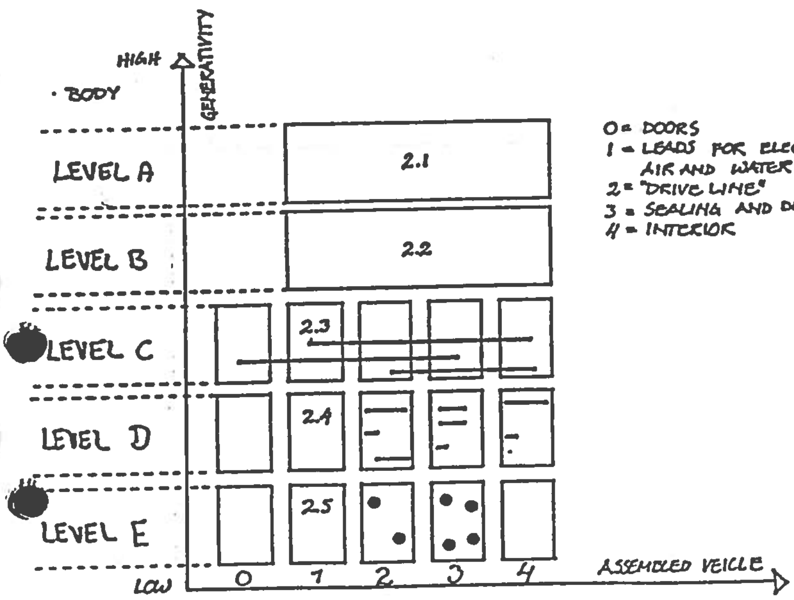
[3] Statistics of change orders show that these behave more logically in the Final Assembly Functional Groups with their Variant Tracks than in the Function Group Register, since the change orders are mainly of two types; changes that lead to changes (the order affects only a few places in the structure), or else the designer changes whole components or systems (this affects areas or tracks in the "Assembly Geographical Atlas").

that previously had been experienced as unsurveyable hereby become logical and surveryable in detail (products that are similar from the point of view of design and assembly should be described in similar ways, not necessarily with regard to details, but to components, systems and prevailing symmetries).



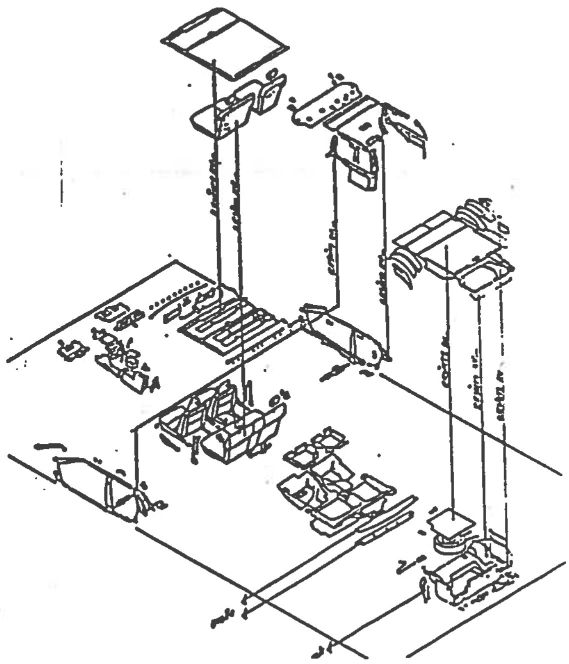


Figure 5. *Schematization of how the possible variation of the product in final assembly is treated with the aid of the "Assembly Geographical Atlas". This gives a "map", where the so-called Variant Tracks have been grouped according to characteristics always present in all automobiles - namely Final Assembly Functional Groups and generativity. These are distinguishing groups, since an automobile does not consist of one part alone and final assembly will therefore of necessity always need to be described in terms of groups of material. Generativity, i.e. those components which have been assembled, or are to be assembled, say something about the expected identity of a specific automobile. Put another way, as a consequence of the automobile being assembled in distinguishing groups, the characteristics (often the product systems e.g. braking system) of the automobile, depending on generativity, will form Variant Tracks of different lengths across the Final Assembly Functional Groups. On the basis of this generative distribution the characteristics are grouped in levels from A to E, where level A represents "the obvious" and level E "unpredictable" characteristics from the worker's point of view. In accordance with the principles of this "map", variant specifications for the different local processes can be drawn up [3].*

Examples of illustrations that we have developed in order to be able to overview differences between variants. The illustation shows the large components that are omitted or added in the final assembly of a four-door or a five-door automobile (level A on the"variant map"). In this case the work content for 1/4 automobile is illustrated, i.e. the Final Assembly Functional Group designated Interior.

In the future final assembly according to these principles will require industry to raise the process-independent formalization of the new assembly work to central pre-production. One of the results will therefore be that there will be both central process-independent Variant Tracks and local ones. Each individual factory will adapt a generally applicable product structure to the pre-conditions of the local processes.

