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REORGANISATION OF MATERIAL FLOW FOR NATURAL GROUPED ASSEMBLY WORK - SOME PRINCIPLES AND RESULTS FROM ACTION RESEARCH

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ABSTRACT

The process of change in the final assembly plants in the Swedish vehicle industry consists partly of an endeavour to develop alternatives to the traditional line systems, thereby increasing the differences between various assembly processes. The development of production systems for long cycle assembly work demand changes in the product and process structures. In these production systems, which are based on functional wholes instead of additive component tasks, new descriptions of the product and the work are demanded in order, among other things, to make them surveyable.

This paper reports some of the results from action research over a five-year period. I discuss principally the consequences of long cycle assembly work on material flows and layout design. The results reported are: -Material flow patterns and space requirements. -Principles for and consequences of naturally grouped work in final assembly in highly parallelized production systems. -The relationship between production planning, production control and naturally grouped work. -The relationship between parallelization, buffer function and space requirements.

The work has been carried out in collaboration with practitioners and in the majority of cases it has been possible to develop and apply results from earlier research in the development of new industrial layouts and production systems. I discuss a number of these basic principles in detail in the following.

INTRODUCTION

Line assembly is today 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 material supply to the line [1].

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 and functional, instead of additive, learning is to be achieved. A reorganization based on the product itself and its variation [2].

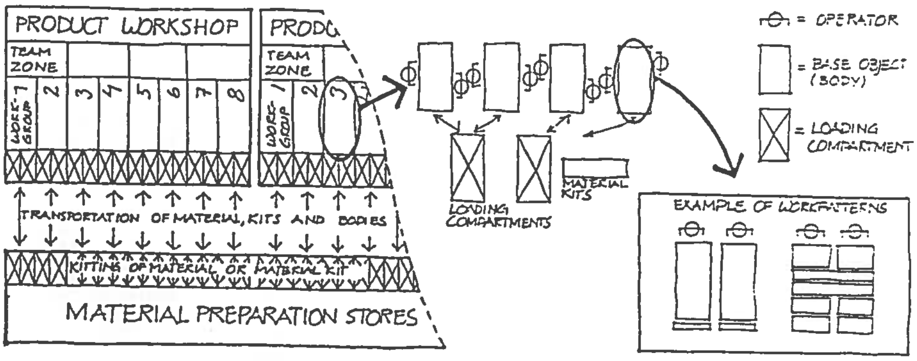


Figure 1. Schematic illustration of a highly parallelized production system in which the material is kitted in one store for all product workshops and supplied as kits to each work group.

MATERIAL FLOW PATTERNS AND SPACE REQUIREMENTS

In these new production systems the body is transported to its assembly position where 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 ^{1}. The flow pattern is organic, comparable to a tree with an ever narrowing branch system [3].

Characteristic is a successively diminishing degree of mechanization with a maintained sorting capacity between the object and the material 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 of one piece of equipment at a given time. 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 in more traditional layouts with mechanistic flow patterns. The latter are characterized by large steps between mechanized transfers and manual work. An example of such a final assembly plant is Saab-Scania Automobile´s plant in Malmö [2 and 3]. The organic flow pattern leads to considerable space saving in relation to line assembly and mechanistic flow patterns. The ratio of space requirements between a fully developed organic flow pattern and a line with highly mechanized stages, for a product with the same "degree of design" as current Swedish vehicles is approx. 1:2.

A further advantage of the organic flow pattern is that bodies, material kits and finished automobiles can be transported more cost-efficiently. In the light of experience from Volvo`s Uddevalla plant it has been possible to further develop the organic flow pattern to the extent that AGV systems, to give just one example, are not necessary. Investment in equipment, and the development of control systems, for example, are thereby reduced. There is thus a future generation of assembly plants but it has not been my intention to describe these in detail in this paper. I shall instead only outline causal contexts of relevance to material flow patterns and layout design in these factories of the future.

