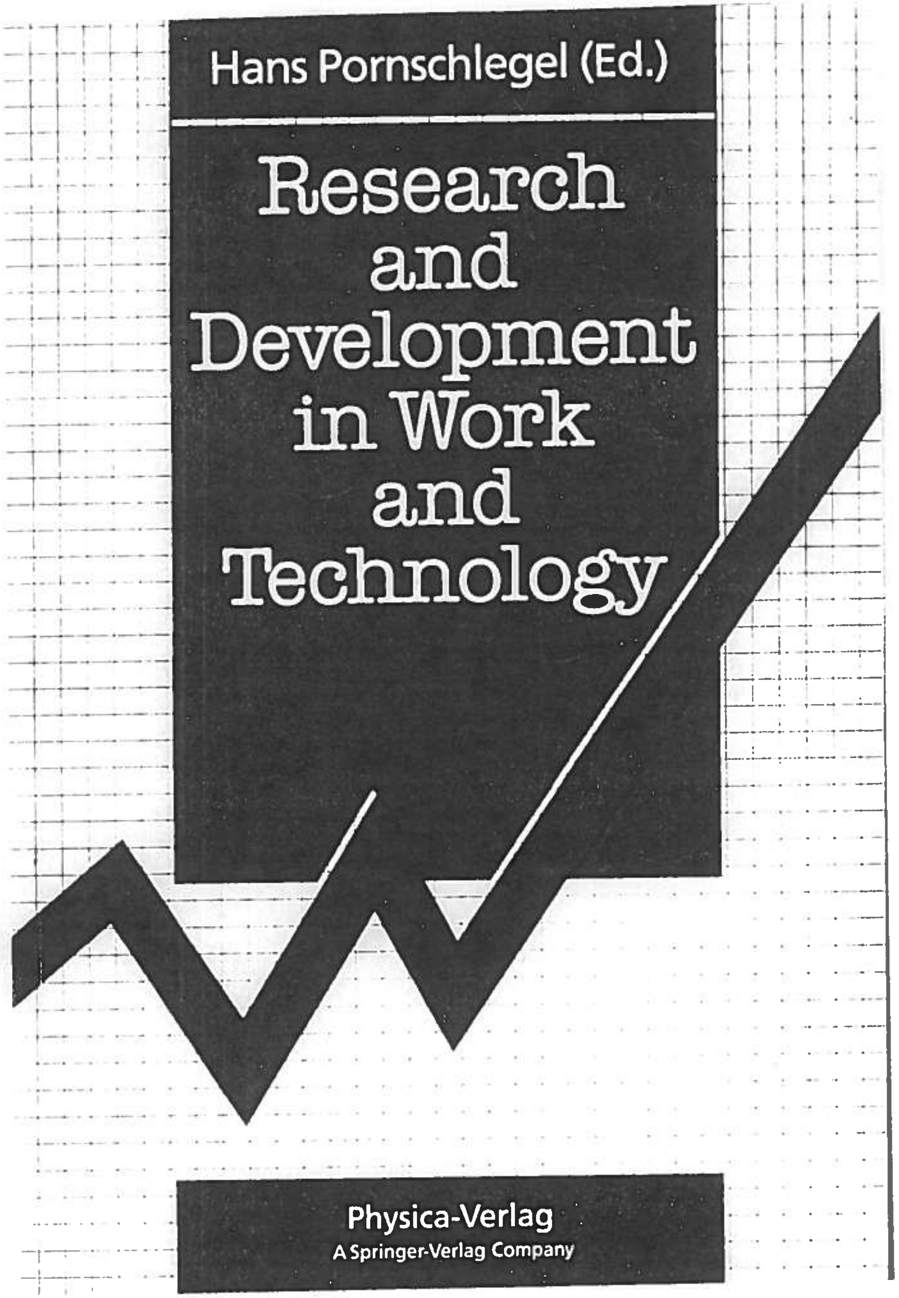

Hans Pornschlegel (Editor)

Research and Development in Work and Technology

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Materials Flow Analysis, Sociotechnology and Naturally Grouped Assembly Work for Automobiles and Trucks

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This paper presents an *overview of Swedish research* concerning some principles and experience in *production system design*, namely the creation of meaningful work tasks, technical autonomy and *functional learning*.

From the point of view of final assembly, automobiles and trucks are all surveyable - even when including the infinite number of variants - if they are described and the workplace is organized according to certain principles. However, the prevalent technical and administrative routines have deformed this logic to unrecognizability.

Reorganization of the technical and administrative *structure based on the "inner logic" of the product* makes it possible to *extend the cycle time*. This reorganization is the basis for reforming the assembly line in, for example, the new Volvo Uddevalla assembly plant.

The *results are based on experiments*, industrial implementations, empirical data and action research during a five year period.

This paper reports the results from the assembly of automobiles and trucks in four problem areas:

- The relation between the research done and the results that have led to industrial implementation during the period up to 1985 (Chapter 1-2).
- A description of the difference between the traditional and the new way of characterizing assembly work (Chapter 3).
- A description of an example of the effects of this *new characterization on the technical system*. In this case, how production planning, production control and external logistics can take advantage of the possibilities that now become available (Chapter 4)[1].
- A look ahead at *future consequences* for companies and research of the reorganization of the technical and administrative conditions (Chapter 5-6).

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1) This chapter has been written together with my colleague Lars Medbo M. Sc. Department of Transportation and logistics at Chalmers University of Technology.

1. Swedish Research into Final Assembly

Younger scientific disciplines such as materials handling within the scope of transport engineering has its practical origin in operation analysis and is connected in its traditional application in serial production in manufacturing industries to the following problem areas:

- Work place design and loading ergonomics.
- Buffers and serial flow theory.
- Group technology.
- Construction and design.
- Line balancing models.
- Layouts and picking method analysis.

The research I have pursued over the *past thirteen years began in 1976* by using picking *method analysis* to seek *rational handling chains* for typical cases of equipment and goods combinations; an optimizing problem applied to an existing reality.

The Thesis Work in Relation to the Insight of Today

The problem areas I have treated have changed over the years. This is, of course, natural also for the arsenal of methods I have had at my disposal - a relationship I shall describe below.

The research became really interesting when *work sociology* was *added to the traditional transportation engineering*, so that with this as a starting point alternative systems to lines could be sought. The initial competence in the problem area was provided by a then qualified work-sociologist with more than four years'practical experience from the shop floor at Saab-Scania's factory in Trollhättan and who, moreover, was from the beginning a qualified engineer (ref. 8).

