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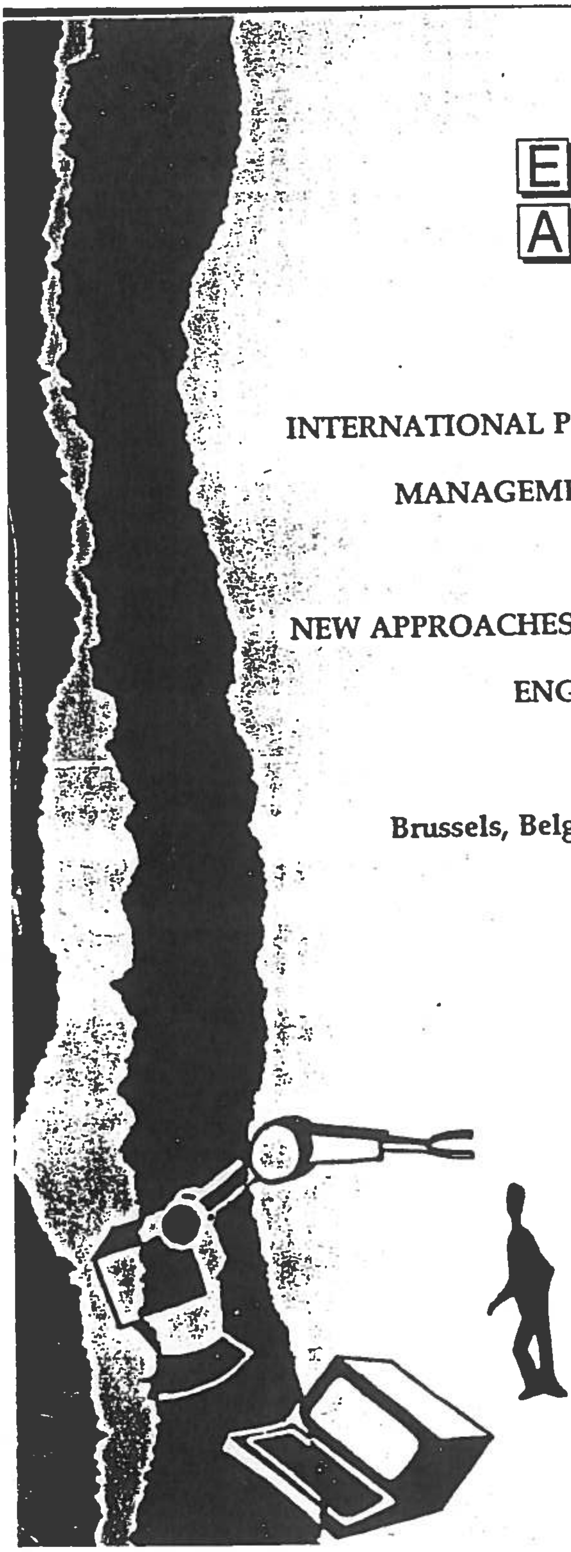

INTERNATIONAL PRODUCT DEVELOPMENT MANAGEMENT CONFERENCE ON NEW APPROACHES TO DEVELOPMENT AND ENGINEERING

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Part 1 (2)

DESIGN ANALYSIS BY MEANS OF AXONOMETRIC HAND-DRAWN ILLUSTRATIONS

TOMAS ENGSTRÖM, MIKAEL HEDIN, LARS MEDBO
Department of Transportation and Logistics
Chalmers University of Technology
412 96 Gothenburg
Sweden

ABSTRACT

In order to develop the logical product structure that proved necessary during the course of Volvo Car Corporation's Uddevalla project, and to support and maintain this structure after completion of the project, the product has been described with the aid of an axonometric visualization system. This system depicts the product components in such a way that it is possible to simultaneously survey the complete product and identify individual components.

After detailing the frames of reference for the theory, the empirics and the visualisation itself, the article describes the principles upon which the visualisation system has been based and some fundamental differences between the work of the designer and that of the assembly worker.

Two important results in practical application have been that the time needed for pre-production activities has been shortened and that the new logical product structure has permitted a considerably improved communication between designer and shop floor.

FRAMES OF REFERENCE

Technical frames of reference

Interest in assessing or expressing opinions on the design of industrial products has been brought to the fore in several research fields, principally with reference to group technology [1], which has its origin in handling and setting-up restrictions in machining operations in long series production. A great number of methods have been developed for this purpose [e.g. 2]. Interest in, and the possibilities for, group technology have further increased through the development of CAD, CAE and CAM).

Over the last few years greater possibilities for automating the assembly operations themselves, automated assembly, have led to the development of methods for putting demands on the design of the product, which means that a relatively simple product with extreme dimensional accuracy must be designed [e.g. 3 and 4].

As regards larger products, such as trucks and automobiles, product assessment in both series production and manual assembly is primarily directed towards balancing models [e.g. 5] and productivity analyses [e.g. 6 and 7].

In connection with the realization of new, alternative material supply methods in Swedish assembly industries, product assessments, so-called design analyses, have been employed [8]. Follow-up studies with the aim of expressing opinions on design work have also been carried out [9].

