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Some Important Principles and Findings Concerning Long Cycle Time Assembly Work

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ABSTRACT

This article summarizes the principles and findings connected with the development of long cycle time production systems using parallelized flow.

We report on four interconnected problem areas; (1) the influence of product design and flow pattern on the requirement of manpower, (2) production losses and material flow pattern, (3) product structures and product perception and (4) the principle of so-called assembly variants. Finally, we comment on some consequences and implications of this principle.

The first three problem areas chronologically summariz the reformation of research questions during the last two decades. The forth area deals with the newly developed principles of codifying product variants, the so-called assembly variants. Theese principles were one of the key factors never put into practice.

By using this codification in a production system with parallel material flow it becomes possible to describe clusters of product variants on the shop floor, as well as to perform efficient planning and scheduling of the variants. For example, it is possible both to achieve the necessary autonomy for various departments in the production flow and to better utilise the buffer volumes between the assembly and the materials preparation store used for kitting the materials being fitted.

1 Background

According to our experience, technology combined with work sociology proved a powerful technique for our research, when seeking alternative production systems to the traditional assembly line during the 1970s in Sweden (initiaded by the work of Karlsson 1979).

The technical aspects concerning materials handling was financed by the Swedish National Board for Industrial and Technological Development during 1976 – 82 and resulted in several practical changes in the motor vehicle industry (Engström and Karlsson 1982).

During these past decades the sociotechnical approach have proved beneficial for the development the assembly work, concerning real shop floor implementations combined with academically progresses (Engström 1983, Granath 1991, Johansson 1989 and Lind´er 1990).

The initial design hypothesis

Initially, researchers and practitioners formulated the hypothesis that "flow parallelization was the most attractive alternative production system for final assembly of large products such as automobiles, buses and trucks".

This hypothesis assumed that a long cycle time represented a desirable aspect in the aim to make professional assembly work so human that the extended learning cost was "financed" by a reduction in absenteeism and labour turnover.

During this period the benefits of production engineering in the form of increased efficiency, but also higher flexibility and product quality, less work space requirement, etc. as a result of parallelized flow were not recognised. The commonly accepted argument was instead some vague line of reasoning of humanization caused by the increased work content.

At the same time, the motor vehicle industry and the research questions focused on optimization of the maximum cycle time, mainly because the cycle time is a general indicator of the meaningfulness of the assembly work. The more meaningful the work is the less the personel turnover and absenteeism will be and, as a result, the manufacturing efficiency will be increased. The design of the wage systems as well as worker participation were also considered important criteria for work structuring.

Not until the late 1970s did one realize the importance of increased technical autonomy as a reward for increased responsibility in the form of integrated non-assembly tasks, such as production planning, cleaning, liaison duties, etc. The generally accepted concept of humanization became a question of replacing the production by other activities and was not primarily viewed as a question of technical development and research work.

However, during this period the production technique benefits in terms of productivity, quality, etc. of parallelization became obvious to a small circle of people, mostly use of a successful industrial application in the body shop at Saab Scania in Trollhättan (Karlsson 1979).

The work in the body shop consists of grinding and welding and did not require a supply of large volume of materials. In final assembly, however, a parallel flow leads to materials supply restrictions, as the limited space makes it impossible to exploit all the components needed in separate materials containers containing numerous identical components, as is the traditional practice along the assembly line. The question emerged of how to find appropriate materials feeding techniques.