The application of a mechanistic flow pattern, as shown in the figure below, requires the coordination of movements within the work group and therefore introduces an interdependence between the workers involved. In the extreme case all movements between work groups must be coordinated. If the object is transported to loading compartments commonly accessible in a central area in the middle of the product workshops the depth of the space required increases.[2] This is because the centre line of the team zones is formed by the diagonals of a given building (here I discuss on the basis of the design of a given building since, in one of my case studies, such a building had already been determined through the projection procedure, but at the end of this paper I will show that there are advantages to departing from such a design). One consequence in this case is that the boundary of the assembly active area with the transport passage increases. It is possible to achieve greater width along individual assembly stations or to increase the number of assembly active objects.[3]

Figure 2. Illustration of the difference between mechanistic - and organic flow patterns. In the product workshop on the left the transport passage is commonly utilized for four so-called double-docks, turned towards each other. "Double-dock" is a term used by practitioners for a serial collective system with a system capacity of two, where work is done on one object while the other acts as a buffer. This method means that assembly requires a large amount of space since one object stands unutilized.

PRINCIPLES FOR AND CONSEQUENCES OF NATURALLY GROUPED WORK IN FINAL ASSEMBLY IN HIGHLY PARALLELIZED PRODUCTION SYSTEMS

The assembly work in the highly parallelized final assembly plants of tomorrow, in which the work will be performed in groups, must be designed in accordance with certain established principles. I refer to the so-called naturally grouped assembly work. This new work has necessitated changes in the prevailing technical- and administrative pre-conditions.[4]

A regrouping has proved to be necessary, i.e. the components to be assembled must be organized in new groupings which first and foremost relate to characteristics of relevance in the new assembly reality. A correctly performed regrouping is a pre-condition for learning to be changed from additive to functional. A significantly increased work content, with realistic learning time, can thereby be learnt at the same time as quality and efficiency increase.

The implication is that long cycle group work assumes a pre-structuring of information and material, which in practice is realized, a.o. by the fact that the material must be supplied in kits. The kitted material supplied from the assembly preparation store serves both as work instruction and as planning instrument on the basis of which the work group members can continuously survey the status of the work.My experience from many years' research within the vehicle industry indicate that a basic pre-condition is a changed view of the object to be assembled. Assembly and material handling work follow from this new view.

The pre-structuring of information about the product and work can be compared to the process of drawing a number of "interrellated maps", in their application which allow different readers to shift between reality and a view of reality while maintaining their orientation. The principle is to create an overview and structure at the same time as the proficient worker becomes all the more proficient by "mastering an increasing number of details".

The regrouping means that the number of variants will be "reduced" in a way that is impossible in line production. It is even an advantage to produce variants, since those automobiles which are identical from the point of view of assembly, while visually and functionally discriminating specific differences in advance (before kitting and assembly have even begun) become possible to describe (the new variants become obvious in relation to earlier assembled products if they are described in a logical way from the point of view of assembly).[5] Even the number of different components will be "reduced" since these will form clusters of components.

HE RELATIONSHIP BETWEEN PRODUCTION PLANNING, PRODUCTION CONTROL AND NATURALLY GROUPED WORK

There are two different points of departure for coordinating production control with production planning. The conventional approach is to count backwards in a production programme to which work groups or team zones are to build which variant and thereafter determine the necessary competence requirement for the worker.

If one regards assembly skills as being in short supply and if the material supply system is able to freely move material, the approach is instead, within the framework of the production program, to start production control on the basis of the skill resource in the number of man-hours per variant available in the short and long term, i.e. a sort of skill balancing instead of, as is normal, balancing so that all operators are maximally loaded within their work area along the line.

The result of the latter approach is increased precision and a better adaptation to local pre-conditions within each individual work group, and also contributes to the groups' autonomy. The production plan is circulated for comment before it is finally fixed in detail. It is therefore an advantage to be skilled and to be aware of one's workmates' competence. This balancing of skill must be viewed as a pre-condition for assembling a wide range of variants with a high work content in a highly parallelized production system. Note that it is not desirable to move individuals between work groups in a way that is unpredictable for the operators.

