◆資　料

Alternativ montering (英訳版)

浅生卯一
猿田正機
田村豊
野原光
藤田栄史

はじめに

本資料は，スウェーデンで刊行されたTomas Engström, Dan Jonsson and Lars Medbo, Alternativ montering: Principer och erfarenheter från fordonsindustrin, Metall, 2005の英訳（仮訳）版である。Tomas Engström（トーマス・エングストローム）とLars Medbo（ラーシュ・メドボ）はChalmers University of Technology（シャルマール工科大学）に，Dan Jonsson（ダン・ヨンソン）はGöteborg University（ヨーテボリ大学）に勤務しており，彼ら（3人の著者）は，1988年～93年の間，乗用車を生産していたボルボのウッデバラ工場（Volvo's factory in Uddevalla）で開発された革新的な生産システムの設計と分析に深く関わった研究者である。

量産向け自動車の組立方式としては，20世紀初頭以降に普及したライン生産システム（フォードシステム）が，21世紀の初頭においても依然として主流である。これに対して，ボルボのウッデバラ工場は，ラインを廃止する代わりに多くの組立作業場（ステーション）を設け，それぞれの組立作業場に車体を固定（定置）したまま，数人の作業チームによって自動車の組み立てを完成する方式を開発し実行したことでよく知られている。この革新的な生産システムは，1990年代初頭に，リフレクティブ生産システム（Reflective Production System）と命名されたが，本資料では，伝統的なライン生産システムに代わる組立システムの第2世代（the second generation of alternative assembly systems）として位置づけられている（第1世代は，1970年代にボルボのカルマール工場で導入された組立システムで，組立工程の一部に定置式が採用された）。

われわれの研究グループ（浅生卯一，猿田正機，田村豊，野原光，藤田栄史）は，1991年以降，3人の著者を含むスウェーデン研究者たちとの交流を開始し，2001年以降，自動車を中心とする組立産業における生産システムとその社会的・技術的諸条件に関して，日本とスウェーデンの比較研究を実施してきた。この共同研究を通じて，われわれ研究グループは，スウェー

デン自動車産業で開発された革新的な生産システム（the second generation of alternative assembly systems）に関する認識を大いに深めることができた。

2005年に，著者たちが，それまでの研究をふまえて，伝統的なライン生産システムに代わる組立システム（alternative assembly systems）についてまとめた冊子を刊行した。しかし，それはスウェーデン語で書かれたものであり，その内容をスウェーデン以外の人々に知ってもらうためには，英訳版を出す必要があった。幸い，英訳について著者の了承と訳者（Mathias Hammargård）の協力を得ることができ，本資料の公表にいたったのである。ただし，本英訳は，仮訳であり，意味がわかりにくいところや誤りが含まれていたとすれば，それはわれわれ研究グループの責任である。近い将来，著者自身の責任において英訳版が刊行されることを希望するものである。

本資料では，伝統的なライン生産システムに代わる組立システム（alternative assembly systems）の原理と特徴について，技術的な観点と人間的な観点からの考察がなされている。とくに，伝統的なライン生産システムに代わる組立システムの第2世代（the second generation of alternative assembly systems）の原理および特徴として，第一に，技術的な観点からいえば，それは，組み立てられる生産物が一本のライン上を次々に流れてゆく（serial product flows）のではなく，多くの作業場（ステーション）において同時並行的に生産物の組み立てがなされる（the assembly is conducted in parallel product flows）ことであり，この組立システムはtime lossが少ないゆえに，効率性の点で伝統的なライン生産（serial product flows）よりも優れていることが指摘されている。

第二に，人間的な観点からみた，この組立システムの原理および特徴として，長いサイクルタイム内で遂行される組立作業が生産物の全体を見通しうるものとなっていること（holistic assembly work），そして，その作業を作業者が効率的に遂行できるようにするために，「組立作業向けの製品構造*」（assembly-oriented product structures）と「製品（車）1台分の組立部品をひとまとまりにして供給する仕組み」（materials kitting system）が開発されたこと，以上の点が示されている。さらに，本資料で示された革新的な生産システムの原理と特徴は，トラックや乗用車のような大型で複雑な生産物の組立システムの諸経験から定式化されたものであるが，程度の違いはあれ，他の生産物の組み立てや組立産業以外にも適用可能であると，著者達は主張する。

