ISBN 0 86176 582 6
ISSN 0144-3577

MANAGEMENT AND NEW PRODUCTION SYSTEMS 1992

Guest Editors Christer Karlsson and Sigvard Rubenowitz

International Journal of Operations & Production Management

Volume 12 Numbers 7/8
1992

MCB University Press

MCB TWENTY FIVE Years of PUBLISHING ACHIEVEMENT

6.1.94.

IJOPM
12,7/8

134

Preconditions for Long Cycle Time Assembly and Its Management — Some Findings

Tomas Engström and Lars Medbo
Chalmers University of Technology, Gothenburg, Sweden

Introduction

Earlier research in Sweden has shown that the combination of a high production flow, a multitude of supply materials and assembly of medium or large-sized products would have been impossible without line assembly. The use of a parallel materials supply is problematic because of the need for space for the material containers at the workstation, which means extra costs of transportation, buildings and capital tied up in material. Furthermore, it had been found that the design of the product was a very important dimension — and in some cases the only determining factor — for the way in which the materials supply and work operation were organized[1].

We have shown that the formulation of detailed production system specifications requires participation not only of labour but also of production engineers, and it is then perfectly possible to combine a high level of productivity with a meaningful work content. Experience from such system changes has been communicated at the international level only to a limited extent. The uniqueness of each system makes transfer of experience difficult. There have been several failures in transferring experience from one system to another, usually because the local conditions had not been taken into account[2,3].

A possible conclusion is that production systems which are very similar are probably not optimized since the products have proved to be so very dissimilar. The reason for keeping unmodified, "simpler" systems may be ignorance about the content of "the technology shelf" or an inability to establish the close co-operation needed for refinement of the system. The long tradition of close co-operation between management and labour in Sweden has greatly facilitated experiments with new production systems and work organization[4].

To some extent the limited production volumes (compared to those of many competitors) have allowed improved flexibility in Swedish production systems. Our experience has shown that it is extremely important to exactly specify the performance requirements of the new systems. In order to understand and be able to meet these requirements, it is necessary to describe clearly and communicate the overall goals to the parties involved.

If line assembly is to be replaced for reasons of efficiency[5] and to satisfy demands for humanization of the work[6] both administrative preconditions and management will have to be radically changed. Moreover, a wide range of variants, in combination with a large number of direct deliveries of complete

International Journal of Operations & Production Management, Vol. 12 Nos. 7/8, 1992, pp. 134-146. © MCB University Press, 0144-3577

preassembled components, lead to unrealistic solutions for materials supply to the traditional assembly line.

Additive and Functional Characterization of the Work

There are essentially two different ways of forming a mental picture of the work task by means of "inner maps". The work is viewed either additively, each element being added to those already mastered, or functionally, so that details are regarded as consequences of a whole[7]. Individual work elements are interpolated from a generally current descriptive structure instead of extrapolated from a number of tasks.

This means that the materials, in the form of components to be assembled, which for the beginner initially only describe how the work is to be performed, have, at a later stage for the skilled operator, been transformed into "inner maps", representing the actual assembly reality. This in turn means that the assembly reality is in agreement with the skilled operator's mental picture of it. The work itself has then been integrated into the operator's professional skill.

One of the basic principles in long cycle assembly work is that there must be agreement between how to carry out the work, how to display the materials and how to describe the work. It must be possible to visualize the product and the work in advance, but problems then arise of how to determine whether the wrong materials or the wrong description has been supplied, or whether there is uncertainty in respect of how to carry out the work — otherwise the worker is forced to test-fit the materials, with the consequent risk of being forced to dismantle them.

It has recently been found, when applying these principles in the final assembly of automobiles, that the learning time for a 120-minute cycle time is two weeks for half pace and has been estimated to be three months for full pace. To achieve these times, the systems for describing the work have not, however, been fully developed. These times should be viewed in relation to the conditions relevant for conventional line assembly with additive work elements. Earlier research has shown that here 20 minutes is the maximum cycle time for automobile assembly with a learning time of three-six weeks for full pace[1].

One conclusion which we have drawn from our research is that, up to the present time, it is the flow pattern on the shopfloor, the descriptive systems used by the company and the existing work organization which have generated most of the unforeseeability, digitalization and additive thinking in the final assembly of vehicles. Furthermore, the need to create new, rational thought patterns in the vehicle industry had not earlier been a prominent issue.