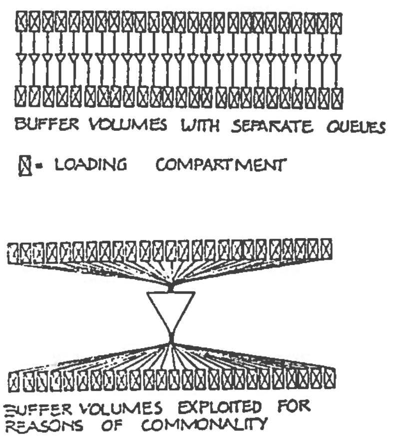
Given certain pre-conditions, the more parallel work groups there are, the fewer sequence breaks there will be in the assembly sequence determined by the production plan. Each sequence break then represents a greater amount of work. The individual parallel work group, which for a given production volume consists of fewer individuals, will be able to master their own pre-conditions to a greater extent and due to their smaller size will also be able to distribute the work and vary work pace more easily, since a.o. it will be possible during production planning to allow high frequency variants, identical from the assembly point of view, to replace each other so that the factory as a whole can follow the planned sequence, so-called assembly variants [2].[6]

Production planning must also take into account the necessity for resistant work patterns within the final assembly work groups, this refers to the distribution of work within the group in a predetermined way with regard to the effect of different variants' spread over time, if certain individuals are undergoing training, if members are absent etc.

These work patterns are a recommended starting point, not a prescribed work method. The work patterns must however describe the work in wholes and in detail at the same time. One must know if the object can be assembled, and how much time is required, and be able to control material and quality. In these new production systems it is not, therefore, a question of eliminating the production engineering work, but this takes a different form and parts of it can be performed to advantage by those individuals who are most knowledgable as regards details in the work process, i.e. by the workers.

If several work groups are served by a common AGV-system and if several kitting fixtures circulate between work groups all work groups must have identical technical pre-conditions for functioning in the same way, otherwise work instructions and kitting fixtures, for example, must be designed differently for different team zones. The transfer of improvements between work groups is otherwise not obvious. This means that the work groups must have the same or similar relationships between base objects, pre-assembly stations and collect/deliver compartments for kitting fixtures, for the work patterns to be almost identical if the different work groups are supplied by means of a common AGV-system.

The highly parallelized assembly plants of tomorrow do not demand AGV-systems between material kitting and assembly. Instead they require production planning and production control which groups products so that distortions in work time between stages around critical equipment do not lead to undesirable movements of objects. The planning will assume that certain pieces of expensive equipment will be shared by several work groups.



