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Principles of Perception and Structuring of Long Cycle Time Assembly Work:

Tomas Engström[ac], Dan Jonsson[bc]

[a]Department of Transportation and Logistics, Chalmers University of Technology, 412 96 Gothenburg. Swden

[b]Department of Sociology, University of Gothenburg, 411 22 Gothenburg. Sweden

[c]Gothenburg Center for Work Science 412 88 Gothenburg Sweden

Abstract:
This paper reports on theoretical and practical references for achieving suitable conditions for long cycle time assembly work. The principles descried have used in the design of several Swedish assembly plants during the last five years, mainly in the Volvo Company.

We report on the implications of work structuring principles on product design, materials handling and assembly work and how to reform the perception of product and work based on generic product characteristics present in almost all vehicles, thus making the principle general.

1 The implications of work structuring principles on product design, materials handling and assembly work

One of the basic principles in long cycle time assembly work is that there must be congruence between how the work is carried out, how the materials are displayed and how the work is performed. One consequence of this congruence is that the assembly work is simultaneously supported by (1) the materials as displayed as well as by (2) documentation of the components and the assembly tasks and (3) the "mental maps" that the operator activates during the assembly work (Engström and Medbo 1990).

This congruence makes it possible for the operator performing assembly work to decide whether the wrong materials has been supplied, or whether the administrative support, in form of for example work instructions, is inaccurate or whether the operator himself is uncertain about how to carry out the work. It is not necessary of test-fit components in order to be sure which one of these three problems that occurred. The consequential risk of being forced to dismantle test-fitted components is then eliminated, reducing the need for extra personnel to inspect and adjust products.

The aim is to create technical and administrative preconditions which allow the operators to perform inspection and adjustments themselves in order to thereby maintain product quality and the quantitative planning of production volume. The knowledge developed must then be transferred into routines and documents which facilitate an expanded assembly work which includes other types of work than just the pure assembly work.

The general principle is that an extended cycle time implies the need to prestructure the information and materials to facilitate the assembly work. This prestructuring calls for non-traditional materials feeding techniques (materials being supplied as kits for individuals automobiles) combined with advanced information systems (relying on precise verbal networks as a complement to traditional part numbers and variant codifications).

The complete product constitutes a whole that should form the basis for work structuring. The product is described in detail in the design phase and the long cycle time assembly work itself may be said to verify the prestructuring of information and materials. This prestructuring constitutes an advantage that is unfortunately seldom exploited in the Swedish automotive industry.

In the now defunct Volvo Uddevalla final assembly plant and the Volvo Ghent plant, it has however proved advantageous to prestructure information and materials before the assembly work is initiated, using information from the design phase. As a consequence, it has proved practically and economically viable in Uddevalla to extend cycle times to 1/4 – 1/1 of an automobile. The training, correctly performed, does not necessarily require more than 1–3 months of experience to reach 1/4 automobile competence. Admittedly, the training methods used in Uddevalla did not strictly follows the principles we advocate. This is a problem area of importance but not in focus in this paper.

Note that short work cycles and line assembly tend to generate fragmented, meaningless work tasks, so that short work cycles and traditional assembly principles are in a sense an impediment to rather than a pre-condition for fast learning, contrary to the classical theory.

2 Holistic learning long cycle time assembly work calls for a reformed perception of product and work

Our experience from concrete processes of change in industry confirms that there is another kind of learning than that made use of in conventional line assembly and which has formed the basis for traditional learning curves, namely "atomistic learning". Such learning can, for example, mean that the focus is primarily on the text itself, in order to be able to reproduce the words of the text. This is related to an atomistic approach; the individual does not see the parts as having any clear interrelation. In "holistic learning", on the other hand, the individual focuses on the message or idea being communicated. Such an individual is said to have a holistic approach, i.e. he regards the learning material as a whole in which the parts are seen in relation to this whole.

Holistic learning of assembly work requires the product to be grasped as a structured whole, since the assembly work itself derives from the product. This is similar to phenomena stressed in Gestalt Psychology.

Even the simplest experience is organised by the perceivers, and the perceived characteristics of any part are function of the whole to which it appears to belong, as visually illustrated in Figure 1.