Work sociology with comprehensive empirical elements is a generalizing science of experience, and proved in the chosen problem area to be a *powerful complement to the technology*. The research began with a *sociotechnical approach*, with the result that researchers and practitioners initially framed the problem area for my thesis research:

- "Flow parallelization is the most attractive alternative production system for final assembly of large products. Parallelization in final assembly leads to materials supply becoming a restriction. How do we solve this restriction?"

Today I understand that this phrasing was missleading. But the knowledge sought could nonetheless be crystallized out.

In theory and in a number of case studies, it proved to be both practical and economically viable to supply materials even to large objects, a situation illustrated in my thesis (ref. 10).

The phrasing of the problem, originating in dialogues with people active in the field, was misleading insofar as it presupposed that these people's descriptive categories were axioms, declared as conditions for the problem phrasing.

My thesis demonstrated possible materials flow structures, the product being analysed partly by means of the so-called "design analysis" (a method of assessing how easy or difficult it is to assemble i.e. "degree of design") and partly by means of the so called "form classification" (a method of assessing the influence of the design on a given production system).

The final assessment of the reliability of the production systems was made with the help of a so-called "zero system calculation", a method of calculation which is a development of loss analyses (ref. 5).

The approach enabled, through its raised scale level (a reference system in the form of a Utopian loss-free system was introduced) together with the possibility of linking product and production system, a relation to be determined between "degree of process" (the capacity of the production system to adapt to disruptions) and the "degree of design". This meant that it was possible to determine when it was worthwhile to allow an operator to adjust an "unsatisfactory product" or when it was more suitable to try to raise the "degree of design". It proved to be the case, for example, that with *the low "degree of design" that Swedish automobiles and trucks had, that raising the "degree of process" was always to be preferred.*

The result generated during the thesis research and the larger STU-project[2] which financed the work, was besides methods of analysis, several practical changes in manufacturing industry (ref. 10) for large products, principally Saab-Scania's miniline system in Trollhättan. Complete parallelization was here thought too risky, because of the need for development of control systems and too expensive with the need for mechanized sorting equipment demanded by the large synchronous pre-assemblies. My method was practically applied to its fullest extent in two factories for Zanussi in Italy. Characteristic for my work during the thesis *research was a constant swinging between simple and extreme products* (from sailing YACHTS to vacuum cleaners and back), finally returning to the classic line products automobiles and trucks. The complete work is based on comprehensive empirics (the basic material for the thesis was in excess of 6.000 pages).

The reasoning on degree of design was put to practical test and linked to adjustment in sailing YACHTS assembly. A complete *"zero system calculation"* was made for two separate yards, Najad on Orust and Comfort in Arvika. The sailing YACHTS were thus subjected to the most extensive analysis, insofar as all operations were treated, the reason being that here the researcher could obtain comprehensive data. Automobiles and trucks

2) Styrelsen för Teknisk Uteckling, Stockholm.

were at this time too difficult to obtain an overview of. Today I understand that we lacked something. It is clear today that the existing description structures lead both analyst and practitioner to false conclusions. This explains today why the efforts of researchers, despite comprehensive empirics and theoretical analysis did not achieve a massive penetration in the really large industrial systems.

In the situation of today with the labour shortage, industries are more prepared to listen. At the same time I realize that the earlier question was also one of personal legitimacy. How could individual researchers argue against the prevailing administrative rationality deeply rooted in routines and administrative systems?

With the help of my collaborators I obtained during the period 1985-1987 unrestricted access to the practioners'theatre of change. *Access was achieved by initially formulating the problem area as a work-place and ergonomics question.* Industry successively placed resources in the form of premises, products and expertise at my disposal (ref. 15, 16 and 17). After exhaustive exploratory studies these resources gave a compact empirical operationalization of the sociotechnology. Operationalization ranges today from an extremely low level up to querying of total factory structures.

2. Streamlining and Development of the Original Problem Area

Over the last few years my research has once again *converged on industrial assembly*, where for the final assembly of large products it was necessary to develop pioneering method instruments, which generated new knowledge of the final assembly process on the basis of existing preconditions in the form of product and human. Choice of layout, materials supply and administrative systems were a consequence of basic processual knowledge, *formalized in the so-called "assembly-geographical atlas"* - a considerable departure from the analytic model crystallized from the original problem phrasing in my thesis. I have chosen the term "assembly-geographical atlas" since one or more operators, depending on conditions, choose their route on the "maps" that illustrate the product. Alternative names are "assembly anatomy", "final assembly topographical maps" or "spatial assembly anatomy".

The difference, in a few words, is that the methods earlier applied had their origin in a given design (a base object), with the operator density and cycle time that proved empirically possible, while today principles for naturally grouped work allow quite different work content and work organisation through the grouping/formalising of the assembly work so that functional learning is achieved (rather than additive learning). The work is described in maps designed on characteristics always found in all products and production systems.

The *materials handling system in the assembly plant* consists then of *combined supply principles*, from completely centralized batching to decentralized material areas with floating borders with the assembly areas. Characteristic is that it is small components (screws, nuts, clips, washers etc) that have to be treated separately. We started an experiment in this respect by batching these small components in plastic bags ("kitting") in a prototype. Today Volvo has further developed this idea in Uddevalla, the reason being that these small components are in the majority, it is impossible to keep the stock balance updated for several parallel material addresses and small components show the largest variation and therefore visualize the assembly work and the product much more precisely than the larger components, which the assemblers moreover learn more quickly.

Solutions with decentralized material areas and combined materials supply systems were penetrated in my thesis, but did not become industrially feasible or mentally tangible until they had been proved by the descriptive structures of the people in the field and through the Uddevalla project being successively forced, with the help of the researcher's results and own experience, to follow principles for naturally grouped work.[3] The work that I and my colleagues did on the layout during the summer of 1987 was the final breakthrough. The present situation in Uddevalla is that functional grouping of assembly work has been tested, introduced and found superior to earlier assembly principles. The groupings have been technically and administratively formalized through assembly instructions with support systems, layouts in final assembly and kitting fixtures ("kit racks") developed by myself and my colleagues. It is naturally satisfying for the researcher that practitioners have accepted knowledge, a knowledge that has influenced the design and establishment of several final assembly plants and related projects. To my assistance i have had excellent colleagues welded into a knowledge compact group, and the support of senior research competence in occupational learnings.

Summary of the Research up to and Including 1985

The sociotechnical school does not presuppose that humans are lazy and uninterested. The reason for lack of interest in the work lies rather in the technology, organizational structure and the bosses' expectations of their subordinates.