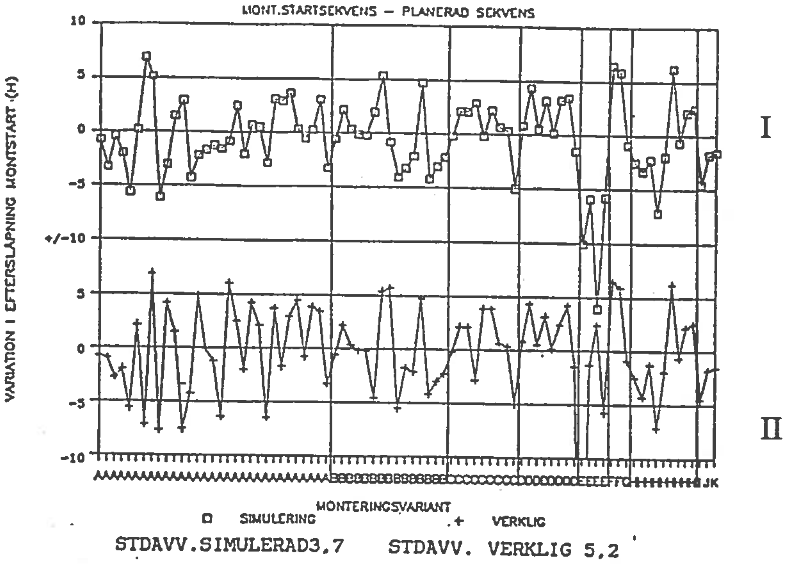


Figure 3. Example of the results of simulations with data from a real, highly parallelized final assembly plant for two cases, with assembly variants, curve I, and planning per individual automobile, curve II. The curves show the distribution of starting time for assembly work in relation to the planned starting time for each individual automobile. The average buffer the work group had at its disposal has been subtracted so that the assembly starting times are grouped around the zero line in the diagram. The variation in time is thus reduced when assembly variants are used. This is shown by the reduction in standard deviation from 5,2 till 3,7. Delivery precision for the completed individual automobiles thus increases, (the effect of varying pace in the different types of assembly is here small). The effects can be read for each assembly variant (A, B, C etc). In this respect it must be observed that it is for the high frequency assembly variants that the real advantages are achieved. It is therefore important in production planning that low frequency assembly variants (by necessity individually controlled) are consciously distributed in relation to the high frequency ones for delivery precision from the factory to be optimal.

THE RELATIONSHIP BETWEEN PARALLELIZATION, BUFFER FUNCTION AND SPACE REQUIREMENTS

The first thing to realize is that conventional thinking is not permitted in parallelized assembly, and as in line production imagine work being carried out with the aid of the movement patterns of the base object. A greater work content means that it is natural to allow the object to stand still - it is instead the operators' competence and work pattern, the content of the tasks, the position of the tools and the movement of the material that best describe the assembly process.

Another basic insight in increased parallelization of the flow is the need for buffers between production stages deceases and flexibility increases through the opportunity to re-sequence the base objects. If, for example, an object requires more assembly work it can remain in position longer than other less demanding objects which can be allowed to proceed. [7]

This resequencing can be done either in buffers in levels next to or in the assembly active area (that area blocked by direct assembly work). These levels extend from sequencing at the work station, in areas immediately outside the work station, at the entrance/exit of the team workshop consisting of several team zones, at the entrance/exit of a product workshop consisting of several team zones etc. This last type of buffer function involves a considerable saving of space, viewed on the whole, and eliminates in its extreme the need for AGV-systems in the final assembly. [8]

In the extreme parallelization the objects stand still during the whole final assembly and tangible, visible buffers of completed or half-completed objects will not exist to describe the operator's working up for him. Working up, which must be defined for individual and work group to permit control of their own work time, appears as the difference between planned reality (in the form of production plans), the current production situation (the status of assembly at a given time) and real time (by the clock). This means that it will be important to have really defined work patterns and support systems in detail, so that the objects can signal how much work time has been consumed since the pacing of the line has been removed. If the objects are placed close to each other the operators can see their work mates and their completed work more than before. [9]

Cycle time (min.):	15	50	210
Assembly active automobiles:	14	14	14
Automobile buffer:	12	6	0
"Empty places":	3	3	0
Total number of places for automobiles:	29	23	14

Figure 4. The minimum required number of base object places within a production stage on a line which is to be redesigned. The production capacity is four automobiles per hour and parallelization varies. The automobile in the example has, within the stage in question, an assembly time of 210 min. It is assembled in the case of the line at seven serial-linked stations of fourteen 15-min. stations; alternatively two operators build the complete car at two 105-minute-stations. In the latter case the number of base object places is halved, due to the greater number of internal buffers required ("empty places" refers to space or automobiles needed as buffer between workgroups for social reasons). The dimensioning of buffer volumes has been based on values for technical autonomy that experience has shown to be acceptable (4). Buffers before and behind the stage in question have not been included. The reduction in space required for the increased parallelization should be noted.