Figure 1 illustrates the difference between describing the work as a sequence of steps and viewing it functionally. In the latter case it is an aid to understanding how the climate control unit in the figure functions in reality. To describe the complete final assembly process for an automobile, 28 "maps" with this degree of detail are required. In our example, conventional line assembly requires 1,900 process instructions from pre-production, each with one to five detailed illustrations. These illustrations are not standardized, with the result that the assembly process cannot be surveyed. The process instructions are spread

6

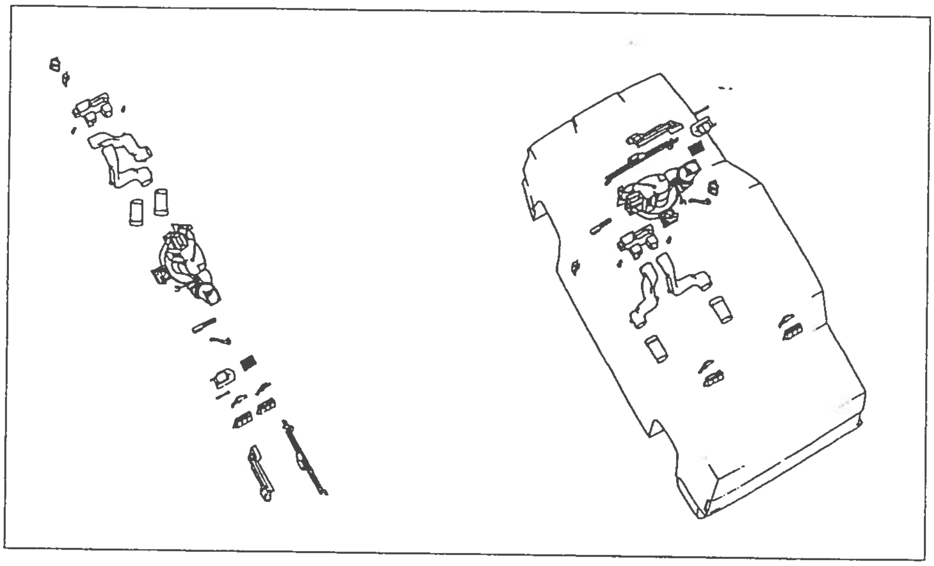

Figure 1. Components for a Climate Control Unit Placed in Assembly Order (Left) and Components Placed According to their Position in an Automobile

over approximately 400 additive line stations to enable the final assembly process to be described and performed.

Explorative Studies, Action Research and Experiments to Formulate an Operationalization Theory Based on Empirical Data

In order to implement occupational learning theory and to convince practitioners of, for example, the possibility of supplying materials, the Volvo Uddevalla project employed researchers[8-13]. These were given access to an experimental workshop ("The Red Shed") and the company's products (including structural information from the administrative systems). The researchers worked together with assembly workers and production engineers in a training workshop which was set up before the Uddevalla plant was completed. Both established and newly developed knowledge could in this way be articulated in terms of "nuts and bolts". It was necessary to depart from an evaluating "label research", whereby researchers merely try to describe and classify that which already exists. This type of research does not lead to any breakthrough as regards knowledge.

One of the aims of the work in the "Red Shed" was to create instruments which would allow the workers to check their own work, maintain a certain level of production quality and perform the quantitative planning of the production volume. Personal control over other conditions here includes responsibility for basic production data, work functions, understanding of functions, working as an instructor, etc. The knowledge developed was then translated into routines and documents, which facilitated the broadened assembly work.

Experience from the periodized assembly work in the training workshop with different layouts and results in the form of, for example, revised work instructions and checklists indicated the preconditions for the assembly work according to stipulated principles.

The formalization of both the structure of the product from the point of view of final assembly and the assembly work itself allowed that times fixed by central pre-production could be made available for more variants than were built at the time in question. These times then formed the basis for our calculations of the production capacity for different layouts. Decisions regarding the assembly concept were also taken on the basis of these times.

The existing structural information systems for the product were primarily designed to steer material to a material address along a line, but the smallest unit in the information systems (so-called product details) is not synonymous with the smallest unit in the assembly reality, which is why components such as loudspeaker grilles are found in one position in the overall design structure but in four positions in parallelized assembly reality, where each work group assembles the doors as integrated subassemblies (one grille for each door).

