Introduction

The persistent decline in sales at the beginning of the 1990s had forced Volvo to reduce its capacity by ceasing production in its two smallest assembly factories in Sweden: Kalmar and Uddevalla. Economic recovery in the American market and growth in demand for coupes and convertibles enable Volvo and the British firm TWR (Tom Walkinshaw Racing), in a joint venture Autonova, to re-open the Uddevalla plant in April 1997 (Boyer, Charron and Freyssenet, 1996; Ellegård, 1997b). Both a welding and paint workshop were also added to it. This decision thus puts an end to any questions raised about the real reasons for the closure (Sandberg, 1995). Many people had looked upon the closure as a rejection of the Swedish work reform method because of the competitive edge of Japanese firms and the superiority of their system. In fact, the Uddevalla plant's particularity lay in the fact that it had completely given up using a moving assembly line system, whereas the Kalmar plant maintained it by using AGV (automated guided vehicles). Vehicles at Uddevalla were assembled entirely in parallel stations, by two or four workers belonging to nine-man work teams (Ellegård, Engström and Nilsson, 1990). This article is a modified version of another article: “La production réflexive, une alternative à la production de masse et à la production au plus juste?” published in the French review, *Sociologie du travail*, 3/95, Paris.

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GERPISA is an international network of researchers studying the automotive industry. Its firts international program (1993-6) was about ‘The Emergence of New Industrial Models’. The results are in the process of being published. The second programme (1997-9) is about ‘The Automobile Industry Between Globalization and Regionalization’, GERPISA, Université d'Evry, Boulevard des Coquibus, 91000 Evry, France. E-Mail: contact@gerpisa.univ-evry.fr. GERPISA’s server: http://www.gerpisa.univ-evry.fr.

However, both carmakers and researchers are pursuing the debate relative to the pertinence and the future of assembly methods used in Uddevalla (Ellegård, Engström, Johanson, Nilsson and Medbo, 1992; Berggren, 1992, 1993; Adler and Cole, 1993 a, b; Freyssenet, 1994a; Sandberg, 1995; Shimokawa, Jurgens and Fujimoto, 1997). Three major points are being debated: the very nature of the system (neo-craftsmanship or radical innovation?), Uddevalla plant performance, the possibilities of using the organization principles in other sectors besides the assembly sector, for example in the automated workshops and in the domain of large volumes. It appears that little headway is being made in this debate due to the fact that the system is not understood well enough and that people have been attempting to compare the physical production of the different plants. In this article, we would like to call to mind the social and economic limits of ‘mass production’ and to analyse both the solutions and limits of ‘lean production’ and ‘reflective production’, the former being the name given to the Toyota system and the latter, the name the designers of the Uddevalla plant gave to their organization. Our analysis is the result of an investigation carried out at Uddevalla before the plant was closed down, involving the designers as well as some workshop assembly workers (Charron and Freyssenet, 1994. A detailed presentation of the plant, its history and organization may be found in Ellegård, 1989), and of a study we did on the evolution of the Toyota production system for GERPISA’s international programme (Shimizu 1993, 1995a; Freyssenet 1993, 1995).

1. Practical obstacles that would render moving assembly line work inevitable

It was widely considered unlikely that a production and work organization system which, at a first glance, seemed unsophisticated, could be as effective, if not even more effective than productive organizations based on principles of ‘deconstructing’ and subsequently ‘reconstructing’ work with a view to saving time (additivity) and moving lines (fluidity). Since the first quarter of this century the application of these principles has allowed for considerable savings of capital, materials and labour. Moreover, for practical reasons additivity and fluidity seem to be unavoidable principles today. Indeed, has it not been demonstrated that operators are incapable of memorizing and carrying out more than a limited number of operations in an efficient way? It also seems difficult to imagine having to create a complete materials store in each workshop, and being required to adjust tools for each new operation. In addition, the Toyota system was able to efficiently adapt additivity and fluidity principles which were initially conceived for uniform mass production carried out by unskilled workers, to a changing and diversified production carried out by qualified workers who actively involved themselves in their work.

It seems difficult to understand how it could be possible to memorise numerous, varied, and variable operations considering how often assembly line workers make mistakes when carrying out a maximum of five to ten operations, while the complete assembly of a Volvo 940 involves more than 600 parts references, each requiring several more varied operations than those needed for lower or mid-range models. And yet, the Uddevalla plant assembly workers did not need to constantly refer back to a list of operations that they had to carry out. Neither did they have to follow a rigid order for assembly. It did not take more than four months to train to assemble a quarter of a vehicle, and by then they had learned how to assemble a new version of the vehicle in two days.
The designers of the reflective production system stress the fact that memorisation became unnecessarily difficult and has to be limited in assembly line work (Ellegård, Engström and Nilsson, 1990; Ellegård, Engström, Johanson, Nilsson and Medbo, 1992, 1994; Ellegård 1995; Engström and Medbo, 1995; Nilsson, 1995). Parts are initially designated by numerical codes and not by words which give them a meaning. Next, and above all, the order in which they must be placed on the sub-unit or vehicle does not reflect the intelligible logic of the product's structure and functioning. The operations which have to be carried out are not linked to each other, because they are distributed among work stations according to the time needed for them to be carried out and the chosen work time cycle which must neither exceed the sum total of time for elementary operations nor be used below its capacity. The structure and functioning of the vehicle and its components, as well as their numerous variants, are concealed by the existing technical and administrative system.