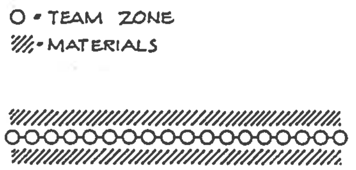
The increased parallelization and the greater work content mean that it is not necessary to simply disengage objects by placing them in a buffer but times differences can instead be accumulated by changing sequences. I here refer to the fact that a buffer can have a greater or lesser sequencing capacity.

Similar discussions refer to relations to pre-assembly stations, whether these have been integrated into the final assembly itself or not. As regards the sequence between the object and its material kits, it is more important to maintain the sequence between the material kits than the sequence between the completed automobiles leaving a work group. The kitted material represents more work time laid down than preparing and transporting the empty body to the assembly active area does, which is why the material kits must determine the timing of bodies.

SPACE REQUIREMENT
(Automobiles/m^2/year)

1,6

FLOW PATTERN

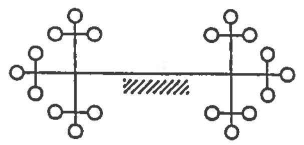


1 Conventional line-production with a certain amount of kitting in smaller packaging. Most of the pre-assembly is performed separate from the line. Cycle time is 2 - 3 minutes.

SPACE REQUIREMENT
(Automobiles/m^2/year)

2,0

FLOW PATTERN

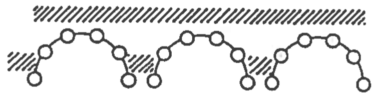


2 Organic flow with AGV between central material preparation stores and a number of parallel small workshops. The body and material are transported to the entrances to these small workshops. Certain tools are shared between the various work groups. Work-intensive pre-assembly is done in the work groups. Cycle time is 2 - 7 hours.

SPACE REQUIREMENT
(Automobiles/m^2/year)

2.9

FLOW PATTERN



3 Organic flow without AGV, but with a combination of central and decentralized material preparation stores and direct deliveries of material to the parallel workshops. These workshops share space and tools. Flow intensity is reduced and inside the assembly active area itself resequencing capacity between objects is maintained. Cycle time is 2 - 7 hours.

Figure 5. Differences in space requirement for three different final assembly systems. The calculations have been made for a production of 22.000 automobiles per year, two shifts and for automobiles av the degree of design corresponding to that of Swedish automobiles. In case 3 space requirements have been calculated on the assumption that heavy equipment such as that used for marriage, electronics testing and leak testing have been designed to be mobile and and are shared by several work groups. The two first factories exist, while the third has still to be realized. Experimental work in a development workshop has however verified the function and space requirements. The work time, as discussed above, can be buffered in levels from the assembly active area. This insight can be consciously utilized by, for example, replacing buffer volumes intended for socially conditioned technical autonomy at group level with sequencing capacity between two parallel sub-groups within the team zone. Space is then gained and the number of interdependent operators is reduced.

My studies of assembly work indicate that worker concentration in a contemporary case of complete automobile assembly within a work group of ten members varied greatly, the assembly of the automobile was divided into four, and the possible worker concentration varied from 1,8 to 3,2 between the different each part. To try continuously, from a narrow production engineering viewpoint, to maintain equally great amounts of work for 100% loaded workers or to assemble the automobile in a four-stage flow, for example, with two workers per stage, borders on the absurd. [10] Absurd since it means that the workers do not have the same work (it moves, for reasons of balancing, partly through the existence of variants). A great deal of production engineering is necessary to maintain an even flow.

The solution is instead to under-load certain objects, i.e. not allow certain worker positions or objects in the normal case to be blocked by individuals who are engaged in assembly, so-called increased system capacity (5). Despite the space increase and the under-utilization that are the apparent results, more efficient work is achieved, if viewed as a whole. [11] This is because the increased system capacity allows: -Work for all operators even if all are present. -Overcapacity for working up, 25 % is a norm which has proved to be desirable but not always realizable in practice. -Smoothing of variations in operators' work time due to distortion in the work time, so-called Weibull curves (5). -The critical competence level per operator in the group is lower. Even with a certain degree of absence in the group, balancing losses can be avoided. The less skilled worker can still achieve full pace by swapping "difficult" work tasks .