Since we were endeavouring to develop a new, descriptive structure that would support long cycle time work, it was necessary for us to dismantle a number of products. As an aid and for registration purposes, data printouts and reduced photocopies of production engineering information were laid out on tables. In this way we were able to understand both the real products and their current administrative description. This work was carried out in stages over a number of years, in order to identify the new groupings and the principles valid for them.

We first had to understand a single product, which was a variant of a simple design. This was identical to the first 50 automobiles assembled in the training workshop. Then followed the dismantling of a number of extensively equipped variants.

When this work had been completed we had learned enough to be able to perform both manual and computer-based analyses. For three years all the components remained laid out on the floor, marked with structure information, to enable us to check when we felt uncertain. Another reason for keeping the components for so long was that during this period we also produced visual illustrations which described the new structure of the products. To help us with the illustrations we employed an architectural research student specializing in visualization techniques.

Alongside the work of assembly and dismantling, empirical manual explorative studies were made with pens, scissors, glue, paper, copying machines, and a word processor. All results were purely manual to begin with, i.e. written by hand or on a machine, drawn or cut and pasted. As the project progressed a certain amount of computer support was made available and collaboration with practitioners, who willingly put resources at our disposal, intensified. An important feature was, therefore, that manual explorative studies led to heuristic models which were further elaborated by means of computer support and finally led to formalized data models and computer systems.

Stages in our Method during the First Two Years of Research

The stages in our method for developing the principles of naturally grouped work are illustrated in Figure 2. We first tried to find distinguishing groups of materials for a particular automobile. Then a number of support systems were built for various purposes, such as to maintain the new groupings (these could, for example, consist of various types of indexes, often alphabetical).

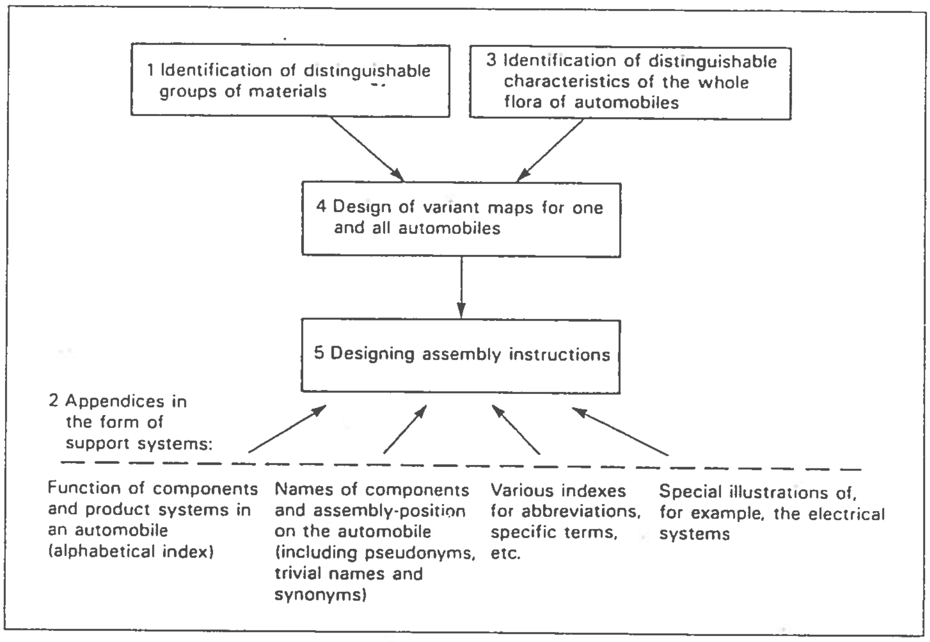

Figure 2.
Stages in Our Method for Developing Naturally Grouped Work

To cover the possible variation for all markets an automobile family is described by means of 77 different areas of characteristics. Twenty-eight of these affect the assembly work. The corresponding figures for all variants for one single main market are 46 and 13[11].

Now that it has been fully developed, the information system is able to isolate each individual component with the correct central information complemented by process-dependent local information for each particular automobile for any structure week. This information system allows the product to be derived from the perspective of different users, for example assembly instructions for fitters and picking lists for material handlers. It functions also as a protective shield to prevent incomplete or incorrect information from negatively affecting the assembly or material handling work. The descriptive structures used by the whole company are compared and changed to agree with the assembly principles.