以上の見解，とりわけ，この革新的な生産システムが生産性の点でもライン生産システムより優れているという主張に異議をとなえる向きも多かろう。とくに，自動車の量産組立工場ではそうである。周知のように，トヨタ自動車の組立工場では，組立ラインを維持しつつ，その改善が積み重ねられており，今や，世界中でリーン生産（lean production）やトヨタウェイ（Toyota Way）がもてはやされている。これに代わる組立システム（alternative assembly systems）は存続の余地がないかにみえる。しかし，そのトヨタの工場においても，alternative assembly systemsで開発された方法および手段と同様のものが部分的に導入されている。自律完結工程（autonomous complete processes）とSPS（set parts supply）がその代表的なものである。

読者は，本資料によって，alternative assembly systemの原理と特徴，そのスウェーデンにおける経験，さらには，トヨタ生産システムとの差異と類似性について，認識を新たにすることができるであろう。それは，より効率的で人間的な生産システムを創造するために有益な一歩となるはずである。

＊詳しくは，トーマス・エングストローム／ダン・ヨンソン／ラルス・メドボ（藤田栄史ほか訳）「製品に関する情報の組み替え・変換と組立作業の再編成―ボルボ・ウッデバラ工場の経験に照らして―」『名古屋市立大学人文社会学部研究紀要』第12号，2002年を参照。

Tomas Engström, Dan Jonsson and Lars Medbo（Translated by Mathias Hammargård*）"Alternative assembly systems: Principles and experiences from the automotive industry"

*Mathias Hammargard was born in Stockholm, Sweden in 1978. He has since also lived in the United States of America and Germany. He has studied law, business administration and economics. Since the year 2002 he lives in Stockholm and he is now employed by one of the largest financial institutions in Northern Europe. He also works as a free-lance consultant and translator.

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Preamble

In 1985 Metall[1] launched the term "The good work". The idea behind it was to through better and more qualified jobs unite individuals' development with the industry's demand for increased competitiveness.

For some time several companies evolved in that direction. But today, we can unfortunately see that many industrial companies return to more tayloristicly focused systems. Assembly lines are reintroduced in assembly work at the expense of full-time jobs.

The reasons for the return sometimes appear unclear. The production technical motives are seldom tried against knowledge about what the alternatives may look like. One problem is that experience and knowledge of parallel assembly systems seldom is collected and systematically processed.

Metall wants to contribute to decisions on these matters becoming well-founded since it concerns long-term security and development of businesses, which leads to more jobs and thus increased welfare. Additionally the choices also affect the contents and conditions of the tasks to be performed.

Solutions that give the employees stimulation, growth and commitment does not only contribute to the short-term survival of the company, it also strengthens the long-term competitive advantages. It is not the low cost of labor that brings Swedish companies success. Internationally standardized systems for production are not always a recipe for success.

Products with high refining value that are manufactured in companies that quickly and efficiently can handle many variants, different qualities, altered delivery times and new products are becoming increasingly important. Likewise the working conditions are important in the competition for labor.

Metall has taken the initiative for this publication to increase knowledge and experience about alternative assembly flows. By contributing to it being written down, systemized and distributed we want to take part in creating both a competitive industry and good jobs for the employees.

Göran Johnsson
Chairman Metall

The Authors preamble

Production technique is an area which lately has come into focus again. Sweden needs to keep industrial manufacturing within the country. In order to be internationally competitive Swedish industry must use the most modern and best production technique.

With this book we want to contribute to the development of production technique and the debate within Swedish working life, by spreading knowledge about the principles of what we refer to as alternative assembly systems also outside the scientific community. Our book is based on a several decades long research- and development cooperation with mainly the Swedish automotive industry, this cooperation has mainly been with AB Volvo and Volvo Personvagnar AB, but also earlier with SAAB Scania AB and Scania AB. It is important to emphasize that our research had not been possible without a constructive and trusting cooperation with the companies under conditions which are not always possible to in a traditional manner organize within the university.

Most important were the extensive project together with Volvo Personvagnar during the nine years 1985-1993, when the factory

for final assembly of cars in Uddevalla was developed and implemented. There we got, through own facilities for experiments with equipment, data and products, the possibility to in direct connection with the companies continuous development work, influence the design of this and other factories. The authors wish to in this context extend our warm gratitude to the people who worked in these companies that we during the years have cooperated with.