An important ingredient in work *design in industrial systems is to design the activities as rewarding or tension reducing in themselves* (ref. 6). The work itself must consist of *meaningful unities* and *demand skill and mental capacity*. The human must himself be able

3) Naturally grouped work presupposes that the traditional disintegration is broken and professional skills created - skills involve a number of tasks being combined in work functions. There are generally four characteristics in a skill:
- Natural rythm surveyable over time.
- Wholistic views of one's work in relation to the product.
- Functional grouping.
- Result orientation, where the central element is not time but "what one is doing" (ref 15).

to choose the way in which to perform the work and must continually be supplied with information on his performance (conditions discussed in ref. 1, 2, 3 and 7).

The *technological structure* which influences the *attitude to responsibility* has a decisive influence, so that most accept *responsibility as the price paid for technical autonomy* (the possibility of working-up) and *administrative autonomy* (the elimination of supervision and detailed control). Working-up is moreover, in serial production systems, a precondition for administrative autonomy and presumably the strongest reason for most to accept responsibility (ref. 8).

Preconditions for functional learning must be created, where the work can be learned in the working environment (ref. 9).[4] If meaningful unities, technical autonomy and functional learning do not exist, then it was, for example, absurd to learn more than 20 minutes' work content in automobile assembly. Buses on the other hand gave a limit of up to two hours. The reason was found principally to be *differences in product* design (the bus functioned as a reversed cassette, while the automobile consisted for the most part of hidden fitting-in movements).

Today I realize from my latest research that the difference was *mainly dependent on the design of the materials flow pattern* and the *way of describing the products*. Buses, automobiles and trucks are all surveyable - even including "the infinite number of variants" - if they are described and the work/work place are organized according to certain principles. But the previously *prevalent technical and administrative rationality has deformed this logic to unrecognizability*. For automobiles this was exacerbated by the product being transported at this time along a long line. The buses on the other hand were assembled in a threestage dock, where the chassis was moved sideways, which enabled the assemblers themselves to find structures of their own.

3. Knowledge-wise Breakthrough in Relation to the Difference between the Traditional and the New Assembly Work

The development in the final assembly of *automobiles and trucks* is in Sweden *moving from production systems with short repetitive tasks*, which are controlled outside the work process, *towards more connected, complicated tasks*. In these new tasks the worker *makes important decisions together* with his co-workers on, for example, variation in pace and how exactly the task is performed. To make this possible in the Uddevalla plant, a *radical renewal of various technical* and administrative sub-systems was necessary.
Some of the preconditions for this renewal were to be found in the characteristics of the *production system that has dominated* until today:

4) I would like to point out the difference between functional learning which is an established concept within occupational learnings, while final assembly functional grouping here refers to the practical groupings in final assembly I have developed for automobiles and trucks.

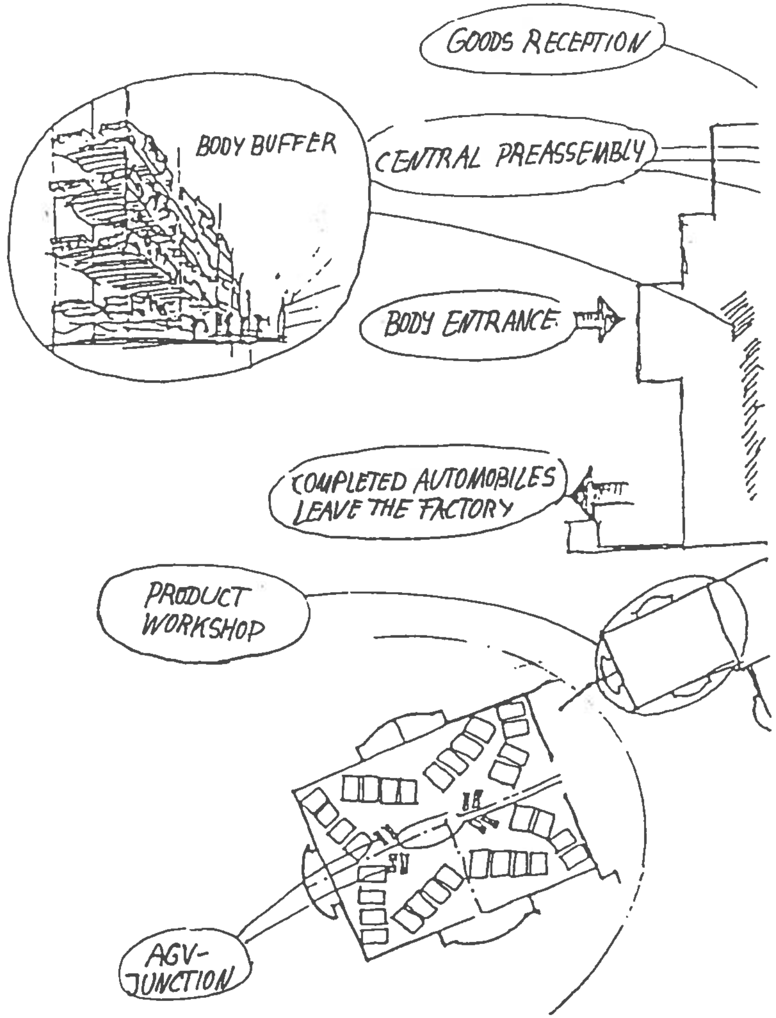
- To achieve successful production in the traditional line system it is not important for the individual operations to be meaningful for the worker performing the assembly. Each part has a low information value for the worker. A minimum of language and concepts is therefore required. It is sufficient for the worker to know where the component is to be fitted, it is sufficient for the materials handler to supply the correct quantity of components to the right address.[5]
- This situation means that the *formation of concepts* (language) on the production shop floor, *can be kept to a machine-friendly syntax, i.e. suitable for computer-based storage and communication.* Any necessary adaptation to the production organization can be made after a short training session and with a limited social system. Characteristic of this adaptation are a low level of communication, and a minimal amount of planning in the separate work tasks, which leads to a one-sided utilization of work potential and not of intelligence.
- The control lies in the fact that each worker has only a limited number of possible combinations. One of these is to teach him the correct assembly sequence, an assembly order consisting of a number of meaningless part numbers in assembly sequence (a knowledge of little value or permanence).

In such a production system it is important that the preconditions at the level of the *individual are prescribed in detail*, i.e. that tools, materials and *work methods* are trimmed together and defined beforehand.

The *possibility of humanizing* the work lies *outside production itself* and must be introduced through *some form of distribution mechanism* (in the general meaning of "The Swedish Model" this has been accomplished through active union participation via mutually agreed systems of rules).