One of the tools in the engineering design science is value analysis, which involves the assumption that the product can be resolved into a number of functions [10], where a distinction is made between main and sub-functions. Characteristic for value analysis is that it is normally applied in order to consider qualities relevant to design work with regard to the use of the product.

Note that only the function and design of the product's components and the linguistic and numerical abstractions of the design work itself, so-called physical product structure, are focused here, not the logical representation of the product itself from different points of view, so-called logical product structure.

As regards the physical product structure and physical qualities for a given product, e.g. an electric motor, it is not only the motor's function of converting electrical into mechanical energy that attention is paid to. It is also important that the motor has, for example, a high starting torque and a long service life, and also that it can be delivered to the right place at the right time etc.

In this respect a broad spectrum of characteristics is referred to, which can be categorized into classes [11].

The characteristics of any particular product (e.g. a clutch) can thus be classified into purpose (torque transmission), function-related characteristics (maximum torque, torsional strength, etc) and other characteristics (design, supply lead time, etc).

Regarding logical product structures, these can very well be constructed in accordance with the same spectrum of characteristics as the physical product structures. But their purpose is in fact to describe different impressions of the product in a formalized way, for activities outside the design work itself. It is unfortunately only too usual that the design work structures are also used as the basis for logical product structures.

One of the most tangible logical product structures is the "bill of materials" by which is meant a description of the product's components, which operationally forms the basis of the production process. Since planning and scheduling activities are regarded as being most dependent on the product structure, their demands will in general determine the design of the logical product structure [12].

We wish to point out the ambiguity in the term "structure" and that we use it below with both general and specific meaning.

In this context it should be noted that research into learning during the 1970's began to look more closely at how the human memory treats, codes and stores information [13], i.e. how the individual builds so-called cognitive structures in his mind. This is of great importance in industrial activities with regard to how different descriptions of products are to be designed, i.e. how figures, letters and illustrations interact perceptually both in the formalized information systems and in the real work both on the shop floor and in the offices.

We have therefore worked on, and paid close attention to, how illustrations are produced. We refer below not only to the work of the operator and the designer, but also the work of the illustrator (in this context any person, or persons, who in some way works with visual representations in connection with industrial activities to communicate information).

Frames of reference for visualization

It is said that cognitive structures are formed in the human mind as pictures [14], i.e. an intimate relation exists between perception and thought.

When producing illustrations it is important to take into consideration the situation in which the illustrations are to function [15].

For the designer, the illustration he produces is a direct consequence of the design work itself, i.e. a physical reality is registered. His drawings develop as the design work progresses. The designer must, among other things, choose function and form; through his work he produces models of the components he designs, e.g. by means of a drawing board and/or CAD.

The illustrator on the other hand must balance his own ambitions in relation to the purpose of the illustration and thereby emphasise those aspects he is to illustrate. If, for example, he is developing illustrations for assembly work instructions, he must identify one shape among many others. The illustration need not in this case be an exact representation, but must be an expression of the assembly work.

This demands receptiveness and sensitivity, an intellectual attitude towards the process of producing the illustration, since the production itself presupposes empathy. In his mind's eye the illustrator must see what is to be described, the illustration exists inside the head of the illustrator before it is put onto paper, so-called visual attitude [14], and graphic thinking [16].

The most commonly used illustrations within the Swedish motor vehicle industry have up to now been drawings of photographs or CAD-designs with, for our purpose, no defined systematization (the interrelation between different illustrations is not defined in advance - the ability to interpret one picture is not necessarily of any value when interpreting the next).

Proficiency and confidence are required to enable the illustrator to feel his way forward through different sketches (in literature, however, this process is not explicitly related to industrial activities).

In order to communicate information by means of visual representations, these must be designed in accordance with certain definite, but often unstated, principles if they are to be understood correctly; for example, reality must be "distorted" just enough for the message to be clear. In this respect the term reality levels [17] is used to refer to the degree to which the illustrator has distorted reality in order to emphasize the message. The aim is the interaction of every detail in an illustration, through the conscious application of the reality level concept. If each detail is given the same reality level a more universal applicability is achieved.

An important question for the illustrator is the choice of type of perspective. Two fundamentally different types of perspective exist. The most common, similar to a photograph and the way in which the human eye interprets reality, is called the central perspective. This differs from plan oblique and other measurable (axonometric) perspectives in that it represents reality as it appears to the eye, while axonometric perspectives in fact show three different views of the subject simultaneously. Summaries of different types of perspective can be found in swedish standard for building plans [18].

Knowledge is incomplete with regard to both the production of visual representations and types of perspective. Investigations into the uses of different types of perspective in the projection of residential areas have proved these insufficiencies [19].

In the practical work of producing our illustrations in measurable perspectives, "Aksonometri og dobbelt retvinklet projektion" [20] and "Perspektive Fur Architekten" [21] have proved to be of most value.

Empirical frames of reference

We have found that if the work content in the final assembly of large products, for example automobiles and trucks, exceeds 40 - 60 minutes the product itself then functions as a work instruction for the assembly workers. The fewer times it is moved between work stations and the fewer people involved in assembling the product, the greater the learning effect.

The reason is that the products' innate structural characteristics, its inner logic, becomes apparent. The interrelation of different components becomes obvious, partly because the components generatively form physical qualities (product functions in the completed product). Descriptions of the product should exploit the fact that the product is simple to understand once it can be surveyed as a whole, on the assumption that it has been described according to certain principles [22]. This is not the case if the degree of labour division is high.