Descriptions of the product and its systems comprise, among other things, registers of all concepts required to be able to understand the function of all automobile variants. The total number of concepts is 137. The register includes synonyms and the constituent components of variants, indicated by different printing styles. If the automobile is to be fitted with air-conditioning, a rectangular rubber plug is fitted in the upper fire wall, with two holes for the AC-leads. If the automobile is not to be equipped with air-conditioning, this rubber plug has no holes. The rubber plug is in this case a constituent component for air-conditioning. There are also descriptions of how common the systems (functions) in the product are, the components in them and how they work. These descriptions include references to various information sources, such as production details, spares catalogues and service handbooks.

From the beginning these support systems were the analytical instruments of the researchers. Identification of distinguishing characteristics of the whole flora of automobiles followed, which in turn gave "variant maps" with new variant specifications. Only then was it possible to begin the work of developing work instructions for the operators. In Figure 2 the method stages have been numbered according to the order in which they were performed. As is shown, the research work did not start directly with developing the work instructions, but these were instead a consequence of the subsequent stages. It would not have been possible to start by producing instructions.

Functional Characterization and its Relationship to Additive Assembly Sequences

Expressed in a few words, through research, a verbal and visual network for a final assembly plant has been developed and implemented, which makes it possible, without exception, to relate individual parts to different wholes. This network of texts, words and pictures is named "the assembly geographical atlas" (a series of interrelated maps). This atlas is based on characteristics always present in all vehicles. There are certain generic characteristics, built-in hereditary factors, which we have used to obtain a new description that is resistant over time and between different products, irrespective of whether these vehicles are automobiles or trucks. We have carried out a similar analysis for Volvo Truck Corporation and today the results are in the process of being applied.

The description of the final assembly of the automobiles exploits symmetries in real objects and variations around these symmetries, i.e. the point of departure is that distinguishing characteristics, which are always found in all automobiles must be used (e.g. if a right hand component exists then there must also exist a corresponding left hand component, if central locking is fitted then mechanical locks are not fitted, etc.).

The guiding principle, as stated earlier, is that there must be agreement between the way of working, the material display and the description of the work, where the description of the work is based on a number of "basic maps", so-called *final assembly functional groups*, of the product and the consequent assembly work. These "maps" are at the same time both verbal and visual, and are based on the fact that the automobiles' variations are an asset. They describe the product and the assembly work in a way that maintains stable relationships between the description of a specific automobile and all possible individual variants. The criteria "distinguishability" and "generativity" were the bases for producing these maps. The assembly geographical atlas constitutes rational thought patterns and "inner maps".

Figure 3 presents results of our research in the form of exploded views which illustrate the final assembly functional groups. In order to provide an overview of the product and thereby the whole final assembly process, a system of stable illustrations has been developed, in which the body is viewed at an angle from above and behind. The illustrations are grouped according to level so that they range from one automobile to all automobiles and from a complete automobile to an individual component. These illustrations are available in different forms with a varying degree of schematization, i.e. both realistic and symbolic pictures.