In order to give a new meaning to work and encourage the expression of workers' intelligence, thereby motivating them to a higher degree, the Toyotist solution consisted in attempting to have workers internalize the very principles of time saving and just in time by having them implement them themselves. Along with their team leaders, Toyota workers had the responsibility of balancing the work operations among the assembly line stations, and of using as completely as possible the work time cycle at each model, or vehicle version's daily production volume change. To encourage them to accomplish this, wage and promotion were linked to their capacity to reduce standard time. It therefore became possible over a period of several decades to achieve assembly line polyvalence and a rhythm of change and production diversification which astounded European and North American carmakers. Work had not, however, changed in nature. Today, Japanese carmakers admit that young people are refusing this method. At the end of the 1980s, the Toyotist model came up against social, political, and productive limits which forced Toyota management to turn to European experiences, particularly the Swedish one, in order to render work in their plants more socially acceptable (Shimizu, 1995a, 1995b; Grönning, 1995).

The method the Swedes were using during the 1970s was quite the opposite. Instead of relentlessly pursuing the logic of additivity and fluidity principles, the Swedes loosened their grip on line and time cycles by dividing up the line and increasing time cycles as had been done at Volvo's Kalmar plant. Even though this produced interesting economic results, it was still disappointing from the worker's standpoint (Aguren, Breddbacka, Hansson, Ihregren and Karlsson, 1985; Auer and Riegler, 1990; Sandberg, 1995). As in the Toyota case, the very nature of work was indeed unchanged. Uddevalla's radical novelty lay in the fact that it definitively broke with the principle of 'deconstructing/reconstructing' work, according to theoretical time saving. In order to render assembly work intelligible, it was reorganised according to the logic of the structure and function of the vehicle that was to be assembled. The product thus guided its own assembly and gave workers the opportunity to anticipate in a logical way what parts they had to find and use: hence, the name 'reflective production' given to this work method by its designers (Ellegård, Engström and Nilsson, 1990).

First of all, the division of the vehicle is spatial, and it is based on two perpendicular axes creating a right and a left side, a front and backside, as well as a top and a bottom. Thus, the assembly worker has an initial representation of the vehicle, as if the parts were laid out on the ground according to the two axes, an image facilitated by the vehicle's symmetry. The distribution of parts and sub-units between six kitting fixtures, and...
the way they were presented, reproduced this spatial image. Indeed, the structure of the vehicle could thus be seen by simply looking at the kitting fixtures and their compartments. Then, the parts were organised in ‘kins’ representing larger functions or larger physical entities. The ‘kin’ represents a context and its constraints. Already, the worker logically expected to find within these ‘kins’ a certain number of particular functions and collections of parts belonging to the entity in question. In each kitting fixture, there are several kins. The particular functions to be carried out by, or to be found in these ensembles are assured by interrelated parts which have a given precision and a determined place. Hence, these parts can be classified into ‘families’ defined by their function, the assembly type that they share, and their position in the vehicle. The parts then possess an intelligible identity, capable of being verbally and visually described on ‘maps’, and designated by meaningful words alongside numerical codes. The parts and the families are then arranged according to an incremental growth model terminating in the ‘kin’, giving each element a temporal position within a holistic and organic assembly procedure. This makes it possible to modify the order of operations as long as the structure and coherence of the entity are maintained. Consequently, discrepancy between the way parts are placed on boxes and the assembly procedure allows an erroneous or missing part to be located rapidly.

As the worker passes from working with the ‘dismantled’ image of the vehicle to dealing with elementary parts, he passes from one scale to another with regard to position, description, and designation just as one may alternate between a very large scale map and a small scale map. The way the ‘maps’ are filed forms what could be termed as a ‘geographic assembly atlas’ with which it is possible to go from the whole to the part, and return to the whole in both space and time. Kins, families, and parts may have variations which correspond to the vehicle's variations or to the options available for the model. Therefore, one may find ‘variation paths’ which can lead to certain modifications in the assembly of the entity, or even the vehicle, if the variation is significant. These variations, far from being a supplementary complication and being sometimes very difficult, fulfil a heuristic function. Differences allow workers to understand more easily essential and shared functions accomplished by a part or a family of parts.

As one may note, memorisation has neither the same object nor the same cognitive supports in this type of assembly as in moving assembly lines. Instead of being a separate function, memory is an integral part of the product's intelligence and of what contributes to its quality. The bottom line is that the problem is no longer one of memorising more or less large numbers of operations, but becomes one of learning an assembly process. Thus, the nature of work changes. While remaining within the allocated time according to the type of vehicle, assembly work becomes an activity that allows workers to apprehend the entire product and assembly process. They are allowed to make choices and arbitrate about the order of operations and time necessary to carry out each one, while keeping in mind diverse risks. In this reflective production system the workers are able to recognise quickly and thus efficiently correct their own errors or those of suppliers, because they see in their very own work any interference, incoherence, obstacles, and both their punctual and global consequences for the vehicle. They can take note of adjustments, positioning, and the assembly of parts which were badly designed initially. Their overall view is not narrow or curtailed as is the case for the assembly line worker, whose possible suggestions remain limited in pertinence and are therefore often rejected for this reason.
The supply to assembly line work stations of parts or already assembled small sub-units is provided either by fork-lift truck operators or conveyors, car bodies on which parts are attached which advance along the assembly line. Boxes containing parts come from either a central materials store or sometimes, as in the Toyota example, from the supplier who directly equips workshops by working in synchronisation with them. The solution found at Uddevalla consisted in automatically bringing into each work station from the central materials store (using AGV kitting fixtures), on the one hand the painted car body and on the other hand the parts and mechanical sub-units required for the vehicle's assembly. Following the assembly of a vehicle, the assembly team orders the parts for the next vehicle according to the week's production plan, using for this purpose a computer terminal connected to the plant's computer network. The parts are not placed on kitting fixtures on only purpose to limit congestion as in the case, for example, of a furniture assembly kit. We have noted that their place and presentation according to cognitive principles are essential in order to allow the workers to assemble them. The possibility of a complete assembly by two or four workers is thus included in the act of handling the kitting fixtures (Engström, Jonnson and Medbo, forthcoming).