In a traditional production system, production is thus planned in advance down to component level by others, not by the workers. The *forming of concepts around production theory* is thereby divorced from the workers' concepts. Humanization then becomes a question of replacing production with other activities.

5) On a line, work content will continually move between work stations for reasons, among others, of balancing. Components that are identical or have a connection with characteristics in the automobile or truck will seldom be assembled at the same station. If, on the other hand, the object stands still during the whole assembly, direct adjustment can be made, i.e. the worker can correct faults directly, immediately after the assembly is completed.
This is illustrated by the Arendal project within Volvo Truck Corp. at the beginning of the 1970's. When the worker had mastered the whole chains of tolerance for the assembly work, the components were first pre-fixed. When they were correctly related to each other and the chassis, they were then tightened. This procedure is no possible in short cycle line work, since the worker deals only with a few components. Components which are not obviously part of the same chain of tolerance. In the final assembly, of an automobile of the "degree of design" of Swedish automobiles, there is not time on a paced line with no intermediate buffers for direct adjustment (ref. 10 and 11).



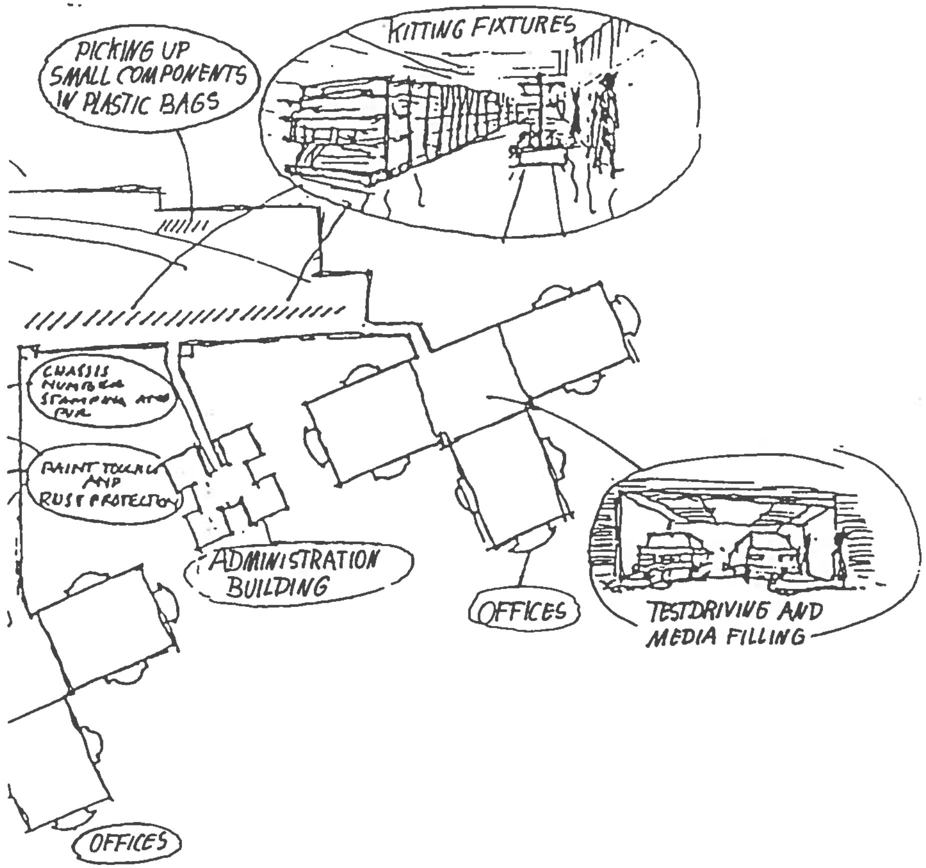


Figure 1: The Uddevalla plant with its six parallel product workshops. These product workshops are grouped around two test workshops where media are added and the automobiles are test driven. The materials workshop prepare and supply in kitting fixtures to the final assembly. These fixtures serve both as a work instruction and as a "clock" to give the work teams an overview of the total assembly time.

Characteristic for *naturally grouped assembly work* in, for example, the new Volvo assembly plant in *Uddevalla* are:

- A *nuanced language in the assembly work*, developed from classification systems which allow a richly developed use of language. A professional grammar related to the work, containing amoung other things a *syntax which permits the individual worker* to perform assembly processes which previously were regarded as impossibly long.
- An advanced administrative system (based on *relational databases*) for *distributing assembly sequences within the work team*. An economy system which feeds back experience to the workers and allows autonomous correction.

A comparison of the Uddevalla plant illustrates the differences:

- Increased complexity in materials handling with combinations of high and low mechanization. The body itself is moved few times while the components to be fitted have several simultaneous supply methods.[6]
- An *administrative system* which can *break down each single component* with its correct name to each individual automobile, no matter what structure week applies for the automobile in question. This system functions as a "protective membrane" around the factory. The external administrative structures at team level are compared and changed to achieve agreement with the assembly principles.[7]

One of the bases in the principles behind the Uddevalla plant is thus the *reclassification and regrouping of the assembly work*. This regrouping allows a *deeper understanding of the*

6) The body is moved to its assembly position. It stands still during the final assembly itself, while the materials that are to be fitted to the body are transported to it in kits for each individual automobile (ref. 12). The flow pattern is organic (comparable to a tree with an ever narrowing branch system). Characteristic is a successively diminishing degree of mechanization with a maintained sorting capacity between the object and the materials kits for each individual automobile. In such a flow pattern, there are points where mechanized equipment is applicable, depending on the degree of mechanization of the equipment (set-up time and operation time in relation to the total final assembly time for the object, and/or the total time at the disposal of the work team, determine where in the organic flow pattern each piece of equipment will be placed). The result is that the production design as a whole is not determined by the degree of mechanization at a given time of one piece of equipment. But the position in the complete flow is determined by how far mechanization has been driven in the direction of manual or machine work. This is not possible on a line or in more traditional layouts with mechanistic flow patterns (ref. 15).

7) Where one of the basic principles is that there must be concordance between carrying out the work, displaying the materials and describing the work. It must be possible to visualize the work in advance, but also to determine if the wrong materials or the wrong description have been supplied, or if one is uncertain of how to carry out the work - otherwise the worker is forced to test-fit the materials, with the consequential risk of being forced to dismantle.

relationship between *production sequences, component grouping*, the sequence restrictions of the components and variant affinity, etc.[8]

The consequences of this deeper understanding has implications in two directions. In the one, a considerable potential is made available for the design of new administrative systems and automobile models, with consequences for the degrees of ease of production built into future designs and also gives new guidelines for future logistical and distribution systems at the plant level. In the other, the new classification allows *the opportunity to develop the training pedagogics for the professional automobile builders* of the future.