Example: - A brake cylinder should reasonably perform some function in relation to the brake pedal and leads. The effect is further amplified if the component is given its correct name, formally speaking, in the "bill of materials", as designated in the design and development processes. In Swedish industry this aspect is not normally exploited; instead, a part number and abbreviations are used on the shop floor, which is not completely satisfactory. (It should be noted by way of example that components are traditionally stored according to final digit).

By combining illustrations and correct verbal descriptions it is possible to exploit the designer's work to articulate shop floor reality, an articulation of value for the individual (in the form of an inner monologue), in communication with others (in order to transfer knowledge from generation to generation within a profession), and in the dialogue between design and production.

Individual components will thereby form clusters of components with common characteristics related partly to categories (e.g. screws and rubber mouldings) and partly to qualities (the function or rôle of the component in the completed product, cf. the discussion above regarding value analysis).

Example: - Both the plausible and the absurd then become more or less obvious. Compare "bracket for L-jetronic fuel injection system control unit" with "plastic silencer for automobile fitted with catalytic convertor " - the former is a component that can be assumed to exist while the latter is absurd.

As in grammar and syntax, both the real product and its different descriptions consist of a number of elements. These elements interact to form structures in which two phenomena may consist of different kinds of elements yet have the same structure. Both automobiles and trucks are, for example, organic in structure, but in contrast to humans, vehicles consist of mechanical components. Another way of expressing this is to speak of distinguishing between shape and substance.

Note: - In the manufacture of vehicles it is an advantage that the product is determined down to the smallest component as early as the design stage. This means that it is possible to exploit the designer's work to an even greater extent, so that work preparation can be done in the local assembly process by organizing materials and information in advance, i.e. before final assembly even begins. However, in the case of series production, this presupposes that new principles and aids are developed and implemented in order to support new product and work concepts.

DESIGN AND FINAL ASSEMBLY

It is desirable that consequences of the designer's work can be traced back to the designer from experience gained on, and demands from, the shop floor. The more competent the shop floor work force, the more important this feed-back is.

Volvo´s Uddevalla plant brought to the fore a number of new demands that had to be put on bills of materials and thereby indirectly on the designer's way of describing the product.

The Uddevalla project exposed the need for two-way channels of communication instead of the previous one-way channels. When the project began, the exchange of information, formalized in computer systems, took place via material planning and scheduling, while the design department at the same time supplied information to central pre-production, and material and planning at the various production facilities, via two separate channels. The consequence was that the different departments had diverging perceptions of the product [23].

This meant that the local production engineering departments, using traditional methods had the arduous task of continuously re-balancing the work on the shop floor, and translating/clarifying information "from the top down" to ensure that the product was assembled according to specification. The responsibility of the material supply departments was thereby reduced to ensuring that the correct components were available when they were to be used in production.

Assembly workers in traditional Swedish facilities have therefore often accepted the consequences of a product that is difficult to assemble (because of a low degree of design, [8] and that the logical product structure has not been adapted to the preconditions of the assembly process; the result being that they have had to assemble a product that to a certain extent is not only impossible to assemble correctly but also impossible to understand. It should be noted that production systems with a high degree of labour division have led to low efficiency and inflated final inspection departments.

In much simplified terms, the designer works with the future (as yet immaterial), with design solutions that do not yet exist. He is responsible for translating customer demands into qualities and then into real, manufacturable components. He is concerned with physical properties, cost, time schedules, drawing-files, etc.

In the same way, the assembly worker works with the present (material). His position is at the point of convergence of materials display, work descriptions and workplace. He is concerned with work pace, torque demands, chains of tolerance, whether he has the correct components, etc.

Note: - In order to prepare information and materials in advance for the various final assembly processes, it is a precondition that the product can be described from all aspects of final assembly in a way that is independent of the configuration of the local production process, but has an unambiguous relation to the designer's work, which means that different activities within the corporation as a whole must be able to understand the same product from different points of view.

RESEARCH QUESTIONS AND METHOD

Our work was originally initiated in connection with Volvo´s Uddevalla project (1985 - 1992) and was later also to include collaboration with Volvo Truck Corporation (1987 - 1992). Both these projects include the task of developing alternative production systems to traditional line production with greater productivity, greater flexibility and with the aim of developing human competence on the shop floor.

Among important questions were: - How should technological and administrative preconditions be organized to facilitate and support long cycle assembly work? - How can the existing logical product structure, common to both companies, and with orientation towards design and material control, be transformed into an assembly related structure?

The new logical structure was developed and expressed by means of new illustrations collected in what we refer to here as the illustration system, which both functioned as research instrument and later became the final result.

On the one hand this method permits design and on the other hand facilitates description, support and communication of what has been designed.

This work was carried out in collaboration with the company and an experimental workshop, the so-called "Red Shed" was set up. In this spacious workshop we had at our disposal large tables on which paper print-outs and production documents were spread out. To quote one external commentator [24]: - "Among those experts who have been of significance for the project for the longest period of time are the technologists from Chalmers operating from the Red Shed and led and guided by Tomas Engström. Activities here began in the summer of 1985. Among examples of significant work can be mentioned: - It was in The Red Shed that the automobile was dismantled and laid out on the floor and the components grouped for functional assembly. The basis of an alternative frame of reference for materials handling was created. - It was in The Red Shed that kitting fixtures were constructed and experiments made with small components in bags. - It was in The Red Shed that a student on a work experience programme proved how superior functional assembly was from the point of view of learning...."