The plant encountered difficulties precisely at this stage of the fabrication process: such as errors, delays, tension among the assembly workers and relatively long materials handling periods. Volvo management, thinking it was establishing guarantees for itself, and despite disagreement from designers, had wanted materials handling work to be carried out in a classic way, that is to say based on an administrative list of the parts necessary for each vehicle. When faced with supply difficulties, assembly workers went so far as requesting to prepare the kitting fixtures themselves. In the end it was decided to offer the same assembly training to those whose job it was to handle the kitting fixtures as that offered to the assembly workers. A reorganization of the materials workshop according to holistic and heuristic assembly principles was also taking place when the decision to close down was made. The materials workshop had to spatially reproduce the ‘geographic assembly atlas’ and keep the ‘dismantled’ image of the vehicle in mind thus allowing one to immediately find the necessary part since it was logically in the place where one was looking. Finally, the automation of the stocking of parts as in the case of painted car bodies was being studied. This reorganization and these plans are once again being examined in light of the reopening of the plant.

The tuning and adjustment of tools, essentially electrical screwdrivers, is carried out once and for all at the different assembly positions in a Toyotan or Fordian-type plant. In Uddevalla, it was not possible to provide each assembly work station with all the necessary specialised and adjusted tools. Neither was it possible for assembly workers to adjust their tools before each operation. The solution found for electric screwdrivers was to have the assembly worker initiate automatic adjustment at his workbench by removing the appropriate tip necessary for the operation from the screwdriver. Practical obstacles given as a justification for the inevitability of assembly line work were thus avoided at the Uddevalla plant, first of all by using a heuristic presentation of the parts that needed to be assembled and a holistic conception of work, and secondly, by automating the transport of parts, production administration, and mechanical tool adjustment. This type of assembly presupposes that parts do not need to be adjusted. The Uddevallian system shares with the Toyotan and Fordian system the industrial principle that parts must be standardized and interchangeable. Did the Uddevalla assembly model contribute to saving time, thus improving performance, in a way which...
was at least equal to that observed in plants organized according to the principle of the moving assembly line?

2. Assembly time and other performances on the moving assembly line and at parallel work stations

Not long before its shutdown, the number of work-hours per vehicle at Uddevalla had become inferior to that of the Volvo Torslanda plant, where the same vehicle model was also being assembled, in an assembly line 2. This result, which is stressed by defenders of the Uddevalla plant, does not necessarily qualify as proof of the efficiency of the reflective production system. The performances of Torslanda assembly lines can be considered as low when compared to Japanese plants producing the same type of vehicle. According to the study run by IMVP researchers (International Motor Vehicle Program, MIT), differences in productivity appear to be such that it seems as if the reflective production system could never reach the level of plants which function according to principles of ‘lean production’ (Womack et al. 1990) 3.

However, this type of comparison raises too many questions to be thoroughly convincing. The IMVP researchers say they were able to compare assembly plants satisfactorily by proceeding with ‘rectifications’ in order to account for differences between them 4. Nonetheless, the ratio used does raise some questions. The ‘number of working day work-hours per vehicle produced’ indeed presents two shortcomings. By definition, it is very sensitive to the volume produced. However, the produced volume depends first of all on each carmaker’s markets in the year of the study 5, on the success or failure of the model under consideration (independent of all competition in prices and quality), on the moment in the vehicle’s life cycle, on the distribution of production among plants producing the same vehicle, and finally on exchange rates, long before being influenced by productive efficiency. The second problem with this ratio is that it has no

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2 Figures given to us by Uddevalla management were as follows: for January 1993, 35 work-hours per vehicle in Uddevalla, compared to 40 work-hours per vehicle for the same model in Torslanda: the 940 Volvo.

3 The Uddevalla plant did not belong to the sample of assembly plants studied by IMVP team. It began operating in the summer of 1989, the year of the MIT study. Nonetheless, Adler and Cole (1993) calculated a productivity gap of 16.8 work-hours per vehicle between Uddevalla in 1992 and Japanese producers in 1989, by applying the rules of data comparison adopted by the IMVP team.

4 It seems they were able to ‘rectify’ the ratio of ‘work-hours per vehicle’ of the sample plants by compensating with differences in vehicles (models, versions, options...), with accomplished operations (assembly delimitation and ‘integration rate’ of parts...), with categories of labor (full-time/part time permanent workers, part time/seasonal workers, temporary workers, subcontracted workers), with time definitions and the manner of counting time (absenteeism, overtime hours, legal time spans and obligations, plant and firm ‘structure’ time and its apportionment (time not directly linked to production>, training time, specific subcontracting capacity). Results could only be published in an aggregated form relative to Europe, the United States, Japan, and newly-industrialized nations, by origin of capital (American, European, Japanese) and by large categories of cars, due to the requirement of maintaining anonymity of those carmakers who participated in and even financed the study.

5 In 1989, the year of the IMVP study, the Japanese domestic market was undergoing an extraordinary boom that had no historical equivalent in other countries, under the effect of what was called ‘the financial bubble.’ Figures went from 3 million personal vehicles in 1986 (the average since the preceding ten years) to 5 million in 1990. More precisely, between 1988 and 1989, the Japanese market increased by 13.6%, the European market by 5.7%, whereas the American market decreased by 7%.
direct relationship with global performance. A firm may have a number of hours by vehicle which is higher than in other firms and still be globally more profitable if it manages to ‘launch’ its new models more rapidly, if it can adjust its production on demand without delays, if its functioning costs are lower, etc. Reaching a superior global performance could even necessitate a smaller ‘work productivity’ rate (Freyssenet, 1992).