The application of occupational pedagogical principles in *long cycle work means* that, unlike in short cycle work, a *system of concepts and a language have been developed*, which facilitate *communication*, the building of *experience*, and *orientation in the reality of assembly*. This language allows the transfer of production engineering and pre-production activities to a more qualified personnel than that of today, namely to the spearhead competence on the factory floor (such spearhead competence is in use abroad, see ref. ref. 14).

This new language forms a firm base for the mental insight into context and structure that is required to enable the new production system to function generatively and yield the efficiency desired.

By linking the components to names which connect them to function and sub-system, a foundation is laid for communication between planning, assembly and materials handling work.

The most important contribution of this new use of language is that it makes it possible to *communicate* with regard *to materials and parts and the interrelation of the components*, their spatial position and their sequence in the assembly. It becomes possible *to create natural grouped work*.

8) In order to operationalize occupational pedagogical theory and to convince practioners of, for example, the possibility to supply materials, the Uddevalla project employed researchers (ref. 8, 9 and 15). 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 the education workshop that was set up before the Uddevalla plant was completed. Both established and newly developed knowledge could in this way be articulated as "nuts and bolts". It was necessary to depart from an evaluating "label research", whereby researchers try only to describe and classify that which already exists. This type of research does not lead to any breakthrough as regards knowledge.

In order to influence large industrial systems, research established on thorough empirical data is required, where researchers and practitioners work together in action research projects. Industrial changes occur so quickly that action research is a precondition for my aims to transfer and, together with industry, develop new knowledge and in order to influence the ongoing projections in industry.

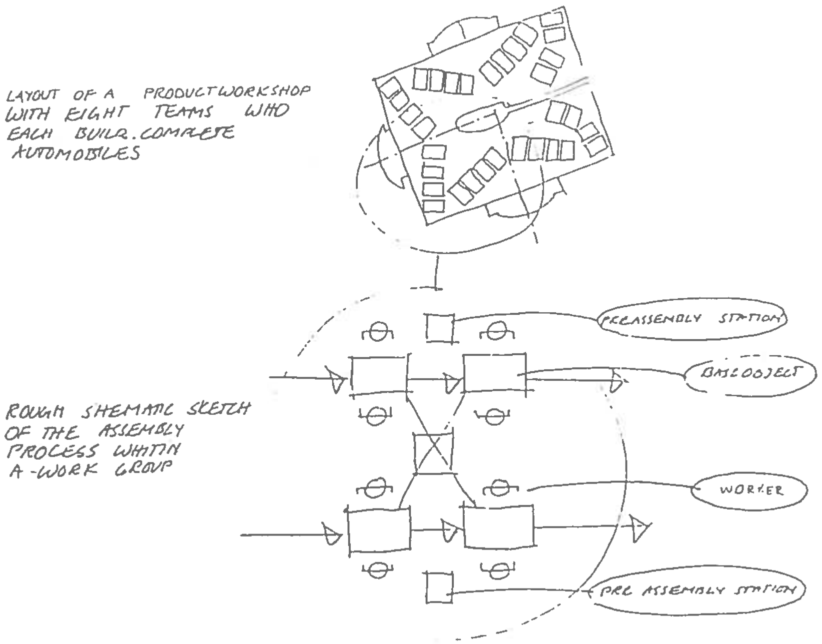


Figure 2: Schematic function of final assembly within a team zone where one work team assembles a complete automobile. The automobile is assembled in two phases, with a sideways transfer within the team zone. The labour intensive pre-assemblies (principally doors, engine and dashboard) are integrated in the team. The aim is to increase the internal assembly-active buffer and to allow variant-resistant work patterns on the team level.

Through the components being given a meaning by linking them to a language, it also becomes possible to regard assembly work as a meaningful occupation. It then becomes *a job* to which it is possible *to have an intellectual relationship*, thereby enabling the learning of an ever larger work content.

There is thus an intimate relationship between reality (in the form of components and their construction), and the linguistic and visual representation of this reality.[9]

9) Both a verbal and a visual network have been developed for the Uddevalla plant, which make it possible, without exception, to relate individual parts to different wholes. This network of texts, words and pictures is named "the assembly-geographical atlas". This atlas is based on characteristics always present in all vehicles (there are certain generic characteristics which I have used to obtain a description that is resistant over time and between different products irrespective of whether these vehicles are automobiles or trucks). My colleagues and I have carried out a similar analysis for Volvo Truck Corp. and the results are today in the process of being applied.

4. Assembly Variants and Production Control

For final assembly of automobiles and trucks in highly parallelized processes with long cycle times to be successful, the products must be able to be described in a, comprehensible way, from the point of view of final assembly. This is especially important, in order to be able to plan and control activities both within and between units in production systems, such as, for example, materials kitting, centralized preassembly workshops and parallel team zones assembling the final product.

Existing descriptive structures consist of market-oriented product numbers and of design-oriented material control codes. There are no descriptions relevant to the total final assembly in the Swedish motor industries of today for either complete vehicles, or parts of them, based on assembly similarity.

The present descriptive structures lead to erroneous conclusions when they are applied to the new production systems. They are not able to discriminate in the way required to support and create wholes as holistic maps in assembly and materials handling work.

As discussed earlier, one of the bases for Volvo's Uddevalla plant was a *reclassification of the products' components*. It was hereby possible *to revise the perception of the product*. This reclassification allowed the description of these wholes, in respect of understanding of the product itself.

The *assembly work content* was then able *to be radically changed*. This changed work means, among other things, *that the materials display* and the *administrative description are normally in agreement with* the work itself. In this context assembly variants are an administrative description of the products' similarities and differences.

Assembly variants involve access to a more nuanced language, a broader application of the "assembly-geographical atlas", a language that from the point of view of final assembly, identifies the products. A language suited to the purpose is a precondition for effective communication. The identification has its origin *in the categorization of the characteristics* of the products. The basic idea of the categorization is that different examples of the same assembly variant will be interchangeable. This means that there are three principal categorization criteria:

- *Competence requirements.*
- Assembly time.
- Tool and equipment needs.

There may be further demands, related to specific production systems (for example, low frequency variants), or if the concept is applied outside the chosen production system (for example, external logistics). To obtain *assembly variants*, the *characteristics of the products* are grouped in levels:

Level 1: The *same assembly work*, but with *different components*, for example panels of different colours.