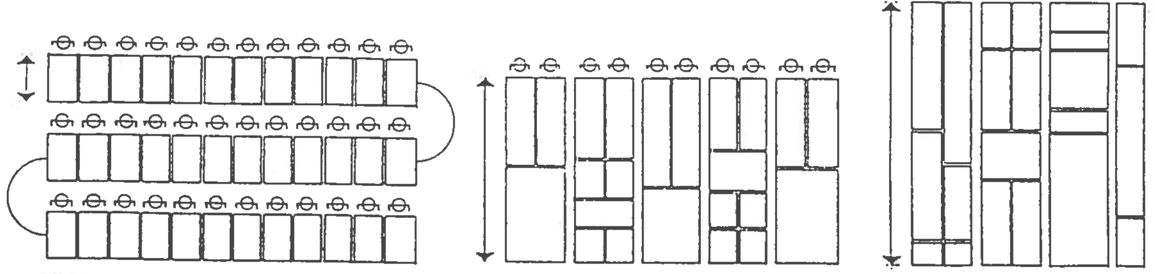


Figure 1. There is a relationship between material flow patterns for the product and work content. A higher degree of parallelization implies a longer cycle time. The vertical arrows representing the individual operator cycle time and the rectangles representing modules of work performed individually or by a pair of operators, show this transformation of work for an automobile in a normalised form. To the left in the figure are 36 operators on individual serial work stations and to the far right are seven operators assembling a complete automobile. In practice, the 36 operators need a minimum of 18 automobiles, while the seven operators have proved to require only three, which is a considerable saving of space in the latter case.

Earlier research and its contemporary full-scale realization

Our development and research work, performed together with Swedish auto manufacturers, proved viable for supplying materials. Our studies were based on the product design being analysed by a method of assessing the manufacturability of a product and how resource-consuming the assembly of a product was.

This method was used because the product was the common denominator and it proved important to understand, from a technical standpoint, the interaction between man and machine. The time and motion studies focused on the human, and therefore an instrument had to be designed for evaluating the product design also from an assembly point of view. Applying these methods of analysis during the late 1970s, we were able to show that one of the reasons for the superior productivity of some Japanese automobile manufacturers, and in fact also Opel was the reduction of the total number of components needed to manufacture a complete automobile.

We formulated the concept of the "design degree", a method for classifying the ease by which a specific component or subsystem might be assembled. It was intended as a tool by which the designer might analyse his proposed design. The easiest way was to count the number of components included in the product. The ultimate theoretical design was to replace all components by a single component, which was to be snapped into place by a single movement.

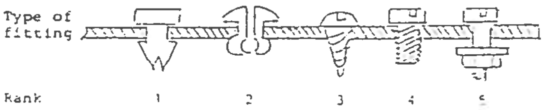
In a study the number of components was counted in one European and one Japanese automobile. The more advanced methods included classifying the design into number of components, number of fittings of various types and number of fitting points of various types.

A regression analysis based on 49 observations of industrial products (refrigerators, vacuum cleaners, automobiles, trucks, etc.) resulted in the following formula:

- Assembly time in minutes = 0.60 + 0.25 x (the number of components) + 0.16 x (the number of fittings of types 4 and 5) + 0.01 x (the number of fitting points of types 5 and 6) + 8.0 x (dummy variable set to one for large products and/or heavy components and otherwise to zero).

The development and research work performed during the 1970s resulted in, among other things, a number of new production systems, more or less traditional. The most radical systems had a semi-parallel flow of automobile bodies, characterized by work shops in a series with differnt parallelization within each work shop.

Note that these production systems, applied in automobile assembly, were tailored to suit the learning restriction of a maximum cycle time of 20 minutes – the assembly of buses and trucks being a different matter. The lower production flow and the self-instructional character of these products, due to variant synchronous sub-assemblies (the frames have prepunched holes to suit sub-assembled valves), constituted a cycle time of two hours (Engström 1983).



Fitting points were classified similarly as below.

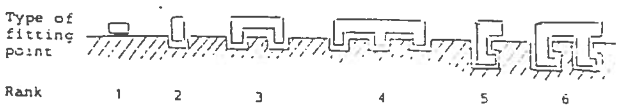


Figure 2. Classification of fittings and fitting points used for the analysis of products (Engström 1983).

Although an identical production system was planned for Trollhättan in the late 1970s and early 1980s, it was not until 1987, when the Saab Automobiles' final assembly plant in Malmö was finished, that the semi-parallel flow production system was realized on an industrial scale for final assembly of automobiles.

Earlier, this system was considered far too risky by the Saab Company, because of (1) the need for mechanized equipment necessary to resequence the synchronous subassemblies (doors, engine and gearbox module, instrument panel, etc.) and (2) Saab's unfavourable experience of the development of complex production scheduling and planning systems.

This might have been a correct assumption at that time – it is not relevant today. Now applicable computer systems are more powerful and misinterpretation of complex products is no more a restriction. There is a need for a non-traditional way to codify products and plan the production sequences not readily available and obvious during the 1980s.