In this context we would especially like to thank engineer Bertil Johansson, nowadays retired from Volvo, who during more than twenty years has been the driving force in many projects with Volvo. We have also together with Bertil, in many instances on his initiative, ventured into areas whose extent, difficulty and consequences we from the beginning did not always comprehend.

Further we wish to thank Professor Lennart Nilsson at the Department of Education at Göteborg University who during the past twenty years have helped and supported us through his knowledge in vocational pedagogy. Especially important and constructive was our cooperation during the planning of Volvo's factory in Uddevalla. We then got the joint opportunity to both theoretically and practically develop and implement research from our respective areas.

Resources for our research and development work has been put at our disposal from different research boards, mainly the Swedish Governmental Agency for Innovation Systems —— VINNOVA (previously the Swedish Transport Communications Research Board) —— Swedish Council for Working Life and Social Research —— FAS (previously the Swedish Work Environment Fund and the Swedish Council for Work Life Research) and the Swedish Agency for Economic and Regional Growth —— NUTEK (previously the Swedish Agency for Technical Development). At the end of the process of writing this book funds from VINNOVA have partly been used (the project: "Development of system solutions for integrated transport/material flows Phase II")

Regarding this book we especially are thankful for the initiative of Metall and in particular Max Fagerstedt and Margareta Pettersson at the division for work development. We also want to thank all the people within Metall, including the Volvo union branch in Gothenburg that in different contexts have helped out with, among other things this book. Bo Blomqvist, PhD at the Department of Sociology at Göteborg University and the Division for Logistics and Transportation at Chalmers University of Technology has additionally contributed to, inter alia, make the presentation considerably clearer and more thoroughly worked through.

1. Introduction

1.1 The Swedish model for work life

In 1973 as the newly-appointed CEO of Volvo Pehr G Gyllenhammar published a book with the title "I believe in Sweden"[2]. There he, among other things, wrote: "But the work organization, working conditions and the work environment is increasingly criticized and the assembly systems and the production technique which has been the foundation of the industrialism of our time now have to be reconsidered. The demand for what one refers to as work content has increased considerably during the last few years. A lot of people consider this a disquieting sign. In my opinion these are sound demands."

/…/

"If the forces that so far have been engaged in what is referred to as labor science are committed to adapting the production to the people of today and their demands, it should be possible to create new production technical solutions in factories and in offices, solutions which combine rational systems with more meaningful tasks so that one also satisfies the demands for increased efficiency. If this succeeds, Sweden will be well upfront from an industrial point of view."

In his book Gyllenhammar brings up Volvo Personvagnars factory in Kalmar (Volvo's Kalmar factory), which was created in the beginning of the 1970s and whose design was guided by the same kind of thoughts which were presented in "I believe in Sweden". The Kalmar factory and Volvo Personvagnars factory in Uddevalla (Volvo's Uddevalla factory), which was created fifteen years later became well-known abroad and influenced the development within Swedish industry outside Volvo as well; they became symbols of "the Swedish model" for work life.

These two factories were however not the only examples of a bold new approach to production technique within Swedish industry, nor within Volvo. Another earlier initiative within Volvo, still more radical and completely independent of the Kalmar factory, was the assembly enterprise which was temporarily conducted by Volvo Lastvagnar in a workshop at Arendal, where a workgroup of nine operators built complete trucks in a more efficient way than along the traditional assembly line. The Kalmar factory and the Arendal experiment were succeeded by a number of initiatives, not the least within Volvo, where different variants of alternative assembly systems were introduced. A later initiative was Volvo's factory in Uddevalla which is the only example of the realization of what is called holistic assembly work on an industrial scale, where it from the beginning of the planning process existed ambitions to realize such assembly work.

The most interesting of these initiatives were the ones that meant a radical change of the actual assembly system away from the assembly line system (assembly along the assembly line), towards a production system with several parallel (i.e. separate) product flows, where the product in the extreme cases is located at the same place, in what is called a dock, during the entire assembly procedure. The assembly system is therefore most commonly referred to as dock assembly. These parallel product flows replaced the assembly line with its joint product flow, where the product is moved from operator to operator (or from workgroup to workgroup) during the assembly work, which is customary in traditional mass production.