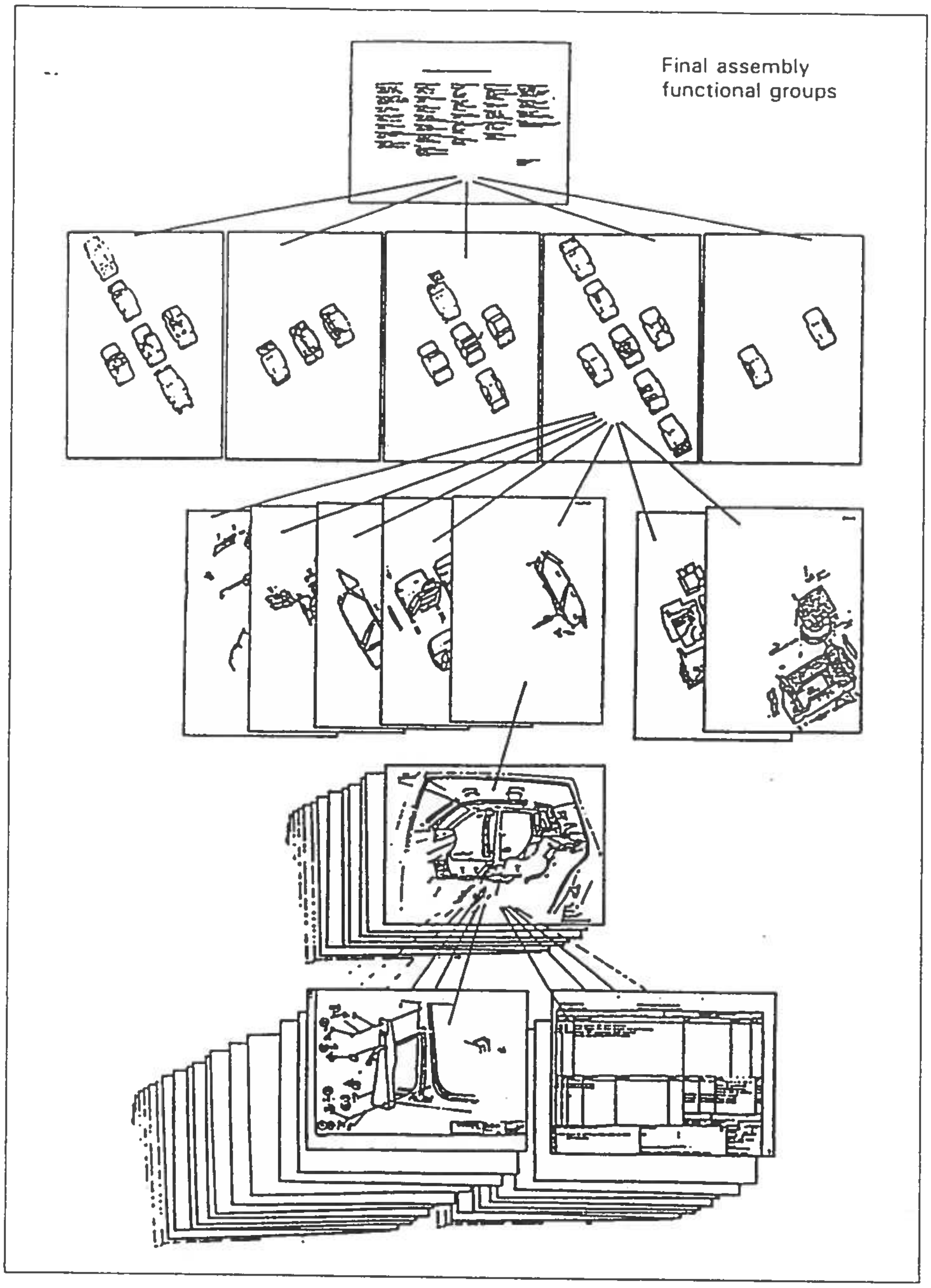

Figure 3.
Examples of Exploded Views which Illustrate the Final Assembly Functional Groups

These illustrations are based on a number of reference diagrams of the body and hierarchically build various sorts of illustrations from part to whole. They are drawn in military perspective so that it is possible to shift the components around without deforming the perspective. The overviews serve as instruments for survey at group level.

The automobile is viewed at an angle from above and behind "as a town planner views a town". It is important first of all, in the context of long cycle work, to be able to see who will be working on the right and left hand side, respectively, as well as at the front and rear of the body. These illustrations also contain a number of basic views originating in the same diagrams.

Together with the fitters, we have also used the illustrations to balance the assembly work for all possible and tested assembly layouts. In the system of illustrations, each final assembly functional group has been assigned its own colour, which makes it easy to perform engineering analyses by using scissors, glue and paper.

The final assembly functional groups are used as a starting-point for assembly instructions, which consists of various assembly sequences. These sequences can be derived and developed, according to the production system employed. This is achieved by means of the work distribution, which consists of so-called assembly phases (a section of the assembly sequence) and the worker positions