Our work led, among other things, to a new way of describing the product and in order to validate and exactly define the analytical models which we developed, it was necessary to dismantle and reassemble several products. Each component was marked with information to allow comparison to be made between reality and its administrative formalization in the existing information systems. Physical and logical product structures could thus be integrated.

Alongside the work of dismantling and reassembly the empirical explorative studies were made mainly with cameras, scissors, pencil, etc, which gave the researchers an advantage over the practitioners engaged on the project. By this choice of method the researchers were able to master, in detail and with surveyability, empirics vital to the desugn of the production concept. We were then spared the trouble of chasing practitioners for data; the situation was on the contrary the reverse!

All analytical research instruments were from the outset completely manual, i.e. typed or hand-written, drawn or cut and pasted. Computer support was available at times as the project proceeded. An important characteristic was thus that the manual explorative studies produced analytical models which were later formalized with the aid of a computer system.

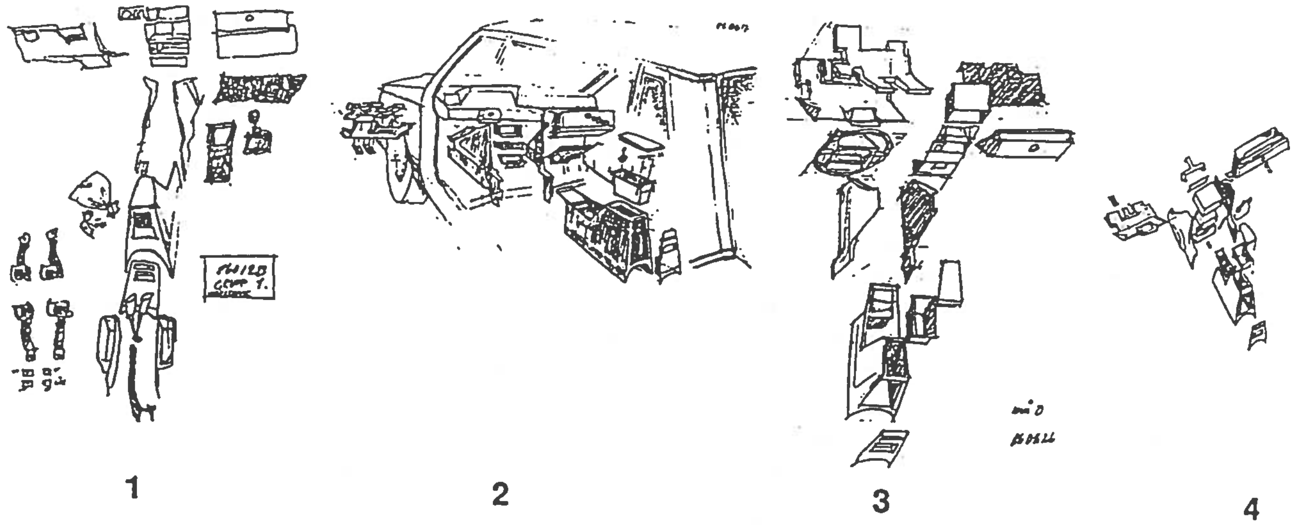

Figure 1. During the development of the illustration system one of the problems was to find a generally applicable means of expression, viz. the selection of a suitable reality level. Above are shown, in chronological order, 4 sketches in the series of 20 that were needed to achieve the final form of the illustration of certain components fitted inside the passenger compartment. The sketches depict; 1 components spontaneously drawn from above in twopoint perspective, as they appeared laid out on the floor (23 Jan 1986), 2 components drawn in twopoint perspective viewed from the position of the operator (17 Feb 1986), 3 components drawn in plan oblique, but with incorrect angle of perspective, viewed diagonally from the rear left (26 Feb 1986), 4 final version, components drawn in plan oblique, true to scale and with correct angle of perspective, viewed diagonally from the rear left. (12 Apr. 1986). In all, 30 illustrations were required to show a complete automobile.

THE ILLUSTRATION SYSTEM

The components from the dismantled products were spread out on the floor in the experimental workshop. They were then drawn by hand. normalized, drawn against a transparent outline of an automobile.

One of the results of our work is then that individual components have been arranged in an illustration system with different levels of resolution and a given reality level, in which the vehicle body itself is depicted so that, for example, the members of a work group, view the object diagonally from behind, as if entering an automobile on the driver's side. The individual members of a work group then have the possibility, among others, of determining the redistribution of the assembly work within the group.