Figure 1. Experience tends to be organised into whole, continuous figures. If the stimulus pattern is incomplete. the perceiver tends to fill in the missing element. For example the figure shows a dog, not twenty discrete blotches (Berelson and Steiner 1964).

The product as a structured whole

To reform the perception of the product, we dismantled automobiles and placed their components on the floor of an experimental workshop. The components were arranged so that components which in some way belonged together were placed adjacent to one another.

The grouping relied on principles analogous to Gestalt psychology principles about "good figures". According to these principles, experience is organised into wholes on the basis of criteria such as proximity, similarity and continuity.

As a consequence, when wholes are perceptually divided into parts the lines of division are drawn so that the resultant parts constitute "good figures", as visually illustrated in Figure 2.

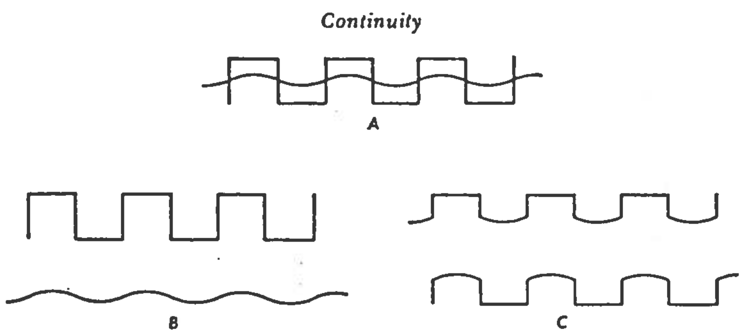

Figure 2. A appears as composed of elements in B rather than of those in C. The straight lines and arcs are grouped to produce the greater continuity (Berelson and Steiner 1964).

Similarly, the subsystem of leads and valves in a truck, for example, may be perceived as being composed of (1) electrical leads, (2) oil leads, (3) air leads, (4) tube and clamping and (5) valves.