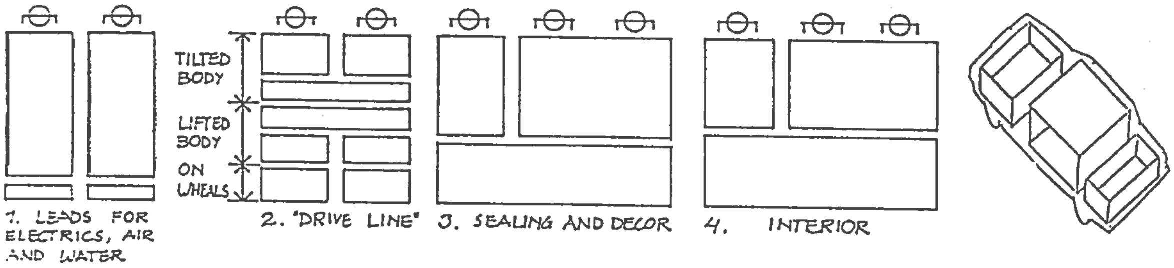


Figure 6. Results from the work survey indicating the difference in worker concentration and work pattern for the case in which an automobile is assembled in four stages where each stage corresponds to the so-called Final Assembly Functional Groups, i.e. a distinguishing group of material (6). Note that the possible worker concentration differs between the different groups. The schematized automobile above shows the worker position in relation to the position of the automobile body. I have used this schematization to group assembly work using the survey as a basis so that the need for tilting and lifting equipment could be concentrated to a single work station. [12]

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[1] For a normal automobile produced in Sweden this kit consists of six kitting fixtures (approx. 1,9 x 0,8 x 1,6 m) with a total volume of 13 m^3. The assembly work to which each fixture is reflected instead by the way in which the parts are structured. This is achieved in practice by the components being brought together, on shelves, in boxes (0,6 x 0,4 x 0,15 m) and in bags (screws, nuts etc), depending on connection, size and assembly position. This results in approx. 190 components directly in the fixture and 32 boxes containing a total of 90 bags.

[2] These parallel loading compartments for bodies at the entrance to the team zone reduce the dependence of the team zone on the delivery precision of the material supply system. Loading compartments can perform several functions simultaneously. Examples of such functions are: -Allow work to be done on objects arriving at or leaving the team zone. -Alternating use as entrance and exit compartment or assembly active area. -Extra compartments for sequence breaks within the team zone or carrier system (if a central carrier terminus is built different team workshops can temporarily alternate between each others' non-blocked compartments). The consequence is that regular assembly stations need not necessarily be blocked by objects which for various reasons are not being worked on.

[3] Each work station has a maximum width requirement, determined by where tools, carriers, automobiles, workers and kitting fixtures will meet or pass. These dimensions collectively give the maximum width for a number of assembly places. For one of the

plant projections I have participated in four assembly stations were required for automobile assembly, a module with a width varying between 19,2 - 26,4 m. depending on where the material kit was placed.

[4] Principles which include work rythm and time distribution ("periodicity"), preparation of material and equipment and successive development of knowledge with regard to quality, production volume and the ability to instruct, where the assembly work has been distributed in natural groups. 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. -Holistic 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" (3). I would like to point out the difference between functional learning which is an established concept within occupational pedagogics, while final assembly functional grouping here refers to the practical groupings in final assembly I have developed for automobiles and trucks [3 and 5].

[5] My and my colleagues' analyses indicate that the production of 10.000 automobiles of one type for three principal markets corresponds to twelve different identities at customer level and 1.900 at design/product planning level. From the point of view of assembly, however, these correspond to only 125 different variants, 20% of which, in our selection, represented all of 88% of the number of automobiles produced. This relationship must in the future be exploited both in production planning and in the development of the work groups' competence [2].