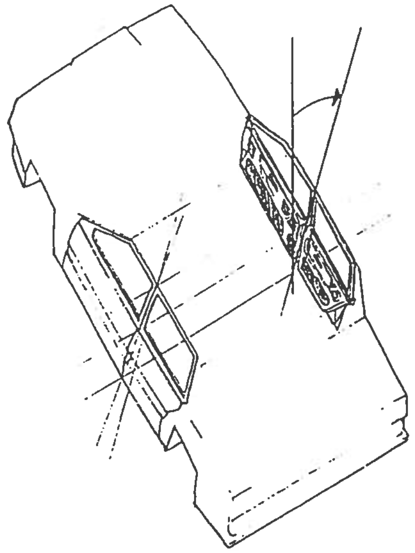

Figure 2. The outline used for normalizing the illustrations. This outline deviates from an exact reproduction, i.e. as prescribed in a correct application of the perspective method. The sides have been tilted a few degrees and by this means more of the right hand side of the automobile is exposed, in order for the illustration to show the components clearly. The paper format is also better exploited. The illustrator will sometimes consciously distort the illustration to allow it to achieve its purpose.

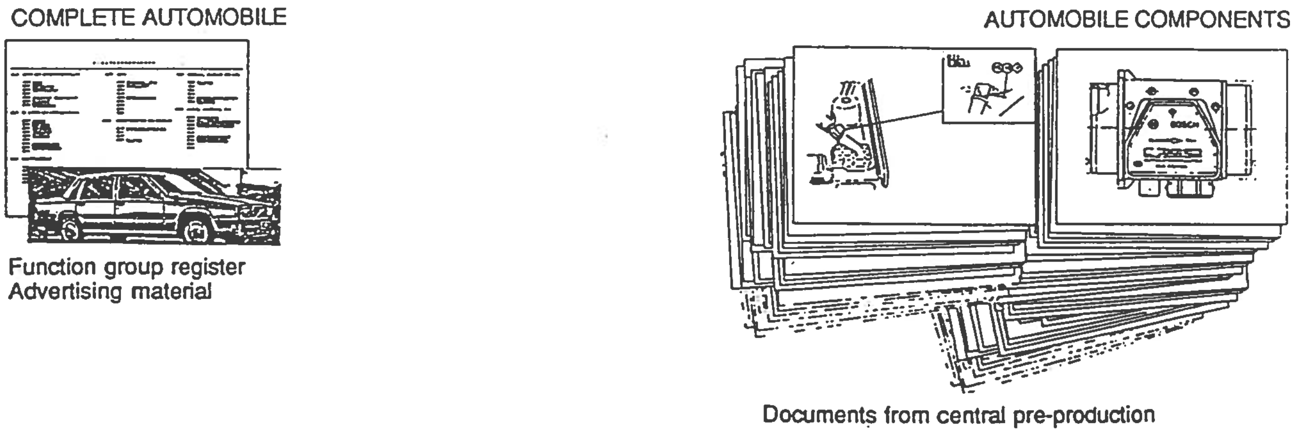

Figure 3. At the beginning of our research no illustrations of complete products were available ("complete automobile" in the figure) exept for advertising material. The product as a whole was described at that time only by means of the design department's logical product structure, the so-called function group register. At the component level there were illustrations in the from of documents produced by the central pre-production department. ("automobile components" in the figure). These were aranged according to the function group register. Between the function group register and the central pre-production documents there existed no unambiguous relations other than those allowed by the function group register. This was not satisfactory, since the function group register does not make it easy to understand and survey real complete automobiles. This is because it was originally designed to be general for all types of vehicle. The consequence is that components not relevant to automobiles are omitted (the register contains "holes") while other parts of the register are so tightly packed that required levels are missing. Moreover, certain product systems occur in several different function groups. For example, electric cables are in their own group in the function group register, which means that cables for some product systems are assigned in certain cases to one function group while ancillary components to cable harnesses are assigned to another.

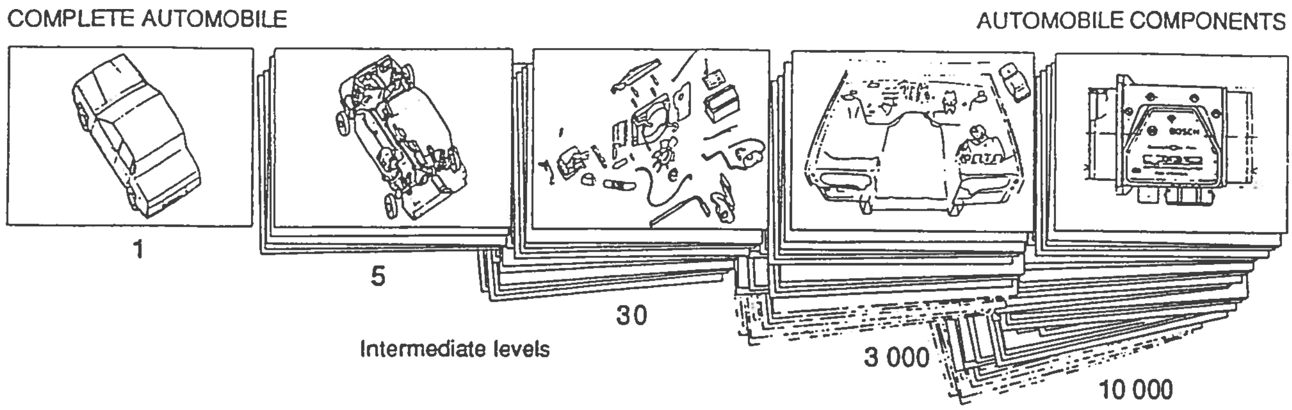

Figure 4. Our contribution is the achievement of intermediary levels by means of three levels articulated through the illustration system and the logical product structure adapted to assembly. These, previously missing, levels lie between the complete automobile and the detailed documents from central pre-production. When applied to an automobile family, the number of illustrations required is indicated by the figure at each level. If the components in the automobile family are supplied to assembly in the form of kits, e.g. in 6 kitting fixtures, as in Uddevalla, then 1, 6, 79, 860 and 2 500 illustrations respectively, are required.