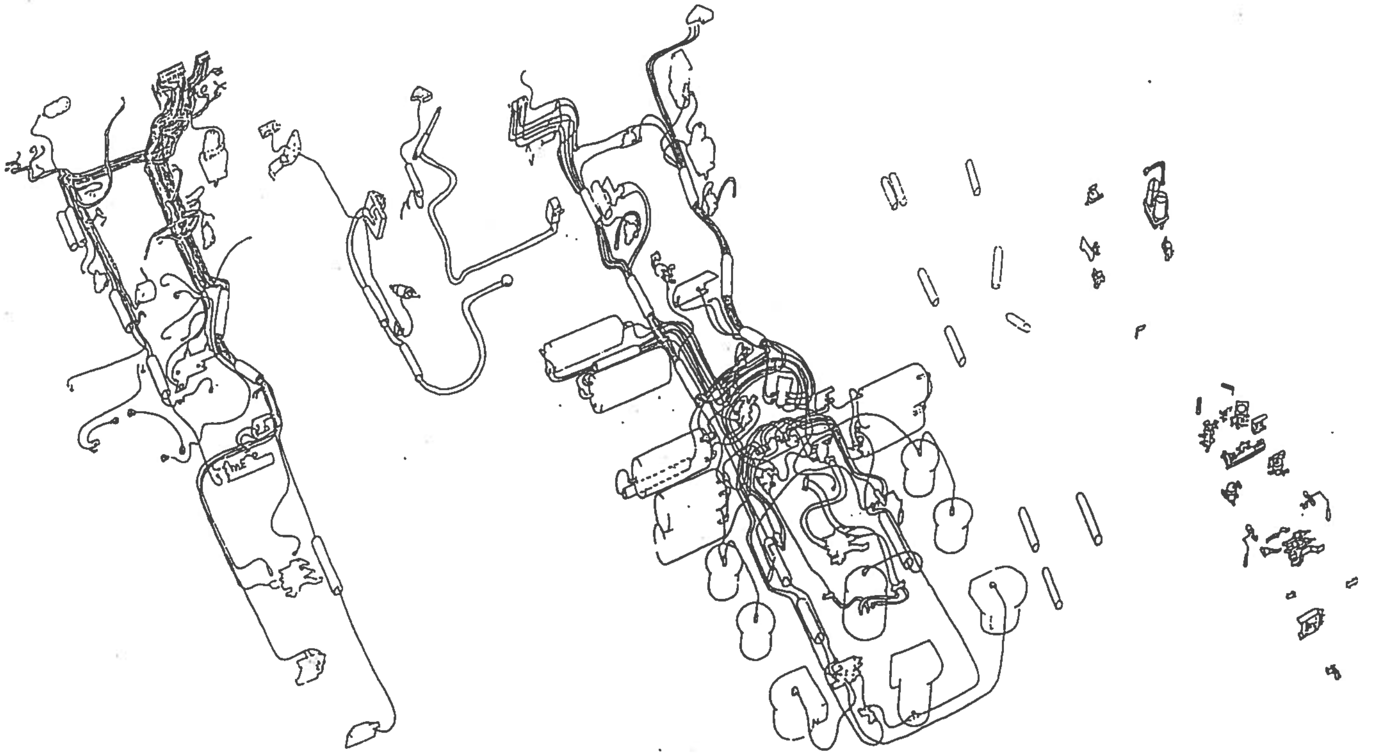

Figure 3. Truck components, from left to right: electrical leads, oil leads, air leads, tubes and clamping and valves. Note that components not included are visualised as "transparent", only the contours of these components are outlined. The truck are viewed from above and behind. The components are normalised, drawn against a transparent outline of a truck.[1]

An additional point of departure was the necessity to divide the work in such a way that a work group could build at least a quarter of a automobile (the logic in the automobile only became clear at the 1/4 automobile level). The main so-called final assembly functional groups were (apart from doors): (1) leads for electric's, air and water, (2) "drive line", (3) sealings and decor and (4) interior.

This grouping formed the basis for an assembly oriented product structure needed for organising the materials feeding and administrative work at the Uddevalla final assembly plant, and supporting the long cycle time work within the context of the materials feeding techniques (kitting fixtures containing components for one automobile), the layout (stationary assembly work where one group manufactures complete automobiles) and the information system (multi-level work instructions using component names as a complement to the part number and specially designed variant specifications describing the automobiles according to the product characteristics in final assembly).

We aimed to group the components hierarchically so that the groups (both individually and in interrelation) form contexts and are distinguishable from each other. If the interior is to be assembled, this is clear not from one single component, but from the individual components being related to a group that has been assigned a descriptive Swedish name.

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1 The illustration shown has been used for work structuring at the Volvo truck factory at Tuve in Gothenburg. In this plant, work groups of twelve operators assemble complete trucks, achieving a productivity superior to that of the assembly line in the same plant.

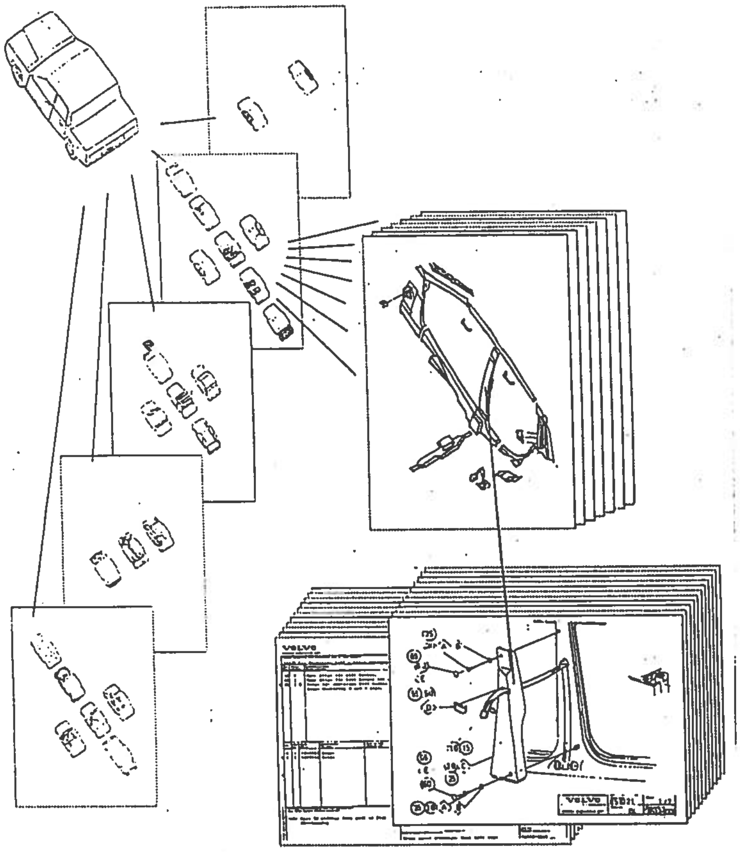


Figure 4. An assembly oriented product structure, i.e. distinguishable groups of components, the so-called final assembly functional groups.