2 Production losses and different material flow patterns

One important tool used was the analysis of production losses. The productivity of different real and hypothetical production systems was obtained with the help of a so-called "loss analysis" (Wild 1975).

This method divides resource consumption into 18 different quantifiable factors, five of which are so-called "inefficiencies", which we here call "work inefficiencies" and the other 13 "system costs". The five "work inefficiencies" are balance, division of labour, system, learning and set-up losses. The most significant losses relevant to assembly in traditional assembly line production are balance, division of labour and system loss.

	Serial flow pattern		Parallel flow pattern	
	Minimum theoretical	Observed	Minimum theoretical	Observed
Balance loss (%)	5	30	1	5
Division of labour loss (%)	6	25	4	15
System loss (%)	25	80	5	20
"Work inefficiency" (%)	35	135	10	40
Total need of manpower (%)	136	236	110	140

Figure 3. Theoretical and observed "system inefficiency" for two different flow patterns. It is obvious that the parallel flow pattern is the most efficient one, the observed data derive from several of our studies of the Swedish motor industry. The table is based on "necessary work" corresponding to a manpower of 100%.

The size of each loss is expressed as a percentage of the "necessary work" to perform the assembly. This means the assembly time that is considered necessary and dependent only on the product. "Necessary work", in manual assembly, thus means the work time required for one ideal operator to carry out all the work, with the components materialising in his hands.

In the most radical automotive final assembly plant, the flow pattern is organic, with a successively decreasing degree of mechanization, i.e. gradually increased parallelization. Work consuming sub-assemblies (examples in the automobile case are; doors, instrument panels, engines and in some cases the sliding sun roof) are integrated in the parallelized work groups. The work positions along the automobile body are not always all blocked by operators performing assembly on the four bodies exposed for assembly work. Time representing the work on one body is free and floating around as an internal buffer to absorb the variation in work pace of one operator or the interaction of many, thus eliminating waiting time and maximizing production output.

All these characteristics lead to improved organic flow pattern efficiency and a smoother material flow and are a preconditions for the autonomy necessary for humanization of the work. The full-scale example of this type of production system is the Volvo Uddevalla final assembly plant.

	Total manpower required for a;		
	(1) Swedish serial flow pattern (hour)	(2) theoretical serial flow pattern (hour)	(3) theoretical paral-lel flow pattern (hour)
A Automobile requiring six hours "necessary work"	15	8	6,5
B Automobile requiring four hours "necessary work"	10	5,5	4,5

Figure 4. Example of the "necessary work", in manual assembly, which means the work time required for one ideal operator to carry out all the work (Wild 1975). The table above clearly indicates that greater efficiency (man-hours per automobile) will be achieved by manufacturing an automobile with a considerable amount of "necessary work" (i.e. a Swedish automobile) in a final assembly plant with parallel flow, than by manufacturing one requiring lower assembly hours (i.e. a Japanese automobile). Note the obvious fact that, the less assembly work is required the better the product design needs to be – a fact that in most cases implies a large production volume. Or put another way, in the case of a fixed product design with relatively much "necessary work", a parallel flow pattern is more favourable.