This altered way of production in turn created prerequisites for a new work organization, with a more extensive and qualitatively different work and increased self-control (autonomy) in what is called self-governing (autonomous) workgroups. Workgroups or in some cases individual operators could here be given responsibility for assembly of an entire product. Table 1.1 gives a few examples of alternative assembly systems within Volvo[3].

When this is written in the year 2004 the pioneering initiatives which have been covered above are at risk of being forgotten and the valuable experiences are at risk of being lost. The production technical development based on domestic experiences and conditions as well as on socio-technical theory, as it is called, that can be said to have started in the

Table 1.1 A few examples of alternative assembly systems within Swedish automotive industry.

	The Volvo Arendal workshop (1974):	The Volvo Kalmar factory (1974):*	The Volvo Uddevalla factory (1989):	The assembly docks at the Volvo Tuve factory (1991):
Work cycle time:	240 minutes	20 minutes	80 or 100 minutes	240 minutes
Number of operators per work-group:	9	8	7 or 9	10 or 9
Number of operators simultaneously working at each product:	3	2	2 or 3	3 or 4
Number of work groups working on the same product:	1	27	1	1
Number of product flows:	1	1	35	6
Integrated sub-assemblies in the workgroup:	Yes	No	Yes	Yes**
Materials supply technique for large components:	Traditional	Traditional	Material batches transported by means of forklift trucks	Traditional
Materials feeding technique for semi-large components:	Traditional	Traditional	Material batches transported by means of automated guided vehicles	Material batches transported by means of forklift trucks
Materials feeding technique for small components:	Traditional	Traditional	Automated batching of small components in transparent plastic bags	Traditional

*) In 1987 the factory was quite radically rebuilt, at the same time many buffers were removed, in a production sector parallel product flows were introduced and the total area of the factory was also increased. After this reconstruction it was possible to have a work cycle time of maximum 40 minutes, including the sub-assembly stations.

**) The sub-assembly stations were later on removed, and the assembly system was modified to, in connection with an increase in production volume, include three steps instead of two, i.e. the truck was moved four times during assembly instead of three.

1970s have virtually ceased[4]. Today, research and development work in this spirit is virtually non-existent within Swedish industry.

Within many large Swedish industrial corporations the management does no longer appear to have faith in Sweden or the "Swedish model" for work life development. During the last decade we have edged closer to international, not the least Anglo-Saxon, patterns which at the same time meant that we have removed ourselves from the "Swedish model". A number of examples can be given of alternative assembly systems within the Swedish automotive industry that have been closed down or replaced by assembly lines.

The Volvo Kalmar factory was closed in 1994, while the Volvo Uddevalla factory stopped production in 1993. In 1995, production with parallel product flows once again started in Uddevalla after a remodeling of the assembly system, resulting in both some successful and some unsuccessful alterations[5]. However, in 2002 this assembly system was rebuilt yet again and the parallel product flow in Uddevalla was replaced by an assembly line. Volvo Lastvagnars dock assembly in Tuve, which had substantial similarities to the temporary Volvo Arendal workshop operated in 1974 to 1977, was closed down in 2002.

The long-standing door assembly at the Volvo Torslanda factory conducted with parallel product flows, which was rebuilt in 2002 and the assembly now takes place along an assembly line, is yet another example the abolishment of alternative assembly systems. It can also be mentioned that the different Volvo Skövde engine factories had parallel product flows earlier. In the last remodeling in the summer of 2002, all of those have been replaced assembly lines.

Outside of Volvo alternative assembly systems have also been replaced by such old revived assembly systems. One case, which has generated some attention, is the Scania truck cab plant in Oskarshamn, where an assembly line was introduced in connection with an increase in production capacity in 2002 (Janbrink 2002; Andersson 2002). Another case that was given attention is the ABB Robotics plant in Västerås which was converted into an assembly line in 2002 (Dahlqvist 2003).

These revived ways of production which in these and similar cases have replaced alternative assembly systems are the foundation of traditional mass production.

1.2 Arguments and motivating forces to initially introduce and subsequently abandon "the Swedish model" for work life development

What then are the arguments to initially introduce and subsequently abandon the "Swedish model" for work life development, specifically when it comes to the automotive industry? Here we will cover some items of importance for this change, and critically examine these arguments and motivating forces.