These two shortcomings of the ratio, which obviously change the perspective regarding differences between firms as presented by the MIT team calculations, particularly concern productivity in the Uddevalla plant. At the time when the Uddevalla plant began operating, Volvo sales were decreasing. In addition, the efficiency of the Uddevalla plant lay partly in the other aspects of performance. Finally, the calculation of the ratio itself should consider variables which are specific to Uddevalla, if only the fact that the system was literally in the process of being invented, as demonstrated by the transition from an assembly by 8, then 4, and finally 2 assembly workers, or even the (subsequently regretted) non-application of assembly principles to the materials handling of kitting fixtures and their parts then brought to the parallel assembly stations, which caused production disturbances.

Therefore, the comparison of global assembly times between plants encounters quite a number of difficulties since the variables which need to be considered are numerous and hard to quantify. Hence, controversy is generally never ending, and the debate comparing the value of ‘lean production plants’ and Volvo's Uddevalla plant tends to reach a deadlock. However, we do have some pertinent elements to consider. One of them consists in analysing loss of time and the limits of performance generated by the very structure of the moving assembly line in order to see how ‘lean production’ and ‘reflective production’ try to surpass them.

2.1. Five structural problems in moving assembly lines

Theoretical assembly time corresponds to the sum of time necessary to accomplish micro-movements required by each elementary operation, a sum to which rest time is added. It is obtained from correspondence tables relative to time and motion, without observation. This theoretical time is calculated for the average variant of a model assembled by average workers at the same performances, in just the figure required for a given, stable, daily production without interruption. Of course, reality does not correspond to this. Variants are numerous, and their mix varies from day to day. Workers have different characteristics and competencies, not to mention their differences in age and diverse work rhythms. The number of workers can never correspond to that which is strictly necessary due to absences for various reasons, the necessity to train individuals,

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6 The plant was increasing its production at the very moment when Volvo car sales began to drop: from 400,000 in 1989 to 300,000 in 1991. Its production reached 21,800 vehicles in 1992 for a capacity of 40,000 vehicles per year. This is why, in the end, workshops were not all equipped and why all assembly stations were not used. Yet, the plant was overstaffed. It had 820 workers whereas the maximum had been set at 1,000 workers for 40,000 vehicles.

7 The plant was only four years old when it closed. Only one workshop out of five was equipped for a complete assembly by two workers, an organizational form which turned out to be the most efficient. The firm had defined as its productivity objective not to take more time than the Torslanda assembly line. The final operating months of the plant demonstrated that the assembly workers could, if necessary, do much better.
workload variations, time losses, breakdowns and repairs. Daily production varies according to the product’s life cycle, fluctuations in demand during this cycle, and interruptions inherent to this type of activity such as breakdowns, accidents, meetings, strikes, or supply shortages. A coefficient is introduced to take account of the difference between theoretical calculation and predictable reality. However, this difference can be very big, thus totally undermining the meaning of theoretical assembly time. Indeed, it is not rare for it to sometimes reach 50% of this time. It includes time not used for working, as is the case in all sorts of organizations, such as paid rest periods and trade-union voting time. It is above all made up of lost time whose extent depends on the rigidity or flexibility of the technico-organizational system when faced with different types of unknown factors.

An analysis of real assembly time was carried out by Christophe Midler at the end of the 1970s when he proceeded with an economic comparison of assembly line production and parallel work station production of vehicle sub-parts (Midler, 1980). He then demonstrated that they depended on the fact that it was technically impossible to completely balance out assembly line work stations, and on the different types of disturbances relative to product diversification and absenteeism. At present, we must add to this list a fourth type of disturbance: breakdowns and other incidents which at the time had little importance, seeing as assembling was totally manual but now, with the introduction of automated sections, considerably affect assembly line output.

The assembly line relies on deconstructing of assembly work into elementary operations in order to create work stations having identical space-time. Cessation or succession time at each station, called work time cycle, is equal to 60 minutes divided by hourly production. Constructing of assembly process from elementary operations consists in having time cycles used as completely as possible, at each station. This is called balancing of the assembly line: hence, operations which may have nothing to do with each other are attributed to different stations. However, redistributing operations must respond to other demands which limit the possibilities of an undifferentiated redistribution. Certain operations can be carried out only after others have been accomplished, or else, can only be carried out at certain work stations because they require particular equipment. Hence, the assembly line is divided up into sections, and a graph of previous operations is established for each section. These different sorts of constraints prevent one from achieving a perfect balance. A time cycle cannot be fully used at all work stations. Conversely, it can be insufficient when carrying out indissociable operations. It can also be voluntarily circumvented so as not to create a supplementary work station which would be ‘underworked’. Therefore, a difference exists between time cycle and theoretical operation time at each work station. The sum of these differences, which is always positive, is added to global theoretical time, and constitutes what is called ‘balancing loss’. Assembly line mounting of a unique model, without versions or options (as was the case for some years with Ford’s Model T) allows one, through successive approximation, to discover the right sectioning and to reduce balancing losses to a maximum, however without completely eliminating them. On the other hand, as soon as production becomes diversified on the same assembly line (several options, versions, and models), balancing losses increase dramatically. Thus, long and complex preliminary studies are necessary in order to diminish them.

The originality of the Toyota system in this area consisted in reducing to the maximum balancing losses by having operators and team foremen balance out their work stations themselves, and in using as fully as possible the time cycles. Indeed, operators

are in the best position to know how to improve balancing and to adopt it without delay. However, they must accept to do so. Conditions contributing to this in the Toyota case were based on a particular historical context and a particular wage system (Shimizu, 1993).