Level 2: The assembly work is *marginally different*. Different components but relatively "obvious" regarding assembly; a gearstick boot, for example.

Level 3: Assembly tasks that have been decided that *all workers must be able* to manage, both in respect of knowledge and equipment. For example, all the characteristics of the doors can be placed here. The doors can then be used as balancing pre-assembly in a team work pattern.

Level 4: *Assembly differences dependent on competence*, assembly time or equipment. It is characteristics on this level that make assembly difference and thereby define the majority of the different assembly variants. *Low frequency variants on this level must* in practice be treated separately.

In order to describe automobiles with assembly variants, we have applied these to all variants of one model range for three principal markets.

All characteristics with some form of variation were described in 140 areas of characteristics, so-called variant families (with respect to the current descriptive structures used by the design department).

Of these variant families, some 100 were administratively "over defined" (the description had a greater variation than reality). If the areas of characteristics are classified according to level, the following numbers of areas of characteristics are obtained:

Level 1:	23	different characteristics
Level 2:	8	different characteristics
Level 3:	4	different characteristics
Level 4:	8	different characteristics

Thus, on level 4 there remained eight different areas of characteristics which describe the automobiles, *seen from the point of view of assembly*. These areas were doors, engine, gearbox, climate control system, braking system, market and extra fuel tank; the extra fuel tank was a very low frequency variant and was therefore treated separately. One specific assembly variant could then be described as follows:

- 4-door saloon.
- Manually operated sun roof.
- B230FS engine.
- Manual gearbox.
- Air conditioning.
- Anti-lock braking.
- Swedish market.[10]

10) The Swedish market is a collective term for characteristics which in their turn are unambiguously determined by the market concept. Note that the characteristics have here been ordered according to generality. It is clear that the most general characteristics had the lowest assembly relevance.

Since one or more team zones build only certain types of these variants, these areas of characteristics lack relevance there.

When a selection of products in a given production program are categorized into assembly variants, the individual products will be positioned somewhere on a scale ranging from one product to all products.

The number of different assembly variants is considerably smaller than indicated by both the present design-oriented codes and the material. When the frequency of the different assembly variants is known, it is possible to optimize the production system.

In order to test this new categorization, we selected one month's production of 10.000 automobiles, corresponding to 1.900 *different so-called product numbers* (the present system of describing the complete product).

Categorization resulted in *125 different assembly variants*, a small number of which represented the majority of the produced automobiles; 20% of the assembly variants represented all of 88% of the production volume. This is illustrated in the figure below.

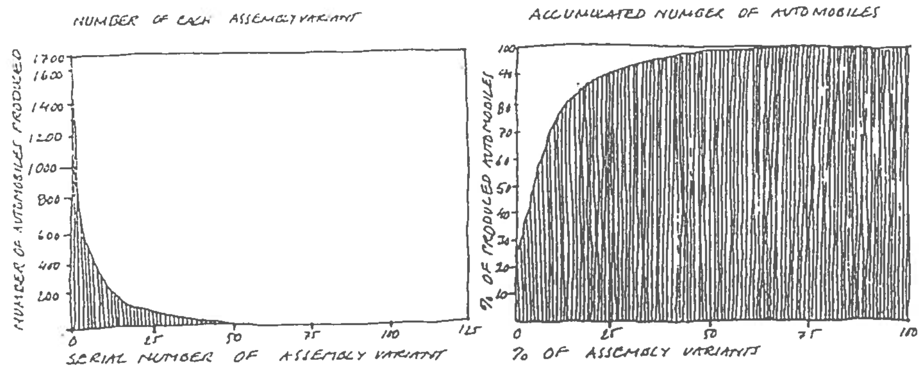


***Figure 3:** Absolute and percentage distribution of automobiles with regard to assembly variant, from high to low frequency. The diagrams are based on one month's production of 10.000 automobiles.*

Consequences of production planning and control by means of help of assembly variants have been studied through simulation. Regarding production in highly parallelized final assembly with centralized materials kitting, planning and control on an individual automobile and on an assembly variant basis have been compared.

The results of these simulations indicate unambiguously that assembly variants improve precision in time for both assembly start and supply precision. This is true even in cases of wide distribution in throughput time per team zone. There is less need for replanning and buffer volumes in the material and assembly workshops are reduced, see figure below.

It is important to use a description suited to its purpose at any given time. Different descriptive methods do not exclude each other but have a different relevance in the separate stages of the manufacturing process.

The effects of using assembly variant as an identity concept are summarized below. They give the products discriminating identities, from the point of view of final assembly, resulting in:

- A tool for personnel to be able to plan production in an appropriate way for them.
- Greater technical and administrative autonomy between different stages in the production chain.
- Simplification of reordering and interchanging of individual products between and within units.[11]
- Easier handling of sequence demands. An example of a sequence demand is that automobiles with assembly similarities should be grouped in twos (resulting in a time-gain as regards "mental set-up time" for the second automobile).

There is less need for detailed centralized production planning in highly parallelized production systems. The number of individuals in the plan fell in our case by 80% when assembly variants were used instead of product numbers.

Greater freedom results through the assembly variants being used for product identity in production planning without lessening the precision demands on the centralized planning. This means that:

- There is less need for replanning in the material and assembly workshops.
- Materials consumption sequence is in better agreement with the planned sequence, leading to less buffering and better JIT efficiency.
- A centralized store is not affected negatively if parallel team zones do not follow in detail a previously determined time plan.
- Delivery precision of completed automobiles is in better agreement with the plan.

5. Future Consequences

Consequences of the Reorganization of Final Assembly Work.

The changed perception of the product itself and the thereby consequential assembly work has brought to the fore such questions as:

11) High frequency products with assembly similarity will automatically be interchangeable. This argument is true for both the whole production system as well as parts of it.

- How will it be possible to exploit efficiently the precise work of the designer, so that it will be an asset in the various processes in final assembly, at the same time as experience attained locally is formalized so that it can be used to advantage in design and pre-production?
- How can the central pre-production work be made to support all local final assembly processes?