Each local final assembly plant communicates via tranfer surfaces, consisting of the Final Assembly Functional Groups and variation in the form av Variant Tracks. Information about product and assembly work (because there must exist a defined, possible method for assembling the product) is then transformed in accordance with the pre-conditions of the local process, which vary from plant to plant or even, at times, within the same factory, in cases with different assembly layouts.

3. Contact areas must be defined between local and central pre-production with regard to, for example, equipment, tools and how these interact with the product. This is shown by the lines in the figure that illustrate tools or material that are common to the different parts of the company. Our original model needs to be modified so that central pre-production surrounds the local processes (C in the figure). When the time comes to change the design department a similar model will be used, but inverted, so that the central pre-production organisation appears as areas within or surrounding the the design depart

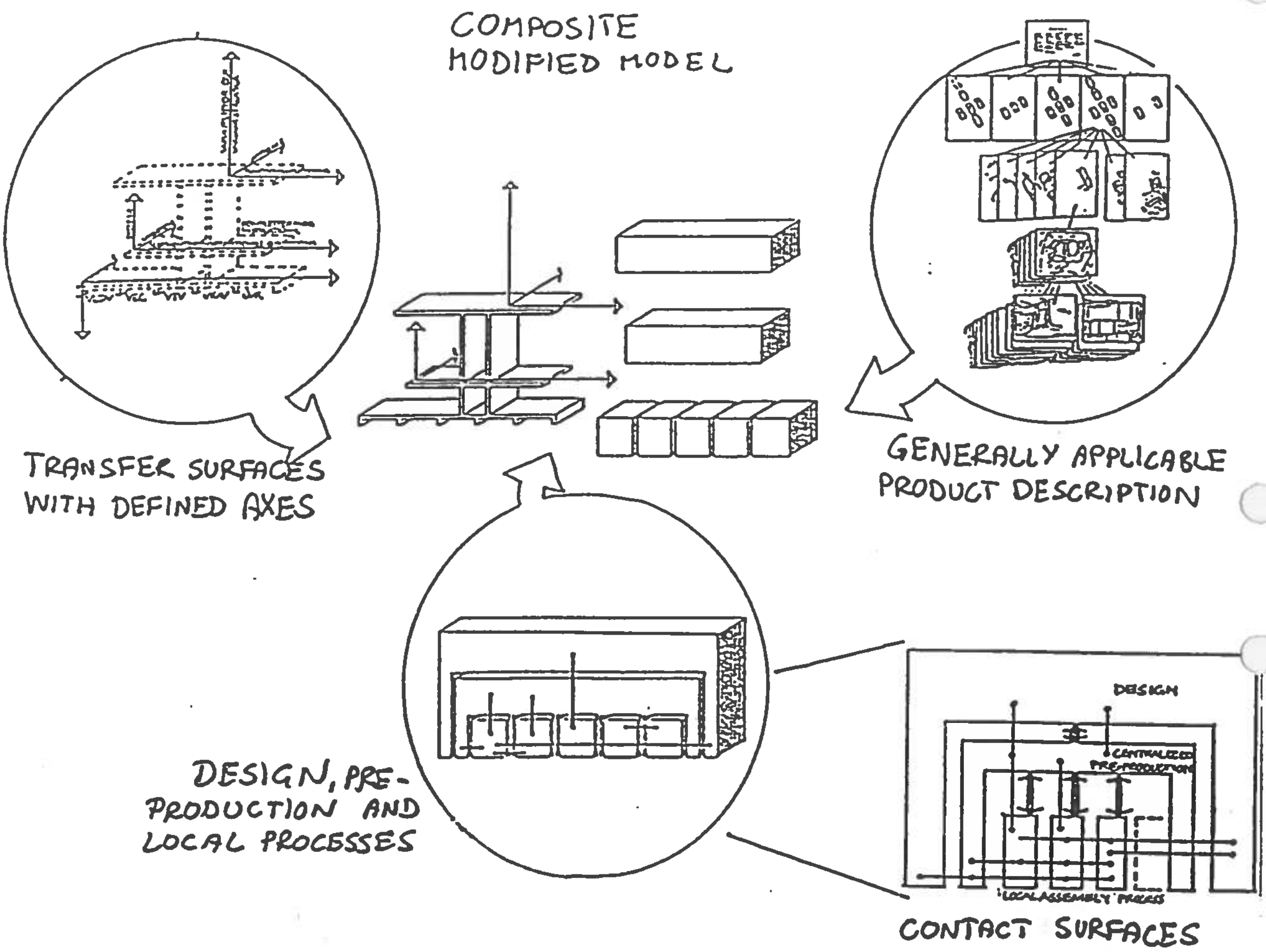


Figure 7. *The three-dimensional model that we discussed earlier required modification on a number of points. It must at the same time contain a defined, generally applicable product structure, possibly based on the Final Assembly Functional Groups. The transfer surfaces between the various parts of the company must be defined, shown by defining the types of axis in the transfer surfaces, as discussed in figure 6. It is also necessary to differentiate between points of contact that are common, but specifically different between the various parts of the organisation, product and, for example, tools/equipment. All three of these modifications must be integrated into the model at the same time, but to make understanding easier, they may be described separately.*