The problem of balancing does not exist with parallel assembly work stations. It is not necessary to define an average vehicle. The group of two or four workers who assemble the vehicle share responsibility for completely assembling the vehicle in an allocated time. If a quarter or a half of the car takes longer to assemble, or if an operator is less experienced than his/her co-worker, the other worker can intervene in order to abide by the allocated time. A team which spends a little more time with another variant does not force other teams to imitate their production time nor to find means to make up for idle work times.

As we have just seen, the task of sectioning an assembly line is long and complex. It is carried out at the launch of each vehicle, in other words, at a greater frequency since the 1970s due to the accelerated renewal of models imposed by competition and customer’s demand. Sectioning must also be reactivated at each change in hourly production. The frequency of these changes varies according to demand and to the degree that models and versions are mixed on the assembly lines. Each time, a technician is mobilized for several days. Hence, the length of time needed for re-sectioning prevents one from immediately adapting to demand and thus requires that either too much be produced or delivery deadlines be extended. Each time, operators must learn how to accomplish new operations at their work stations, and learn to do so immediately during the new time cycle. Before this is accomplished, however, their number has to be doubled either by hiring out temporary workers or by using indirect workers. This is a very important moment because what is at stake is the compromise between operators and their supervisors relative to work norms. If, and due to the attitude of operators, the latter is required to maintain certain doubled positions, then assembly time would increase considerably and become a reference for future sectioning (Midler, 1980). If demand for a model or models decreases and if hourly production must be diminished, then temporarily the surplus workforce must be sent to carry out other tasks.

The Toyota system also tried to limit inconveniences inherent to the assembly line in this domain. When a new model is launched in production, foremen and work teams redefine tighter operating times, based on standard, rather slack times which are calculated by technical services. Operators are encouraged to help each other out from station to station. Worker and assembly line polyvalence serves to maintain the same time cycle when demand for a particular model increases or decreases. However, losses in time and supplementary costs due to the assembly line can not be totally eliminated.

With assembling of complete vehicles at parallel stations, the increase of production during the launching of a new model can take place progressively for both the assembly worker and the plant. Negotiation of the production norm can be spread out over a period of time, whereas on the assembly line, it must be decided quite rapidly. Adapting to changes in demand occurs by opening or closing certain work stations, without having to modify the work of operators throughout the entire workshop, as on a moving assembly line. When purchase orders decrease, surplus personnel more skilled can be assigned materials handling, maintenance, or administration tasks more easily and without additional training. When purchase orders increase, transition to a 2x8 hourly shift can occur in some stations. Adjusting to demand can be millimetric, where-as it is large scale on the assembly line.
Diversification of the product is the third cause of differences between theoretical and effective assembly time in the line. A theoretical assembly time is established for an average vehicle. When a car with little equipment rolls up, workers have fewer operations to accomplish. This then results in balancing losses. On the contrary, if a sophisticated car variant rolls up, the time cycle is insufficient to carry out supplementary operations. Either the operators go down the assembly line, and then go up it by trying to make up for time lost with other simpler vehicles. However in order for this to occur, it must be possible to mix variants, which is not always the case because paint or sheet metal workshops have different types of mixing criteria. Either one increases the theoretical operating time in order to handle supplementary operations, or else another worker is called upon to help out when a more complicated vehicle rolls up. But in all cases, balancing losses are incurred. Co-operation between operators within work teams, training them to redistribute tasks among themselves are all ways developed by the Toyotan system in order to attenuate brutal differences in work loads from one vehicle to another. The diversity of the product does not create problems if assembling takes place in a parallel station. A variant which requires more time in order to be assembled does not have an effect on assembly time of simpler vehicles. Allocated time is simply increased for this variant. Thus, operating time can be adjusted to the time which is actually necessary without having to use an average that was never adapted, thus creating tensions.

Apart from the heterogenization of operating times within the same work station analysed by Christophe Midler (1980), product diversification has two other consequences: the time operators spend moving about increases, and errors are more frequent. The number of boxes containing parts increases on borderline, often requiring them to be stacked into three rows. However, the time needed by the operator to move does not contribute an added value when it is counted as part of operating time. Following the Toyota example, carmakers reduce the size of boxes and stocks on borderline, by supplying more frequently work stations and by preparing and inserting sub-units into the lines. At Uddevalla, on each side of their work station, assembly workers have at their disposal only the parts they need for the vehicle they are assembling. Instead of going back and forth to the different boxes to obtain the parts at each cycle as on assembly line, they pick up the parts they need, which are already grouped and take them to where they are working. Errors and negligence in assembly line work due to lack of time for special or highly equipped vehicles, and the difficulty in memorizing specific unrelated and infrequent operations undermine production because of poor quality and repairs to be made. Errors and negligence at parallel stations become apparent to operators either by the existence of remaining parts on racks or by the fact that it is impossible to assemble. They can be immediately corrected by the same operator as he works or by calling the materials store for an immediate exchange. The possible waiting period is not detrimental since the operator can perform other tasks while waiting, whereas on an assembly line, negligence or an error calls for the intervention of at least one additional person.