The answer can be found in the way of describing the products. I see a need for new product and process structures, or, to be more specific, the automobile industry of the future presupposes completely different descriptive structures to those of today, if the line is to be replaced.[12]

It is therefore necessary to change the technical and administrative preconditions so that these are not an obstacle to surveyability. This surveyability is described, and related to both individual (person, department, production stage, etc) and, as previously, centrally formalized knowledge. It is then that the product description becomes and integral part of the individual's personal professional competence. The products contain an inner logic that it is possible to utilize. This is important, not least because the products are predetermined in detail right from the design work itself, in respect both of correct names and that component functions and systems are known. This is knowledge that interrelates the assembly components to each other and to quality demands.[13]

12) There are at least three different languages applicable in final assembly. These are: 1 A language related to the fact that components have a name (brake cylinders have some connection with brakes). 2 A language related to functions in the sense of how things work (a difference must be made here between functions in general and a mastery of Swedish). 3 A language that is a consequence of the new groupings. The last type of language is today under development and we must allow that certain terms and concepts are temporary, not established and not always well chosen. They are working names; when "the diagrams of the new assembly work" have been fully developed in the future, it will be easy to duplicate them in many plants.

Besides these three languages, there exists a visual language to enable understanding of the necessary co-existence between time and space. If these new languages are established the introduction of future assembly processes will be considerably simplified. In the Uddevalla plant, final assembly functional groups are referred to - these must not be confused with the functional groups 1000 - 9000 that Volvo today uses to describe its vehicles. Note that the term functional is used to mean suitable for a purpose. The final assembly functional groups are suited to the purpose of final assembly.

13) Early in the research my colleagues and I realized that this inner logic in the final assembly of automobiles did not become obvious until 1/4 of an automobile could be surveyed. It is much simpler to interpolate separate work tasks or sequences of these, based on general views known and stipulated from the outset. These views are both verbal and visual (I make a difference between final assembly functional groups and variant tracks). It is only when this perception of reality helps to provide orientation in reality that the new groupings are correct - not the reverse. It follows from this that assembly work as it is carried out is a consequence of work content and its characterization.

In order, in the future, 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 precondition, partly because of the need to reform the factory floor work 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 accessible to the local processes).

Today line assembly is being replaced, for reasons of efficiency, demands for humanization of the work, and a wider range of variants which, in combination with a larger number of direct deliveries of complete pre-assembled components, lead to irrational solutions for materials supply to the line. The differences between the various production systems become so great, that the designer's way of describing the product in combination with the procedures of central pre-production means that the amounts of information to be transferred between design, central pre-production and local process must be reorganized on the basis of formalized knowledge on the factory floor if final assembly with considerably greater work content is to be achieved. A reorganization based on the product itself and its variation.

The basis for this future work is the "assembly-geographical atlas", a classification used today in the Uddevalla plant. A verbal and visual network must also be created, extending over the height, depth and breadth of all the plant's organization. I have illustrated this in the figure above.

Figure 4: *An example demonstrating the difference between using top and not using assembly bottom variants; the consequence is that buffer volumes are either exploited for reasons of commonality (pooled buffers) or develop their own separate queues. The figure shows a simplified example with four different assembly variants with a frequency distribution according to the previous figure. The difference in function between the buffers is shown schematically in both cases. The large upper triangle indicates that the grouping of the assembly variants gives the automobiles differing degrees of interchangeability depending on the frequency of each assembly variant (shown by the smaller, inserted triangles). The highest frequency ones will automatically be interchangeable and thus form a common buffer for all queues to parallel work teams concerned. The significance of this is that there will be degrees of exploitation of commonality ranging from the highest frequency to the extremely low frequency assembly variants. Such low frequency variants must always be treated separately.*