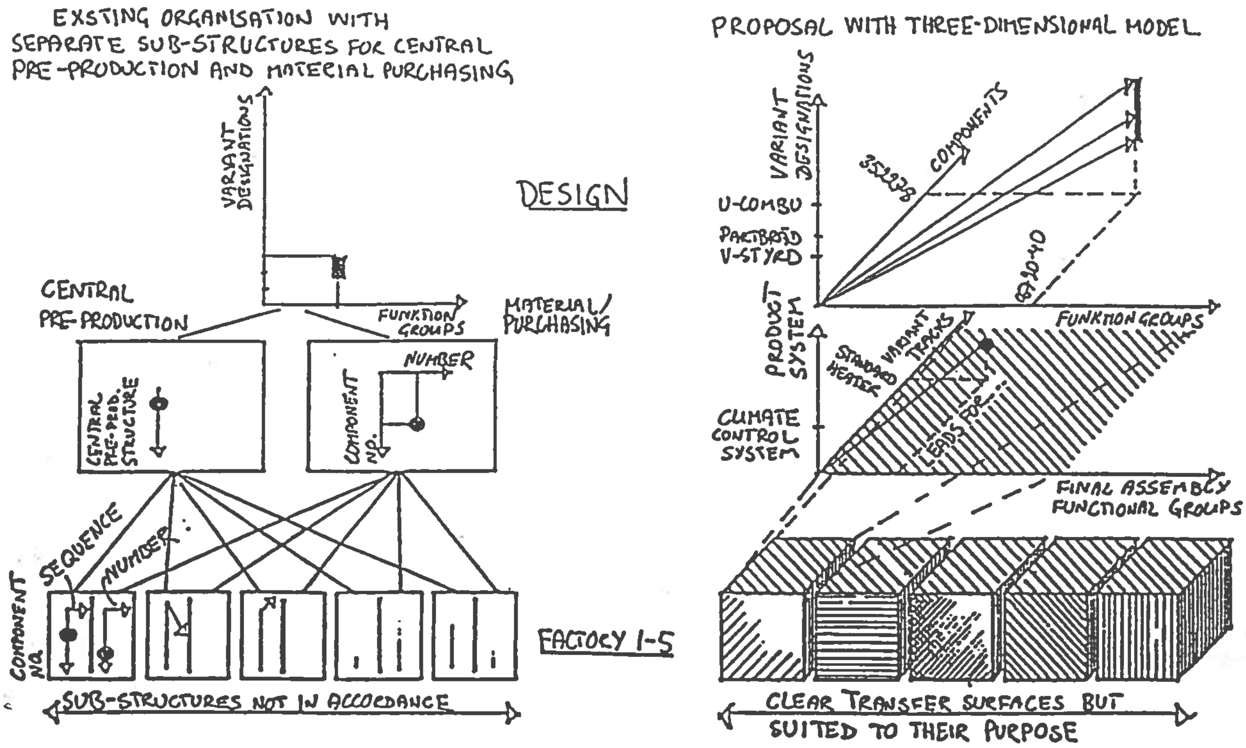


Figure 6. *Example of how a certain component (air mixing box) can be described partly through existing structures and partly through the three-dimensional model that we have presented. In the figure on the left is shown how the flow of information reaches the local factories along two routes, partly as instructions from central pre-production and partly as material usage codes from the material purchasing function. These two information routes are such that it is not easy to move mentally between them; the two images do not therefore necessarily agree although they describe the same automobile and the structures of the local processes can not in practice be based on the central structures. The figure on the right shows how central pre-production, using the design department's existing descriptive method, can shape a general product structure containing both demands from the material purchasing function and central pre-productions process demands. With this structure as a basis the different assembly plants can then design assembly instructions, variant specifications, material lists etc, adapted to their own process. The transfer surfaces between the different parts of the organisation are the Final Assembly Functional Groups with their Variant Tracks.*

CONCLUSIONS AND FUTURE IMPLICATIONS

The three-dimensional model with its transfer surfaces, needed to be modified on a number of points:

1. It must at the same time contain a hierarchical product description with a stable, defined foundation, which could possibly be the Final Assembly Functional Groups (A in the figure below).

2. The transfer surfaces must be defined, i.e. the axes in the figure below will for the design department represent the present Function Groups, components and existing variant designations, i.e. the existing descriptive method for the product is maintained during the transition period (B in the figure). In the future, however, the design department will need to change their product description. Central pre-production, on the other hand, will use and be responsible for a generally applicable product structure, where the axes represent product systems, Final Assembly Functional Groups and variation.