[6] It is necessary to distinguish between different kinds of sequence break. This means that all deviations from the production plan do not as a matter of course one-sidedly affect the store or team workshop. The opportunity also arises to apply different techniques to compensate for the consequences of the break. The more sequence break types production control can handle, the smaller the probability of the reasons for the sequence break coinciding.

[7] If the buffer design is unsuitable in the case of lines or some mechanistic flow patterns the operator is forced to overextend himself in order to be "sure" that there is time for pace changes or breaks. Buffer volumes which are visible immediately next to the work place are to be preferred, principally during learning, before the operator has achieved an insight and confidence for changes in flow in relation to the work pace, which is probably the reason why the operators, during the projection in Uddevalla, expressed a desire for "double docks", since the buffer objects are then placed visibly right next to the work place.

[8] Allowing objects in special areas to represent buffer time steals space in the team zone and means that objects must be moved before the buffer can be accessedd. Several operators must then be simultaneously in agreement and moving the object takes time itself. There is therefore a risk that the operators will choose a less efficient work pattern.

[9] The operators' possibility of achieving a broadened understanding of function as regards which components and systems in the automobile are assembled at the same time, or which exclude each other, also reinforces chains of tolerance and an awareness of consequences is maintained within the group. For the same reasons it is an advantage to turn the object so that it is moved sideways, since the operators can then see their workmates' work more easily. Material flow across the transport passages should therefore be avoided. Engine compartments also should be turned to face each other since these have a greater assembly concentration than the luggage compartment. Operators can not, for example, interpret facial expressions over greater distances than 11 m. In the same way, pre-assembly in the immediate proximity of work on the base object will allow a larger amount of work not directly in the low of automobiles to be accessible (it is simpler to buffer pre-assembly than base objects). Access to pre-assembly improves the possibility to absorb disruptions. By consciously integrating the most work-intensive pre-assemblies into the final assembly, variant-resistant work patterns can be designed, i.e. for those automobiles I studied in this case, the work could be distributed in the same way no mater which variant or variants the group was building. Practical experience has, however, shown that the worker does not gladly prefer a work pattern which means that he or she must leave work on a base object for pre-assembly work, since it disturbs the concentration.

[10] Short undriven lines in four stages means that the first and last stations will alternately control each other. If a number of different variants are assembled there is a risk that this alternating dependence can not be predicted, as is the case in, for example, truck assembly. The risk increases the more people there are involved. For instance, unpredictable adjustment work can mean that group pressure will force the "release" of an automobile before adjustments have been completed. If the groups are too large, group pressure can not be exploited positively. If the number of group members is less than approx. ten then group pressure will lead to a common work pace [4].

[11] For a double parallelized two-stage dock it was necessary in one of the cases studied to allow work time corresponding to one of the four automobiles to fluctuate. This automobile was "split up and hidden" principally because it did not appear efficient to allow an object without workers to be visible for conventional production engineers and uninitiated visitors.

[12] Once the assembly work had been tried over a period of time in the four groups were combined to describe the assembly on the premise of half-automobiles being built. This combining was based on quality demands, "assembling to specific torque " and that 1 Leads for Electrics, Air and Water and 3 "Drive Line" were combined at a station where tilting was required to achieve satisfactory ergonomics, work which demanded precision in quality and fitting, and that 2 Sealing and Decor and 4 Interior required a vertically adjustable platform to be ergonomically satisfactory. Another valid criterion was to combine tasks where the operator dirtied his hands, (i.e. 1 and 3) or did not (i.e. 2 and 4). It has been demonstrated in practice that the difference between machine paced work and the difficulty in learning to fit parts between the two halves was such that it was more difficult to achieve full pace on the last half while the chance to work up was smaller on the first half, due to greater machine paced work and the reduced possibility to temporarily increase worker concentration.