Variations in the workforce in a classical plant are frequent. At the end of the 1970s, sometimes the real number of workers on the assembly line was less than the theoretical figure in 80% of production days (Midler, 1980). It thus became almost a daily problem for foremen. The solution is to dispose of a reserve workforce working in non-assembly line positions from which they can be easily transferred to assembly line positions which have no workers. The size of this workforce will depend on the number of non-assembly line positions, on the autonomy of possible upstream and downstream stocks,
on their extra capacity relative to average needs, and on the workforce's degree of poly-
valence. Most of the time, it involves positions linked to materials handling, control, or
small repairs and alterations. Hence, the workshop is permanently either under or over-
staffed which also results in a decrease in output. At Toyota, in addition to pressure
levied against absenteeism, work teams in assembly line had to make up for absences
themselves (Shimizu, 1993). In the case of assembling in parallel stations, it is possible
to modify the production volume if all the vehicles of the production project are not
confirmed purchase orders. In addition, the workforce is polyvalent by nature: workers
can go from one team to another without any problem.

Since the introduction of automated sections in assembly lines during the 1980s, the
hazards of fabrication and machine breakdowns have become an important cause of
disturbances in assembly line production. Strictly technical breakdowns which were
detrimental when automated sections were introduced into the assembly line, only rep-
sent a small proportion of interruptions today. On the other hand, errors in placing
parts on sub-units to be automatically assembled contribute to frequent and often long
interruptions due to the fact that automated machines do not tolerate anything that is not
rigorously provided for. In addition, forgetting a part or using a defective part, as well
as positioning a part badly, can no longer be immediately corrected as is the case with
an entirely manual assembly line where operators rectify whatever prevents them from
accomplishing their operations. Such interruptions are even longer due to the fact that
the operator of the automated section is often incapable of discovering the causes be-
cause of the machine's opaqueness. Hence, these interruptions turn out to be even more
undermining since the operator is forced to intervene almost blindly and to execute ma-
noeuvres which often result in the progressive deterioration of the product, machine,
and equipment (Freyssenet, 1992).

Toyota theories for limiting assembly line interruptions are well known. Instead of
intervening rapidly to launch production and thereby postponing the need to treat the
real causes of the problem in depth, long interruptions are recommended to eliminate
the problem, if possible, so that the anomaly or breakdown does not occur again, hence
achieving an regular increase in reliability. This strategy relied on the involvement of
team leaders and workers to detect and treat defects. This was achieved by a wage and
promotion system based on participation with a view to improving productivity, either
within work teams or in ad hoc structures (Shimizu, 1993).

In an initial phase, assembly work teams at Uddevalla experienced problems with by
computerized management of production and errors committed in the materials han-
dling of kitting fixtures. The solution to these problems, previously discussed, was
elaborated as part of the same general cognitive principles inherent to the founding con-
ception of the plant.

As a conclusion to this structural analysis of limits relative to the three production
systems under consideration, it may first be said that differences between theoretical
times and real times are structural in the case of assembly lines, and that their im-
portance is often masked within the workshop. The methods used by Toyota proved to

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8 In his thesis, Christophe Midler (1980) reports that this decrease is sometimes hidden by foremen who
impute supplementary workforce time to training costs in versatility or quality control, or still yet who
hire sub-contracted workers.

9 Koichi Shimizu (1993) demonstrates that Toyota foremen also used subterfuges to avoid an increase in
work load and especially that the ‘productive efficiency coefficient’ of their teams not be too low, reduc-
ing everyone's monthly salary.
be more efficient, nevertheless they did not succeed in totally eradicating the problems. More especially, the current social difficulties of the toyotist model resulted in the re-introduction of buffers on the line and the attribution of autonomy to teams (Shimizu, 1995a).

2.2 The thought process applied to assembly time can be used for other performance aspects

However, we know that these aspects, which are rarely taken into consideration, are more important when evaluating and understanding the global performance of a firm than ratios linked to physical productivity (Berggren, 1992). In order to illustrate this, we will now discuss a few of these aspects.

*The cost of launching a vehicle* in an assembly line plant involves more or less important studies and research depending on the sectioning of positions that the launching necessitates and the degree of atomization desired. It is also an opportunity to modify the process so as to adapt it better to a varied production and, if necessary, to the worker population. With parallel production, apart from the case of introducing new automation, the launching of a car consists in perfecting the equipment, in distributing parts in the workshop, in adapting their presentation on kitting fixtures, and in training workers in differences between old and new models. In addition, this experience is totally cumulative both for reorganization and for the workforce who basically train themselves. It is not necessary to start all over again. It is generally recognized that the first year in the launching of a vehicle is decisive for its profitability. It is estimated that during this year, a client who is not immediately satisfied is a client who then turns to see what the competitor has to offer. Hence the importance of launching the vehicle successfully. However, quite often during this period in a classical plant an increase in production provokes difficulties, and delivery deadlines are not respected. Indeed, any problem that was not anticipated results in a general disturbance for the whole system or requires expensive repairs. Toyota tests its new processes in ‘real life’ until it masters them completely, something that other carmakers are also beginning to do more and more. Nevertheless, certain problems only arise when full-rhythm production is underway. Parallel production does not encounter the same kind of difficulty. Delivery of some vehicles can be delayed due to the fact that some assembly teams do not acquire the necessary skills as quickly as others, but this is not the case for all vehicles.

*Downstream piloting*, which means only producing vehicles ordered by the client and no delays in delivery, represents a dream for all carmakers. The time required for fabricating parts, costs of changing tools, and flow production have forced the car industry to adhere to a long-lasting rigid planning of the vehicles which need to be assembled. A number of Japanese innovations set out to reduce this rigidity inherent to assembly line activity and to lean more towards daily adjustments of the production plan according to the latest purchase orders. However, downstream piloting encounters a structural obstacle: modifying the production order is no longer possible once the vehicle enters the flow. If a modification is necessary (and this often happens), it is not generally due to the client's demand, but on the contrary, due to disturbances occurring within the flow: supply shortages, errors in co-ordination of parts flows, blocked machines, etc. which prevent the firm from respecting delivery deadlines.