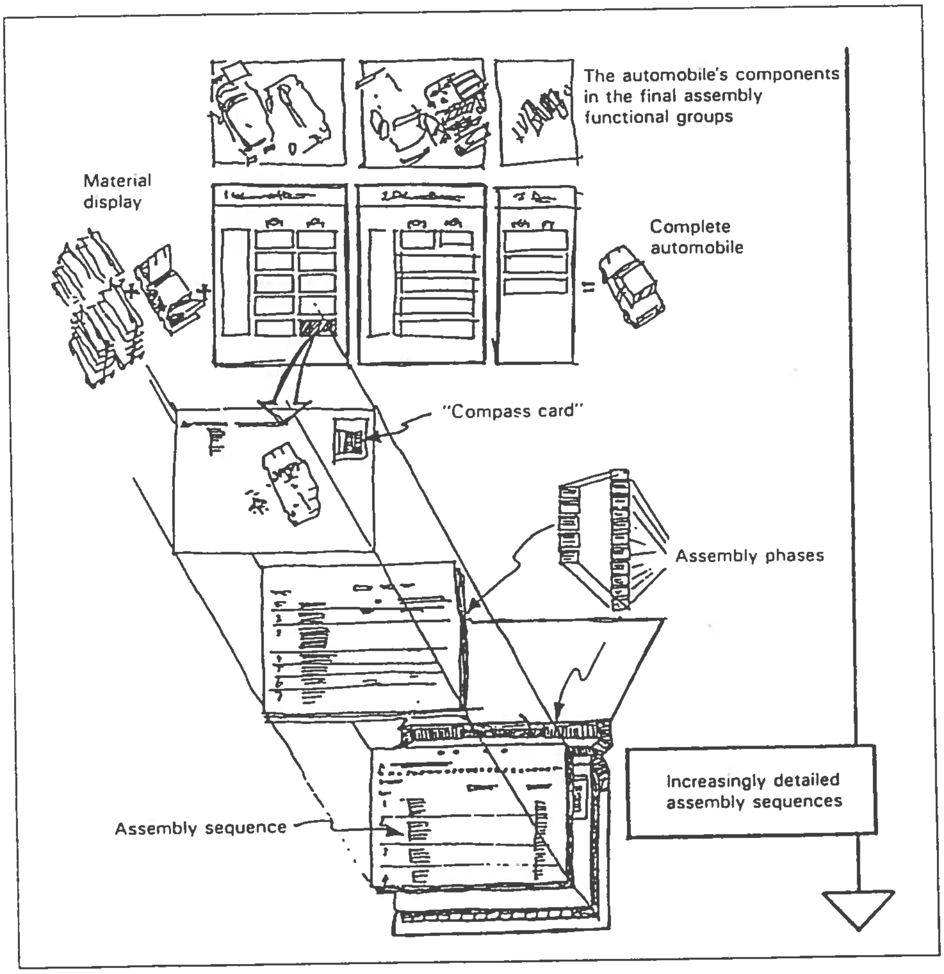

Figure 4. How it is Possible to Shift between the Final Assembly Functional Groups and the Assembly Sequence for an Individual Automobile

in a work team, illustrated schematically as a "compass card", which occurs again in the introductory overview of each section of the assembly sequences. The assembly phases are described in increasingly detailed levels of assembly, as shown in Figure 4.

The material required to perform the assembly work is supplied to the fitters according to the principles applied to the description of the work. This means that the material is displayed by grouping into levels. The material for assembling an automobile is supplied to the fitters in the form of a kit, composed according to the "chosen routes" through the final assembly functional groups.

To supply material to a selected automobile, six specially designed kitting racks (1.9 × 0.8 × 1.6 m) with a total volume of 13 m^3 are required, in addition to the body. Parts that fit in boxes (0.6 × 0.4 × 0.15 m) which can be handled manually are packed together according to the above principles, and kits of small parts are kept in bags. These in themselves form assembly instructions. The surveyability of the automobile's components is thus increased.

As stated earlier, a complete material kit is made up of six kitting racks consisting of 32 boxes and 190 large parts. The boxes contain 410 parts and 90 bags. This makes a total of 690 units supplied to the fitters for each automobile. This must be compared to conventional material supply to line for all variants, which entails the display of parts in over 5,000 different positions.

These levels are linked by indexing, gridlines of varying length and thickness, ancillary tasks described in italics, etc. These assembly instructions also serve as a communication instrument between the various departments collaborating in the final assembly. It is possible, for example, to order materials when shortages occur by means of the assembly instructions. The production engineering aspect of the local pre-production of the automobile has also been taken into account by organizing production engineering in accordance with the final assembly functional groups. This has allowed the implementation time for large product changes to be considerably shortened.

Since the final assembly functional groups are based on the components, one and the same database can contain all the components and form the basis of all the administrative support systems within the factory, i.e. picking lists, assembly instructions and time analyses, etc. are different aspects of the same reality.