3 Product structures and product perception

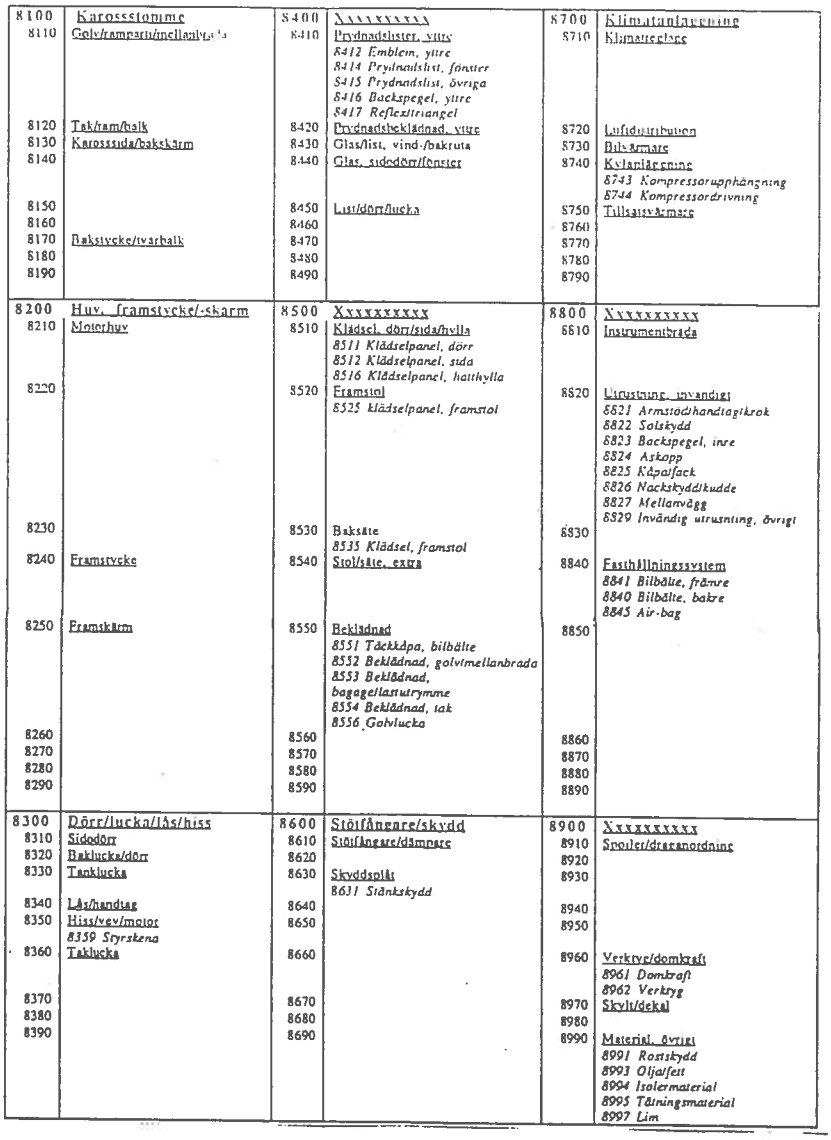
The existing product structures generally used by the Swedish motor vehicle industry consist of market-oriented product codes and of design-oriented material control codes. Previously, there were no structures based on assembly similarity, and hence relevant to long cycle time assembly either for complete vehicles or parts there of.

2 000	3 000	4 000	5 000	6 000	7 000	8 000
2 100	3 100	4 100	5 100	6 100	7 100	8 100
2 200	3 200		5 200		7 200	8 200
2 300	3 300	4 300				8 300
2 400	3 400			6 400		8 400
2 500	3 500	4 500	5 500			8 500
2 600	3 600	4 600		6 500	7 600	8 600
2 700	3 700				7 700	8 700
	3 800					8 800
	3 900		5 900			8 900

Figure 5. The highest levels of a general function group hierarchy used for an automobile; 2 000 Engine and equipment, 3 000 Electric power supply and instruments; 4 000 Power transmission; 5 000 Brakes; 6 000 Wheel suspension and steering; 7 000 Frame, springs, damping and wheels; 8 000 Body, cab and upholstery. In practice, the formal description of, for example, an automobile is far more complex, including part number, variant families, variant designations, market-oriented product numbers, etc. If one only uses the function group hierarchy, for describing an automobile, this will initiate an unnecessaryly complex product perception, because the hierarchy is not coherent. Underlined figures means that these levels are omitted in the register but that they have components at lower levels. Blank positions indicate excluded component. There are no existing automobile components in the general function groups.

It is important to note that the existing product structures used by the Swedish motor vehicle industry lead to erroneous conclusions applied to long cycle time assembly, due to inadequate perceptions of the products and the work. This imposes restrictions on the development of parallel flow, long cycle time assembly, since the product was perceived to be far too complex and containing too many components for any adequate materials feeding technique to be used.

One of the bases for the long cycle time assembly work was therefore a reclassification of the products' components from the assembly point of view. It is hereby possible to revise the perception of the product. This reclassification allows the description of wholes, producing assembly oriented product structures serving the foundation for work design and materials feeding well as generating the needed suitable data for layout planning (Engström and Medbo 1992).