Assembly in parallel stations allows one to give priority to definite orders rather than to the production plan. Production for an urgent order can begin as soon as the kitting...
fixtures are handled and according to the availability of necessary parts in the materials shop and the time needed for suppliers to deliver when a part is missing. The kanban is particularly well adapted and applicable to parallel assembly in order to avoid supply shortages and unused supplies. It is possible to interrupt the assembly of certain vehicles (this was done in Uddevalla) in order to assemble others urgently, when it is absolutely imperative to respect delivery dates. Change in production does not last more than two minutes per two persons and other operations are accomplished in parallel time. The vehicle can be delivered within three hours by having it assembled by six workers from one team.

The reduction of indirect costs is a well-known objective of the Toyota system, the key to its success consisting in eradicating waste. Parallel and holistic assembly should result in structurally lower indirect costs. A systematic examination should be carried out. For example, the initial training (4 months) takes place as the workers produce. Training does not have to begin again with each vehicle launching, when new variants are introduced, or when there is a change in the time cycle. The hierarchy can be reduced to two levels, as was the case in Uddevalla during the last year: that is to say, teams and their spokespersons and a workshop leader working with the plant director. Because of its structure, assembly line activity requires a larger number of co-ordination levels, independent of any preoccupation with work control which generally oversees the other levels. Parallel assembly management does not need to be a heavy ‘machine’ bent on constantly supervising production. In principle, the system easily regulates itself. It is not necessary to proceed with long and costly studies in order to find the origin of any dysfunction or to calculate buffers.

Quality does not require the same conditions and above all varies in nature according to the mode of assembly that is adopted. On the assembly line, the quality control of each operation by the operator is a supplementary constraint that he must internalise in order to respect the procedure. Now Toyota reduces pressure in this area by reintroducing quality control and alteration work at the end of each section of new assembly lines (Shimizu, 1995b). In parallel assembly, the operator becomes aware of the necessity to correct his work when or if he encounters difficulties with the operations which follow. He can identify the causes of his errors and correct them immediately. In all likelihood, the most important difference lies in the nature of quality and its criteria. Instead of only referring to points considered as essential, quality can also be globally apprehended; indeed the sum of both formal and selective checks does not automatically guarantee global quality. It is not enough that quality be respected with regard to itemized points. It must also result from a coherent entity.

A number of product modifications result from the necessity to simplify in order to facilitate flow assembly without necessarily increasing the quality of the product or the number of supplementary options for the client. They can even have the opposite effect. Often, suggestions offered by assembly line operators concerning the product and process are criticized, and they are reminded that these suggestions do not address the consequences of their application on other elements of the vehicle or other assembly difficulties they might provoke. Indeed, in the case of assembly lines, the operator does not have a general overall view of the process. This intellectual limit should logically disappear with complete assembly in parallel stations. In this case assembly workers should even be a step ahead of those researching the problem (Ellegård, 1997a). Throughout the life of a vehicle, they can have an overall and systematic view of all the variants and options, of possible incoherence that engineers often overlook after the
conception phase, if only because it is often not the same people who study variants. They can even be aware of certain clients' expectations or requests since those who have time can come and see how their vehicle is being assembled, as was sometimes the case in Uddevalla.

A comparative analysis of the structures of different assembling modes tends, therefore, to demonstrate that the reflective production system presents possibilities of superior global performance. In order to determine if this potentiality can be accomplished and if the system can be adopted elsewhere, we must now examine if the principles of ‘reflective production’ are applicable to high volume as well as to automated workshops. Just what are the conditions and limits of ‘reflective production’?

3. Possibilities of extending ‘reflective production’

Before closing down, the Uddevalla plant only produced vehicles in low and medium volume. In 1996, it took up this same type of production again. At present, certain European carmakers are interested in assembling in parallel stations for their ‘niche’ and special vehicles which are becoming an important part of their total production. Is this a sign that it is impossible from an economic point of view for the system to be used for high volume? If this is the case, parallel and holistic assembly would only then be a minor innovation: for a long time now, we have known how to produce aeroplane motors or professional computers in small batches in this manner. The interest of the Uddevalla plant, then, would only have been to remind carmakers of this obvious fact. However, our previous analysis of assembly times and other performances has demonstrated that the system can also be applied to large volume as well as low or medium one, if one seeks to overcome structural obstacles in assembly line activity and to reduce the gap between theoretical and real performance in an economic and socially acceptable manner.

For the time being, ‘reflective production’ has only involved assembly activity. Is it applicable to mechanics, pressing, sheet metal work, and painting, activities which are all highly automated at the moment? In our opinion, at the assembly level, the reflective production system must be analysed as another automation strategy. In fact, all small added value operations are automated, that is to say handling and administrative tasks. On the other hand, that which is complex, costly, and too premature to automate, i.e. materials handling and the assembly of vehicles which are increasingly equipped and varied, remains manual for the time being. However, ‘reflective production’ would not have much of a future if it was set rigidly in the actual division between manual and automated activity.