Initially we tried to work with photographs, but for a number of reasons this proved unsatisfactory. Our photographs were indistinct and difficult to interpret - dark-coloured components were shown as "blobs"; it was impossible to achieve correct exposure. Placing the components in the right position relative to each other, i.e. arranging the subject, was time-consuming. It is also difficult and expensive to reproduce photographs in large numbers. Moreover, it is impossible to form new combinations of illustrations quickly from a number of original basic photographs.

The available illustrations that might have been of interest to us consisted mainly of documents of various kinds from central pre-production planning, drawings from the design department, spares catalogues, etc.

These illustrations were unsuitable for our purpose for a number of reasons; they had been produced for a different purpose (too rigid to allow any modification), and they varied with regard to scaling, section, view of vision, and selection. Common for all them was that they were not consistent in relation to each other and certain of them gave too professional an impression and appeared more reliable than they in fact were, while others were merely schematic sketches.

When we tried to understand and dismantle the products the existing illustrative material that was available was more confusing than helpful.

Our solution was to use plan oblique (measurable, axonometric perspective), sometimes termed "military perspective", since this allows the components to be moved without making the perspective incomprehensible.

One reason for our using hand-drawn illustrations is that these are intellectually processed visual information.

Drawing a picture is the equivalent of formulating a message. A photograph, for example, merely reproduces reality with the same clarity - in contrast to hand-drawn pictures where certain details are emphasized and others suppressed or omitted. That which is important can be made quite clear.

The work with the illustrations has covered more than five years. Their final appearance was not obvious at the outset. This resulted in several unique series of illustrations, something that had not previously existed.

The process of designing the system of illustrations has consisted of searching on different levels (one level has helped to explain the next and vice versa). This process can be compared to artists' work methods.

This system of illustrations has, in the Uddevalla project, been an important part of the production engineering processes of rebalancing, determining work distribution and assembly sequences, variant analyses, and providing support for local pre-production.