8100	Karosstomme	8400	Xxxxxxxxxx	8700	Klimatanläggning
8110	Golv/ramparti/mellanbräda	8410	Prydnadslister, yttre *8412 Emblem, yttre* *8414 Prydnadslist, fönster* *8415 Prydnadslist, övriga* *8416 Backspegel, yttre* *8417 Reflextriangel*	8710	Klimatreglage
8120	Tak/ram/balk	8420	Prydnadsbeklädnad, yttre	8720	Luftdistribution
8130	Karossida/bakskärm	8430	Glas/list, vind-/bakruta	8730	Bilvärmare
8140		8440	Glas, sidodörr/fönster	8740	Kylanläggning *8743 Kompressorupphängning* *8744 Kompressordrivning*
8150		8450	List/dörr/lucka	8750	Tillsatsvärmare
8160		8460		8760	
8170	Bakstycke/tvärbalk	8470		8770	
8180		8480		8780	
8190		8490		8790	
8200	Huv, framstycke/-skärm	8500	Xxxxxxxxxx	8800	Xxxxxxxxxx
8210	Motorhuv	8510	Klädsel, dörr/sida/hylla *8511 Klädselpanel, dörr* *8512 Klädselpanel, sida* *8516 Klädselpanel, hatthylla*	8810	Instrumentbräda
8220		8520	Framstol *8525 klädselpanel, framstol*	8820	Utrustning, invändigt *8821 Armstöd/handtag/krok* *8822 Solskydd* *8823 Backspegel, inre* *8824 Askopp* *8825 Kåpa/fack* *8826 Nackskydd/kudde* *8827 Mellanvägg* *8829 Invändig utrustning, övrigt*
8230		8530	Baksäte *8535 Klädsel, framstol*	8830	
8240	Framstycke	8540	Stol/säte, extra	8840	Fasthållningssystem *8841 Bilbälte, främre* *8840 Bilbälte, bakre* *8845 Air-bag*
8250	Framskärm	8550	Beklädnad *8551 Täckkåpa, bilbälte* *8552 Beklädnad, golv/mellanbrada* *8553 Beklädnad, bagage/lastutrymme* *8554 Beklädnad, tak* *8556 Golvlucka*	8850	
8260		8560		8860	
8270		8570		8870	
8280		8580		8880	
8290		8590		8890	
8300	Dörr/lucka/lås/hiss	8600	Stötfångare/skydd	8900	Xxxxxxxxxx
8310	Sidodörr	8610	Stötfångare/dämpare	8910	Spoiler/draganordning
8320	Baklucka/dörr	8620		8920	
8330	Tanklucka	8630	Skyddsplåt *8631 Stänkskydd*	8930	
8340	Lås/handtag	8640		8940	
8350	Hiss/vev/motor *8359 Styrskena*	8650		8950	
8360	Taklucka	8660		8960	Verktyg/domkraft *8961 Domkraft* *8962 Verktyg*
8370		8670		8970	Skylt/dekal
8380		8680		8980	
8390		8690		8990	Material, övrigt *8991 Rostskydd* *8993 Olja/fett* *8994 Isolermaterial* *8995 Tätningsmaterial* *8997 Lim*

Figure 6. All the levels in the function group hierarchy 8 000 (body, cab and upholstery). This is were most of the automobile's components are concentrated. It is also the most non-coherent sub-hierarchy as illustrated above. There are illogical empty spaces and components with out comprehensive higher levels. "Xxxxxxx" in the figure means that these levels are verbaly omitted in the register but that they do have components at lower levels.

Abowe, we schematically illustrate the function groups, a standard used by most Swedish vehicle manufacturers, for describing vehicles in general. If one describes the final assembly of an automobile, part of the hierarchy will disappear, since it is not relevant. In serie production of automobiles and trucks, the function groups are an integrated part of the materials control codes used for identifying components and administering the total materials supply systems.

4 The principle of so-called assembly variants

In this approach, the basic idea of is that different product variants belonging to the same category ("assembly variant") will be interchangeable in the assembly process, because they have certain characteristics in common (Engström and Medbo 1992). By using assembly variants it becomes possible to perform the planning and scheduling of production systems with highly parallel material flows in a more efficient way than the traditional methods allow.

For example, it is possible in parallelized flow assembly both to achieve the necessary autonomy between different activities in the production flow, i.e. various departments and work groups, and to better utilise the buffer volumes. The materials preparation stores, which prepare and supply kits containing components for each individual object to parallel work groups, can thereby control their own processes due to better buffer control through multi-level planning (using both the traditional product codes and the new non-traditional assembly variants, choosing the correct characterization at the right phase in the production flow).