Some Implications for Local Factory Management of the New Characterization

In contrast to short cycle work, the application of occupational learning principles in long cycles in final assembly systems with a high degree of parallelization has necessitated the development of a system of concepts and a conceptual terminology to facilitate communication, the building of experience, and orientation in assembly reality.

This conceptual terminology allows production engineering and pre-production activities to be transferred to more qualified personnel than is normal in today's Swedish factories, namely to the spearhead competence on the factory floor (such spearhead competence is in use abroad)[14]. It becomes possible to create naturally grouped work. Through the components being given a meaning by linking them to a conceptual terminology, it also becomes possible to regard assembly work as a meaningful occupation. It then becomes a job with which it is possible to have an intellectual relationship, thereby enabling the learning of an ever larger work content. This transfer of work tasks to the factory floor is necessary in order to create a profession in the assembly industries of the future. Reality in the form of the components and their design, and the verbal and visual representation of this reality are therefore intimately linked.

Our experiences indicate that, within the Swedish automobile and truck industries, the greatest obstacle to the work of tomorrow (either as an assembly worker or as a designer) is not to be found in the work itself, but in the work description in use today and the resultant perception of one's own work in relation to the performance of others, the underlying principle being that if my conceptions help me to handle reality, then they are correct. These conceptions can, however, initially be derived from qualities that exist in reality, and later be formed into logically resistant patterns. The need for this kind of rational thought pattern has not previously existed in final assembly, and has therefore never been identified and formalized.

When the workers' tasks are broadened the need for central support functions changes (i.e. those parts of the work that are today performed by central pre-production and planning departments). In order to allow the assembly activity both at individual and group levels to achieve the autonomy and gain the support needed to be able to accomplish the tasks, an organization is required that is based on the production activity to a greater extent than at present.

The need then arises for "flat organizations" in the local factory, with completely new delimitations. These organizations will be specifically distinct, according to the assembly process chosen. The staff in these new production systems will then have new functions to perform, at the same time as certain of their present tasks are transferred to production itself.

One example is material pre-production, which was earlier restricted to the communication of information between supplier and store. Its new task will be to carry forward and ensure that the new conceptual terminology in the production activity is correct and that the structural information makes each individual component uniquely defined both in the company's central information system and in the local information systems.

This means a certain screw which occurs in a number of different positions in a certain automobile must be uniquely defined in each case, to provide an efficient administrative image which can support operators and production engineers, facilitate communication and prevent misunderstanding. In today's Swedish assembly plants this structure information is not available in the parts' administrative image (the need for this has not been apparent in line production systems). Compare having only a part number with having complete structure information for a particular component. This complete structure information means that the component is defined via a series of textual concepts relating the individual component to the product as a whole (function, position, subassemblies, etc.).

This can be exemplified by a component numbered *96 84 64* referred to as *Screw ST4.8 x 13* which is part of *Lock cylinder, side doors*, which is part of *Lock cylinder kit*, which is part of *Lock/handle*, which is a component of *Automobile type X*. The italics indicate structure information. This is the formalization of the designer's work. When exploited correctly, this information is a great advantage in the restructured assembly work. At the same time the role of management in or connected to assembly will be redirected from problem solving in acute situations to being responsible for the long-term maintenance/development of the preconditions in production and for the internal knowledge profile of their own work groups.

Conclusions

In traditional line assembly the work cycles are short. New production systems involve parallelized assembly, in which small groups of people assemble complete vehicles. Work content is thereby expanded and work cycles become longer. Such new production systems are based on human beings' natural preconditions for understanding, thinking about and carrying out the work. Naturally grouped work has been created against this background.

Demands for higher efficiency are the principal reason for replacing line assembly, not humanization alone, where Swedish initiatives are regarded as social experiments.

It should be noted that correctly designed, these new production systems will lead to gains such as generally increased efficiency and greater flexibility not only in the assembly work itself but also those functions who are responsible today for production's preconditions, for example production engineering, pre-production and planning.

Work in the new production systems is based on wholes that are surveyable by *one* individual. It must not be disintegrated into small units which are then distributed to different people.

Long cycle assemby work presupposes support from a well-structured material display complemented by administrative support expressed in an assembly-related language.

A precondition in the development of new, parallelized production systems is that the people who are going to perform the work are given the possibility to understand how it is to be performed and why it should be performed in a certain way. On the basis of human beings' natural preconditions for understanding wholes which have been structured for a definite purpose, the materials for the vehicle can be grouped according to the whole to which they belong, ***final assembly functional grouping***. The work is then performed with these functional wholes as the starting-point, and both the work and the object are described using them as a basis.