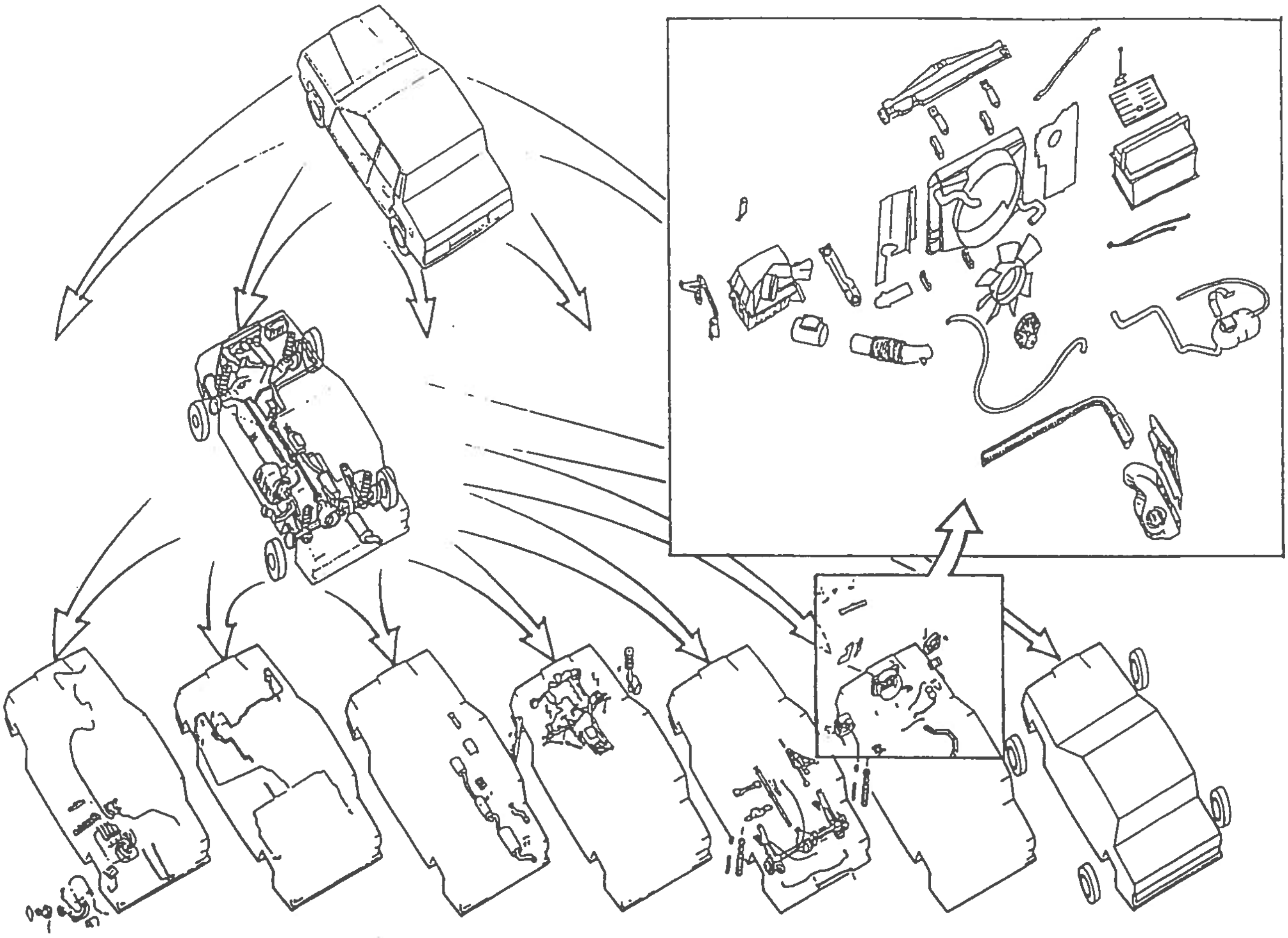

Figure 5. An example of three different levels of resolution in the illustration system; - top, the complete automobile; - middle, the driveline, one of five groups at this level - bottom, example of components in the drive line. Studies have shown that at this level design change notices affect only 1 - 5% of the illustrations. It is therefore reasonable to use the illustrations for one model year (the majority of the design change notices are so detailed that they do not affect the illustration system).

By first rearranging the product with the aid of visual representations it is possible, as was the case in Uddevalla, to significantly accelerate the introduction of product changes since design change notices have not been found to have any influence on the higher, more aggregated parts in our new logical product structure.

These illustrations have also been used in another project, where a generally applicable product structure was to be developed. It is possible to use this central structure, in adapted form, in several different production facilities, irrespective of production principle, which can vary from conventional line assembly to the assembly of complete automobiles by autonomous groups in parallelized flows.

Note: - The analytic tools of the researcher later proved largely to be the support systems that the practitioners required in order to maintain surveyability in the design and assembly work. In the future these methods can complement competitor analyses.