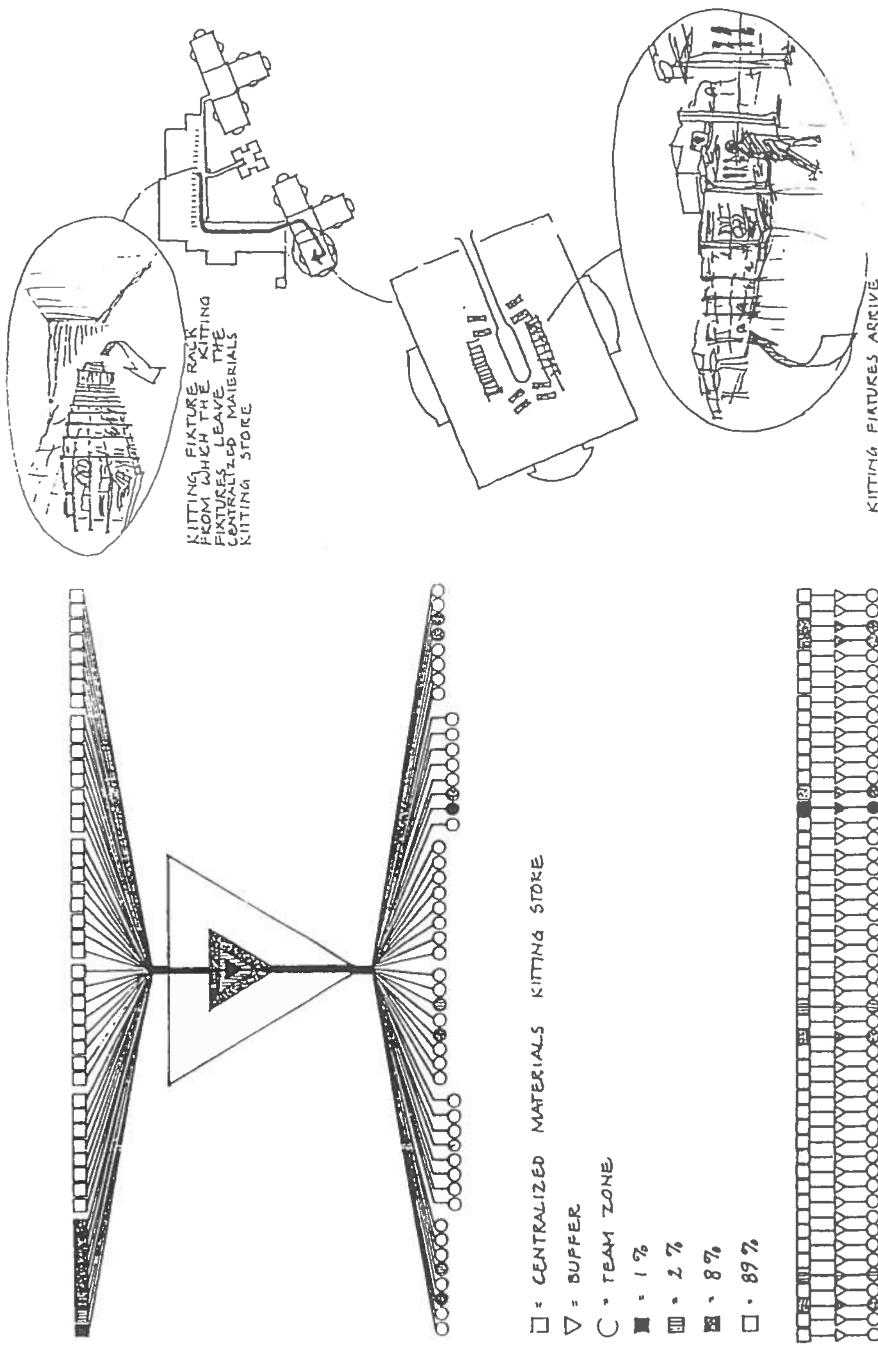


Figure 4

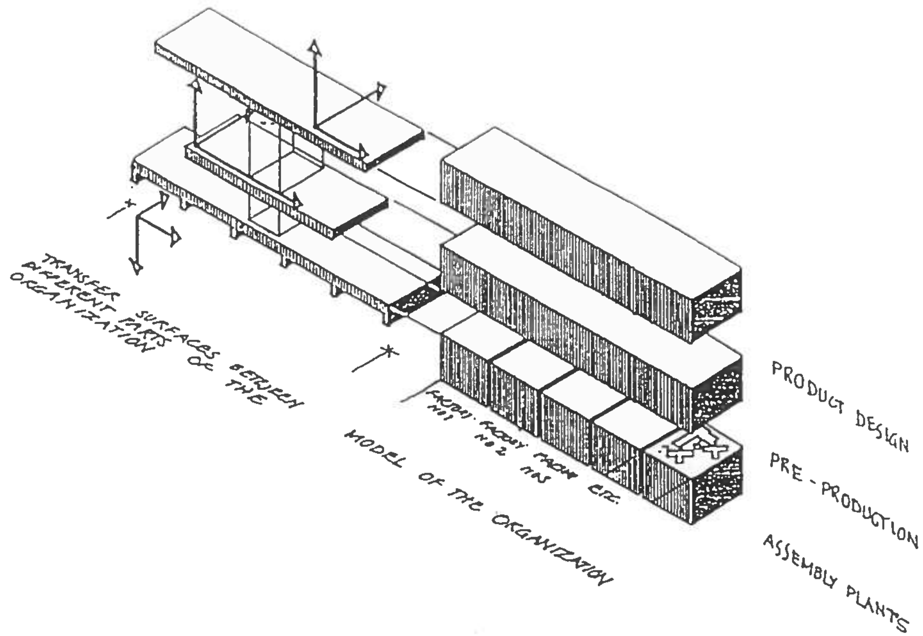


Figure 5: *Three 3-dimensional model of the verbal and visual network. The different parts of the organization separated from the transfer surfaces.The arrows in the figure show how the product is described in different parts of the organization, i.e. how the product description changes according to who is using it. Suitable units must be found for the axes in the transfer surfaces between the different parts of the organization. It is not least important to find common surfaces, lines and points of reference for the whole organization, in order to allow the various users to be able to move between product and process structures without losing their mental orientation.*

The greatest obstacle within the automobile and truck industries to the work of tomorrow (either as an assembly worker or as a designer) does not lie in the work itself, but in the current description of the work and the consequential perception of one's own work in relation to the performance of others. Since it is so, that when my conceptions help me to handle reality, then they are right, not the reverse. However, these conceptions can initially be derived from qualities existing in reality, and later assembled into logically resistant patterns. Rational thought patterns of this kind have previously not been needed in final assembly, and therefore they have never been identified and formalized.

Future Research and Development Work

My conclusion is that the assembly work of tomorrow presupposes a qualitatively new research direction, in which the point of departure will be how the technical, economic and organizational system will be able to create and take advantage of human competence. To achieve this, in the engineering industry, for example, work and materials will have to be grouped according to completely new principles. New forms of job description will also, therefore, be required.

This must be based on knowledge of human learning as well as of technology. Some of this knowledge has today been empirically tested and scientifically proven. But it has not in its entirety, or even in detail, been finally reported in the academic world.

References

1) Dahlström, E., (1966), *Teknisk förändring och arbetsanpassning*, Prisma, Stockholm.
2) Dahlström, E., (1969), *Fördjupad företagsdemokrati*, Lund, Prisma.
3) Lawler, E., (1969), *Job Design and Employee Motivation*, in: Personal Psychology, 22.
4) Thorsrud, E., Emery, F-E. SAF, (1969), *Medinflytande och engagemang i arbetet*, Stockholm.
5) Wild, R., (1975), *On the selection of mass production systems*, International Journal Production Res. No 5.
6) Friberg, M., (1975/76), *Är lönen det enda som sporrar oss att arbeta?*, Sociologisk Forskning no 4, 1975, no 1, 1976.
7) Dahlström, E., (1977), *Effiency, Satisfaction and Democracy in Work*, Acta Sociologica.
8) Karlsson, U., (1979), *Alternativa produktionssystem till lineproduktion*, Sociologiska Institutionen, Göteborgs Universitet (doktorsavhandling). Göteborg.
9) Nilsson, L., (1981), *Yrkesutbildning i nutidshistorikt perspektiv*, Pedagogiska Institutionen, Göteborgs Universitet (doktorsavhandling), Göteborg.
10) Engström, T., Karlsson, U., (1982), *Alternativ montering*, Institute for Management of Innovation and Technology, Chalmers Tekniska Högskola, Göteborg.
11) Engström, T., (1983), *Materialflödessystem och serieproduktion*, Institutionen för Transportteknik, Chalmers Tekniska Högskola (doktorsavhandling), Göteborg.
12) Asterhall, H., Åkesson, S-Å., (1986), *Rum för arbete*, Industriplanering, Chalmers Tekniska Högskola, Göteborg.
13) Koike, K., (1987), *Human resource development and labor-management*, The political economy of Japan, vol 1, Stanford University Press.
14) Ellegård, K., Engström, T. och Nilsson, L., (1989), *Principer och realiteter, projekteringen av Volvos bilfabrik i Uddevalla*, Arbetsmiljöfonden, Stockholm.

15) Ellegård, K., (1989), *Akrobatik i tidens väv - En dokumentation av projekteringen av Volvos bilfabrik i Uddevalla*, Kulturgeografiska Institutionen. Göteborgs Universitet, Göteborg.

16) Ellegård, K., Engström, T., och Nilsson, L., (1990), *Principles and Realities in the Reform of Industrial Work - the planning of Volvo's car assembly plant in Uddevalla*, The Swedish Work Environment Fund (in press), Stockholm.

17) Johansson, M., (1989), *Product design and materials handling in mixed-model assembly*, Department of Transportation and Logistics, Chalmers University of Technology (doctoral thesis), Gothenburg.