The assembly work as a structured whole

If the assembly work is to be perceived as a structured whole deriving from the product as a structured whole, two questions are raised:

> (1) How do you find interrelations between the naked automobile body with no components fitted and the complete running automobile? The assembly work is performed in between these extremes.
> (2) How do you maintain the surveyability of the total assembly work, which contains numerous tools, components and co-workers, and still master the detailed information about single components and their specific requirements with respect to torque, tolerances, etc?

In traditional line assembly, the importance of maximising productivity through securing that the operators do not have any slack during the cycle time is emphasised. This method leads to the erroneous conclusion that the learning of assembly work should aim at the internalisation of the single best assembly sequence.

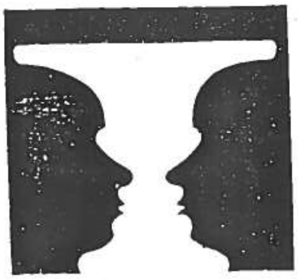
Note that to simply describe the assembly work on the basis of the assembly sequence creates no overview and moreover demands an infinite number of work descriptions, since different product variants require different assembly sequences, and assembly sequences must also be adapted to production plans.

A correct work structuring produces a cascade of interrelated methods for different individuals, naturally having quite different qualifications, and serves as a starting point for the untrained operator to gain a holistic perception.

Long cycle time assembly work is guided by a chain of associations, where the fitting of one component successively generates the choice of the next. The individual operator's assembly sequence forms a track of work tasks through the automobile and the work group's collective work pattern.

For the untrained operator performing long cycle time assembly work, the larger components "call for" the small ones. For the more trained operator, in contrast, the small components claim the larger ones. The most trained operators gain a dual-perception capability, being able to instantaneously switch between different perceptions.

This is analogous to the so-called "figure-ground" effect explored in Gestalt psychology. Briefly, one region of the perceptual field tends to stand out as "figure", while the complementary region is perceived as "ground". The roles of "figure" and "ground" can however be reversed (cf. Figure 4). For the untrained operator, the larger components constitute the "figure" in virtue of their conspiciousness, while the smaller components constitute the "ground".



For the more experienced operator, by contrast, the smaller components constitute the "figure" in virtue of the large amount of information about the assembly work that they represent, while the larger components now constitute the "ground". The most advanced operators, finally, are able to switch between these perceptions at will.

Figure 5. Dual perception illustrated by using the Peter-Paul goblet used to illustrated the "figure-ground effect" (Berelson and Steiner 1964).

Conclusions

To conclude, the principle we advocate for long cycle time assembly work structuring, is that the starting point must be a hierarchical taxonomy of product constituents, i.e. some kind of predefined classification, conveying an overview of the product and indicating the interrelationships between the components. This structure not only facilitates the learning of assembly but also serves as the base for materials feeding and production techniques, securing an implicit structuring of work and work environment on the shop floor (Engström and Medbo 1990).

Expressed in other terms, assembly work for one or several operators consists of flexible routes, i.e. components in sequence, through the hierarchical structure. An overview and structure must be created which do not change over time or between products but which at the same time allows the operator together with his colleagues to make decisions regarding work pace and how the work is to be done.[2]

The work structuring has the effect that operators becomes the owners of a verbal and visual network connected to the work. It is then possible to handle the predictable and also the unpredictable aspects of the work.

3 Generic product characteristics

To make the work structuring principle generally applicable (for all types of vehicles) the inherent generic characteristics, i.e. some sort of features or aspects always present in the product, have to be identified. There are at least five such characteristics (Engström 1991):

1 "Similarity to the human body", i.e. components are symmetrically placed along the centre line. Smaller components appear in pair relationships along this centre line and are either reversed (cannot be confused since they will not fit in the assembly) or identical (and can be confused).
2 "Functions", i.e. the components fitted included form specific subsystems. For example air-condition system, anti-brake-system, etc.
3 "Plus/minus relationship" between different product variants, i.e. if one automobile do not have a manual gearbox. it ought to be fitted with a automatic one.