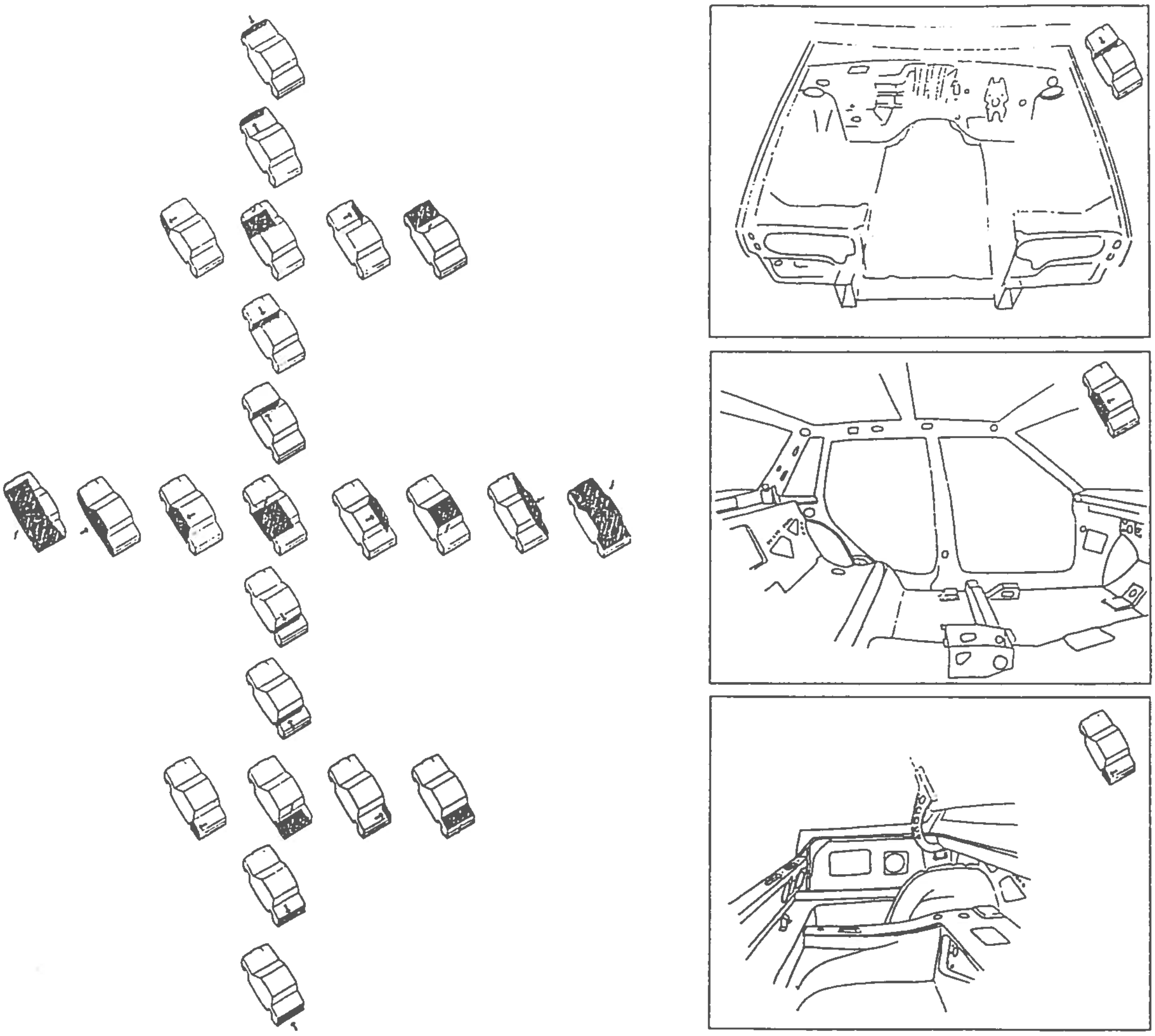

Figure 6. Above left is shown how a schematic representation of an automobile can provide different views of the body. The schematic automobile is then used an orientation symbol for illustrations which include one ore more views of the body. One of the uses of these views was in the development of new illustrations for work instructions.

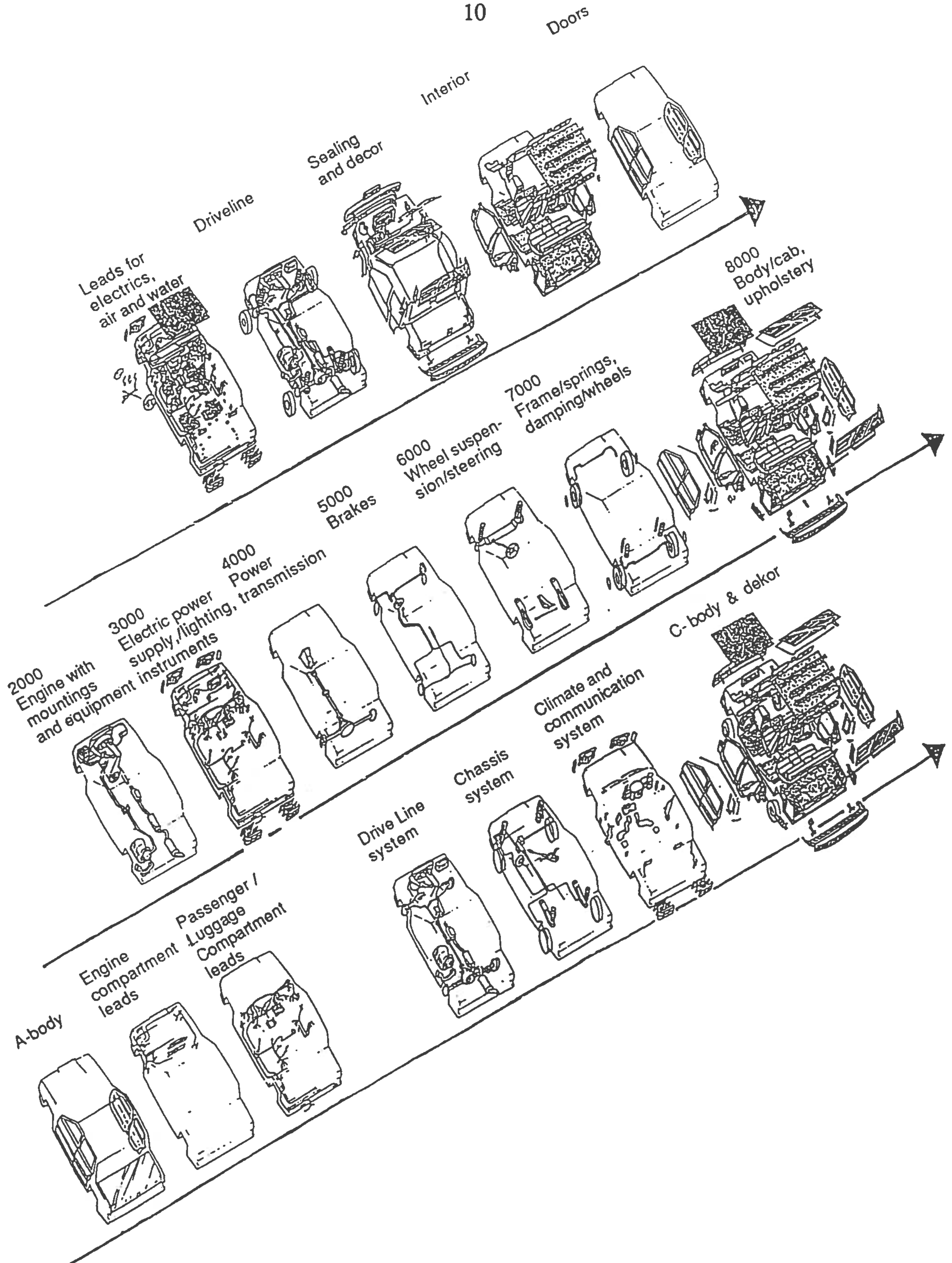

Figure 7. An automobile can be described in three different ways by means of the illustration system. Uppermost is shown the logical product structure from the point of view of final assembly; in the middle, with the same components, the logical product structure used today, the so-called function group register. At the bottom is shown how the vehicle can be understood on the basis of different product systems, approximating to the designer's perception of the vehicle.

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