An assembly-related descriptive method of this kind allows much easier communication between assembly workers, designers, material handlers, marketers, and pre-production planners. All involved, including those who handle material and perform the assembly work, must have descriptive methods directly related to their own activities but which have their points of departure in the same assembly-related product structure. At the same time it must be possible to shift between descriptions without losing any important information.

These new production systems with naturally grouped work mean that a large proportion of activities of the production engineering, pre-production and planning departments must be transferred to the factory floor. This is made possible by the development of the new descriptive methods. Not only will work organization in the assembly workshops be affected, but the whole organization of the company will need to be changed.

Let us summarize some consequences of long cycle assembly work:

- As long as the Swedish vehicle industry has not fully recognized and identified the need for assembly-related product structures in connection with the introduction of the restructured assembly work, the workers in the local assembly plants, and their support functions, will have to perform a multitude of new work tasks compared with their traditional ones. This fragments their activities, since they must be responsible for redesigning the central product structure while supporting the assembly work.
- Our conclusion is that this local activity will be considerably simplified and made more efficient if it is based on an assembly-related product description common to the whole company. This will allow local resources to concentrate on supporting the assembly work. At the same time the new product description will mean that details will be derivable in the company hierarchy and exchanges between different local processes will be simplified. There is also reason to believe that these changes will in the future also have a considerable influence on the work of the designer.

References

1. Engström, T. and Karlsson, U., "Alternative Production System to Line Assembly — A Problem Concerning Material Supply", *Proceedings of the VI International Conference on Production Research*, Novisad, 1981.
2. Engström, T. and Karlsson, U., *Alternativ Montering*, Institute for Management of Innovation and Technology, Chalmers Tekniska Högskola, Göteborg, 1982.
3. Engström, T., "Materialflödessystem och serieproduktion", Doctoral Thesis, Institutionen för Transportteknik, Chalmers Tekniska Högskola, Göteborg, 1983.
4. Engström, T. and Sjöstedt, L., "Development of Production Design and Organization of Work within the Swedish Automobile Industry", *Proceedings of the International Forum — The Future of the Automobile*, Berlin, 1984.
5. Wild, R., "On the Selection of Mass Production Systems", *International Journal of Production Research*, Vol. 13 No. 5, 1975.
6. Karlsson, U., "Alternativa produktionssystem till lineproduktion", Doctoral Thesis, Sociologiska Institutionen, Göteborgs Universitet, Göteborg, 1979.
7. Nilsson, L., "Yrkesutbildning i nutidshistoriskt perspektiv", doctoral thesis, Pedagogiska Institutionen, Göteborgs Universitet, Göteborg, 1981.
8. Ellegård, K., Engström, T. and Nilsson, L., *Principer och realiteter-projekteringen av Volvos bilfabrik i Uddevalla*, Arbetsmiljöfonden, Stockholm, 1989.

9. Johansson, B. and Johansson, M., "High Automated Kitting System for Small Parts — A Case Study from the Volvo Uddevalla Plant", *Proceedings of the 23rd International Symposium on Automotive Technology and Automation*, Wien, 1990.

10. Ellegård, K., Engström, T. and Nilsson, L., *Principles and Realities in the Reform of Industrial Work — The Planning of Volvo's Automobile Assembly Plant in Uddevalla*, The Swedish Work Environment Fund, Stockholm, 1991.

11. Engström, T. and Medbo, L., "Material Flow Analysis, Sociotechnology and Natural Grouped Assembly Work for Automobiles and Trucks", *European Workshop — Research and Development Strategies in the Field of Work and Technology* (in press), Dortmund, 1990.

12. Engström, T., Hart, H., Hofmaier, B., Karlsson, U., Leijon, S., Norgren, F. and Schiller, B., *Arbetsliv i utveckling — Om forskarstött förändringsarbete*, Arbetsmiljöfonden, Stockholm, 1990.

13. Johansson, M., "Product Design and Materials Handling in Mixed-model Assembly", Doctoral Thesis, Department of Transportation and Logistics, Chalmers University of Technology, Gothenburg, 1989.

14. Koike, K., "Human Resource Development and Labor-management", *The Political Economy of Japan*, Vol. 1, Stanford University Press, 1987.