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2 An autonomous work group performing long cycle time work does not eliminate the need for traditional production technique methods like time-and-motions studies. Such tools are of equal importance in long cycle time assembly work, but they should be used by the most knowledgeable, the shop floor work force. Contrary to what has been suggested in the international debate (Adler 1993) shop floor use of time-and-motion analysis is not an exclusive feature of "lean production" plants such as GM's and Toyota's join venture NUMMI. The difference between the two production concepts has more to do with the fact that the principles discussed here (in no way to be identified with what on international arena is labelled the "Swedish model") does not call for standardisation of operators and products.

4 "Generativity", i.e. those components which have been assembled or are to be assembled say something about the expected identity of a specific automobile. The degree of generativity ranges from single components and sub-assemblies not having any characteristics which makes it possible to the materials already fitted or to the materials kitted but not yet fitted to components having obvious interrelations to the product and materials.

5 "Diagonal symmetry", i.e. components shift through turning around the diagonals if the product is viewed from above. If for example a left-hand drive automobile is transformed into a right-handed, the steering wheel and instrument are shifted to right but the exhaust system and carburettor end intake manifold are intact.

The work structuring methods for long cycle time assembly works implies a shift from a focus on flow variables, explicit at the traditional line assembly, to implicit product variables.

These variables are possible to identify in form of generic product characteristics, although they may remain implicit for the non-expert or occasional visitor.

	Assembly work derived from product	Assembly work derived from flow:
Point of departure:	- Generic product characteristics	- Contingent flow characteristics
Layout:	- Stationary assembly of complete products	- Line assembly
Organisation of materials:	- Kits of materials for individuals products	- Material containers at the work stations containing components for many products
Organisation of information:	- Predefined assembly oriented product structure (easy to grasp)	- Sequential (difficult to grasp)
	Leading to	
Corresponding form of learning:	- Holistic learning	- Atomistic learning

Figure 6. Holistic learning, in long cycle time assembly work, implies that the product are transformed into process characteristics. This transformation calls for a assembly oriented product structure, new materials feeding techniques and layouts.

This also explains why earlier attempts to extend the work cycle time has failed. If no structures adequate for holistic learning are initially present, the operator may be able to create temporarily suitable structures for his or her own use, also this would require some intellectual strain. There is no guarantee, however, that such ad-hoc structures are general and communicable nor that they can be transformed into routines and documents.

4 Concluding remarks

As indicated above production systems using parallellized flow and long cycle time of for example automobiles do require kitting of materials, to create a congruence between work, materials and work instructions.

In practice the materials kit also fulfils functions like serving as an instrument for overviewing the assembly time as well as a work instruction.

Materials supply systems and product flow patterns, previously regarded as critical restrictions in efficient learning, as required in efficient long cycle time vehicle assembly, have now been resolved. Our recent findings indicate that it is the size of work teams and intra-team work patterns that are critical.

As Entwistle (1986) points out, the learning process and the complex social context in which individual learning takes place are critical factors. Chaffin (1966) similarly points out that the motivation of the individual to achieve proficiency quickly is an important factor in the learning process. It is our decided opinion that one of the most interesting research fields in industrial work in the future in order to further develop knowledge of learning will concern incentive structures and their interaction with work organisation and technology.

Our experiences from the Volvo Uddevalla plant shows that Entwistle's point is valid, and it is important to distinguish between individual and collective working. The training program and the incentive structures in Uddevalla were focused on individual training, and were not fully in accordance to principles we advocate here. The official training program seemed to require unnecessarily long time, fourteen months to gain 1/4 automobile competence.[3]

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3 Some work groups from the materials preparation store, where materials are prestructured by picking and loading into fixtures containing boxes and parcels of components, were able to reach 75% of full pace of assembly work in 2 – 3 weeks, because they had a collective training before learning the assembly work, as well as a detailed knowledge about the components.

During our research and development work in the Swedish automotive industry we have in some cases noted the so-called "Sörgårds-effect". This means that the more trained workers are neglecting the learning aids they previously used. In some cases they even scrapped the aids (in this case large wall charts containing exploded drawing and small components sewn to the charts).