Assembly variants are based on three principal categorisation criteria;
(1) competence requirements, (2) assembly time requirements and (3) tool and equipment needs.

There may be further criteria, related to specific production systems (for example, low frequency variants), and also when the concept is applied outside the chosen production system (for example, external logistics).

To obtain assembly variants, the differences between products are grouped into four levels, differences that; (1) do not require different assembly work, but different components, (2) require only marginally different assembly work with relatively obvious differences regarding assembly, (3) it has been decided, by agreement, that all operators must be able to manage, both in respect of knowledge and equipment and (4) are critically dependent on competence, assembly time or equipment. The latter category forms the different assembly variants.

When a selection of products in a given production program is divided into assembly variants, the individual products will be categorized into clusters of product variants between, at the one extreme one assembly variant (one unique product) and, at the other extreme, the most common assembly variants (the most frequent products). The number of different assembly variants is considerably smaller than indicated by the present design-oriented codes. When the actual frequencies of different assembly variants are known, it is possible to optimize the material flow in a parallelized production system.

From the point of view of final assembly, the effects of using assembly variant as an identity concept can be summarized; (1) a tool is provided for the operators to be able to plan and communicate the production scheduling in an appropriate way, (2) greater technical and administrative autonomy between different stages in the production chain is created, (3) simplification of re-ordering and interchanging of individual objects between and within different phases in the production flow and (4) easier handling of sequence demands for ordering and replanning the different product variants. There is therefore less need for detailed centralized production planning in highly parallelized production systems.

The number of individual objects in the production plan decreased in our cases by more than 95 % when assembly variants were used. In practice, it has proved sufficient to consider only about 20 different assembly variants representing as many as 1 000 different traditional market and design variants.

Greater freedom is obtained through the assembly variants being used for product identity in production planning without compromising the precision demands on the centralized planning.

This means that; (1) there is less need for replanning in the materials preparation and assembly workshops, (2) the actual materials consumption sequence is in better agreement with the planned sequence, leading to less buffering and better JIT efficiency, (3) a centralized materials preparation store is not affected negatively if a parallel work group does not follow in detail a previously determined production plan and (4) delivery times of completed automobiles are in better agreement with the production plan for the total plant.

5 Consequences and implications of implementing the principles and findings

Our development, research work and practical experience from full-scale production have justified an economically advisable cycle time of a minimum of two hours. In some full-scale cases pairs of operators single-handedly manufactured complete automobiles, at almost net assembly times, accomplishing more than twice the productivity of the traditional assembly line with its serial flow. Through our observations, interviews and video recordings in one of the cases, we found that the performance of the work groups exceeded that calculated by the production engineers by 14 - 16%.

1/4 of an automobile	1/2 of an automobile	3/4 of an automobile	1/1 of an automobile
66 % of the assembly operators	24% of the assembly operators	6% of the assembly operators	4% of the assembly operators

Figure 7. The officially reported (related to personnel statistics) competence in one of the cases studied. The practicable minimum assembly competence is 1/4 of an automobile, though modules of 1/7 full pace work are included in the education program.

One ought to strive for an exchange process during the running-in and full-scale production, where operators exchange collective improvements (productivity, quality, rationalisation, etc) for increased autonomy. In fact, the Volvo Uddevalla final assembly plant for example did not in practice achieve this design criterion, due to the fact that they did not apply the assembly variant principles, although these principles were to be introduced just before the decision to close down the plant was taken.

To summarise, in the Volvo experience (mainly the Uddevalla plant and some corresponding project less well known at the Volvo Truck Company), the technical development and implementation of non-traditional flow patterns, advanced materials feeding techniques (Johansson 1990, 1991) and assembly-oriented product descriptions create new preconditions for the assembly work itself, as well as for efficiency, which can be fully explained by an established and partly newly developed theoretical framework, practiced by us for the design of the technical and administrative preconditions. This framework is only briefly described in this paper.

To conclude, there does not necessarily need to be a contradiction between humanization and efficiency. This is in fact in contradiction with the general assumption in Sweden that new qualifications are to be developed through organisational changes regarded as limited social processes articulated as for example, learning programs disconnected from technical aspects.

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