Hence, the question is raised as to how holistic principles could orient the design of assembly and production automation in general. The construction of welding and painting workshops at the Uddevalla plant can shed light on this issue. It will be necessary to automate certain operations. However, designers of reflective production system hope to apply the same conception of work as that in assembling. When this article was being completed, we did not know how this was going to be achieved. Will we witness a limitation in automation or the appearance of a new form of automation? This is one of the most important issues and one of the most interesting things about the reopening of the plant.
In previous texts, I gave an outlined of what another social form of automation could be (Freyssenet 1992, 1997). It is well known how automation applied in the 1980s by European and American carmakers only reached expected productivity and quality objectives. When it did, after much difficulty, long and costly investment modifications and precision, production losses and premature workforce reductions. By automating apparently simple operations accomplished by direct and unskilled workers, these carmakers wanted to abruptly increase productivity, flexibility and quality. However, they tried to do so without their engineers possessing sufficient knowledge and mastery of the issues at stake for real production. The desired results were not obtained and even contributed to financial difficulties for these carmakers in the 1980s. Since then, they have become more realistic by automating their new assembly lines to a lesser degree. However, they have not entirely abandoned the priority of reducing the direct workforce, which is at the basis of their automation strategy. On the whole, Toyota proved to be more cautious, however it also adheres to the productive philosophy which consists in automating, direct fabrication and assembly operations first.

Difficulties encountered in perfecting automated sections stem from the fact that they are designed, in both their mechanical and computerised aspects, with the objective of reducing to a maximum interruptions caused by dysfunction, and to do this it is necessary to have a predetermined estimate of incidents that could occur. However, unpredictable incidents are more numerous and frequent than expected. Rapid intervention by operators and repairmen to re-launch production as quickly as possible results in postponing and making other workers deal with the major causes of the dysfunction. A holistic conception of work applied to the design of automated sections allows for the operators of the latter to practically and cognitively locate and participate in the analysis of the origin of fabrication hazards and machine breakdowns. It is by creating technical and organizational conditions which give the operators a general intellectual overview of the product and the automated process that one can hope to see a socially ‘anthropocentric’ form of automation develop, thus inaugurating a genuine and long-lasting social process in the reversal of the ‘division of work intelligence’ in automated workshops.

4. Social conditions for the possibility of ‘reflective production’. Should industrial history be re-examined?

Throughout this analysis, three social conditions have been seen to be necessary for ‘reflective production’. They also set limits to its expansion. Time allocated for each model and variant must be negotiated, because technical and organizational means which can impose a work rhythm no longer exist. The significant potential for improving the product and process and for reducing assembly time by assembly workers can only become reality if they do not also reduce employment. Finally, the collective dynamics of a genuine reversal of ‘the division of work intelligence’ which thus comes about must be able to develop in an unrestricted way, which was not the case for Toyota, to make social compromise possible and to make the implication that needs last. In this case, we encounter conditions similar to those necessary for the emergence of an automation whose functioning can be mastered and improved by operators, as I have already attempted to demonstrate. They imply that the firm not only considers its future with regard to its markets, but also in the light of skills developed by its workforce. Such a scenario presupposes a profound change in employment relations.

Hence, the reflective production system manages to overcome practical obstacles used to justify assembly line activity: the fact that it is impossible to memorize a large number of operations, to feed parts into parallel work stations without obstruction and costly interruptions, and to instantly adjust tools for each different operation. As such, it bypasses structural problems inherent to Fordism and which Toyota's innovations, upon analysis, only limit with regard to the negative consequences relative to production time, quality, and flexibility. Finally, it can offer solutions to problems encountered by the current social forms of automation.

Thus, the organization of production and work in Uddevalla plant was not an organization which ‘humanizes work’ in the sense that it renders work in industry acceptable and even interesting. Nonetheless, in seeking to attribute ordinary human cognitive and co-operative dimensions to work activity (Freyssenet, 1994), Uddevallian designers have elaborated radically new industrial principles which are applicable and perform under certain social conditions (as with any system), hence resolving structural problems inherent to the actual principles of additivity and fluidity, which Fordism and Toyotaism notably share. Uddevallian organization of work and production is therefore not a return to craftsmanship nor a form of neo-craftsmanship that would contribute to suspending or challenging technical progress. Apart from the fact that it presupposes the standardization/interchangeability of parts, it can be described as a different way of marrying manual activity with mechanization and automation, leaving the complex part of the productive process in the hands of the direct worker. In a dynamic manner, it can be interpreted as another automation process susceptible of generating a new social form of automation applicable to all production process phases and to all activity branches. At present, these characteristics take on a particular meaning and significance at a time when the Toyotan model is encountering difficulties in maintaining its principles and is borrowing from Swedish innovations.

If such is indeed the case, the Uddevalla example poses quite a number of important problems about the way in which industrial history has been represented. Indeed, and with hindsight, nothing prevented from conceiving production in the same manner at the beginning of the century: a cognitive approach and supplying all the parts necessary for the assembly of a vehicle. How did we conclude that in order to increase productivity it was necessary to proceed with the ‘deconstruction/reconstruction’ and fluidification of the production process? Of the three founding principles of the present-day industrial system: standardization/interchangeability of parts, deconstructing/reconstructing of work according to time saving and moving assembly line, the first one was probably the most important. The remaining two allowed for supplementary benefits with respect to craftsmanship production while ‘disciplining’ the work force at the same time. ‘Reflective production’ requires an agreement with workers in order to benefit from their productive potential and this supposes a profound change in employment relations.

The Toyotist model, if it is considered from the point of view of a pragmatic search for the primary causes of dysfunction by involving workers and their team leaders in the search, did not go quite as far as questioning the production principles which are at the origin of a large number of these very dysfunctions. Taichi Ohno seems to have forgotten a sixth ‘why’! Toyotism attempted to reduce the economic consequences of structural problems linked to assembly line. The pressure that was put on workers to achieve this has, at present, forced Toyota to take a few steps backwards and reduce the workload. The reflective production system, by basing itself on cognitive principles and par-
allel production, eradicates structural problems that Toyotism has not sought to analyse and thus avoid. Therefore, we may believe that it has the potential for much greater productive efficiency, under certain social conditions. However, this will only be demonstrated when it is applied to large volume.

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