Productivity

That assembly line systems will produce superior productivity in comparison with alternative assembly systems has been considered an important argument to maintain or reintroduce this way of production. At the beginning of the 1990s the efficiency of assembly line systems compared to alternative assembly such as dock assembly systems was on debate based on hypothesis presented in the management bestseller "The Machine that Changed the World" (Womack, Jones and Roos 1990), which launched the term "lean production". This notion was based on work along the assembly as it was performed in the Japanese automotive industry, especially at Toyota, during the 1980s (see for example Monden 1997); it was all about an American interpretation of Japanese prototypes.

The authors of the book meant that they could demonstrate that Japanese style assembly line systems were more efficient than traditional assembly line systems as well as alternative assembly systems as the one in Volvo's Uddevalla factory. The comparisons that they present in their book are however largely like comparing apples and oranges. The assembly times of cars in different factories are for example compared, however in these comparisons one has not in a satisfactory manner taken into account that different cars are more or less easy top assemble. Further the study only included comparisons between factories wit assembly lines i.e. no fact based comparisons was to dock assembly or alternative assembly systems were conducted. The alternatives were discarded without any actual data and also as is presented later on in this book without any theoretical analysis.

In contrast to what is presented in "The

Machine that Changed the World", analysis from Volvo's factory in Uddevalla shows that the assembly time for a car there was 2-4 hours shorter than what was required along the assembly line at the factory in Torslanda where 15-17 hours was required (Engström, Jonsson and Medbo 1996A). Volvo Lastvagnars temporary workshop in Arendal and their dock assembly in Tuve are other examples of alternative assembly with high productivity. There are also, which we will get back to in Chapters 4 and 5, other convincing theoretical explanations for these effects.

Product quality

Yet another argument in favor of the reinstatement of the assembly line has been that one wish to keep a high product quality and that alternative assembly is not compatible with high quality. In most cases product quality has however proved to increase in the latter type of assembly, which depends on that the workgroup is granted completely different opportunities to adjust the constituent parts in relation to one another before their final assembly. Improvements in quality can be considerable, especially in manufacturing of small series where it is not economically justifiable with an extensive construction and product development work[6] (which often is true for products that are adapted to each customer or are custom made and thereby have many product variants). For example this proved to be true in the truck assembly at Arendal and in Volvo Lastvagnars factory in Tuve.

The average product quality in Volvo's factory in Uddevalla was considerably higher than for the same model along an assembly line, however it was somewhat uneven between different workgroups and individual products. The quality of the work during the period that Volvo's Uddevalla factory was in business gradually adapted to the special conditions of the new way of production. This development work was not finished when the factory was closed down. Product quality was still very high, and the combined experiences from Volvo's factory in Uddevalla showed that assembly in a production system with parallel product flows makes it possible to in comparison with assembly line systems improve product quality. Exactly how big this potential of improvement could be was however not answered.

Ergonomics

Another argument which lately has been put forth in favor of assembly line systems is that it provides for better ergonomic solutions than alternative assembly systems. The repetitive work along the assembly line does however bring along well-known ergonomic problems, while alternative assembly systems from an ergonomic point of view have clear advantages. The ergonomics becomes better in a production system with parallel product flows because, among other things, the duration of the work cycle is prolonged i.e. the work is less repetitive. The possibilities to vary the work pace within the work cycle and during the work day also increases, which means that the human rhythm can be better followed. The ergonomics also becomes better by assigning some administrative tasks such as materials control to the operators, which in a production system with parallel product flows is both possible and beneficial from an efficiency point of view.

That ergonomic problems may of course arise in alternative assembly, above all where maintenance and renewal of tools and equipment is neglected, is however not surprising. Irrespective of assembly system suitable tools and equipment for the selected assembly system is of course required. (Quite contrary to what is often maintained in the debate a comparison between the need for investment in factories with assembly line systems and assembly in parallel product flows show that the costs for tools and equipment were lower in the latter case, among other things because simpler tools could be used (Ellergård et al. 1992: Engström, Jonsson and Medbo 1996B)).

In certain cases ergonomic problems have arisen in alternative assembly systems because of extreme working up, as it is called, in parallel product flows (see the further discussion on working up in Chapter 3). There are examples of where an operator has performed his production undertaking just after lunch to then proceed to go home, it has required a very high pace with subsequent ergonomic problems as a result. Such a way of working is however not a necessary consequence of assembly in parallel product flows, but rather a consequence of lack of required norms and regulations regarding the work.

Internationalization and standardization of assembly systems

The international ownership has increased, especially in the automotive industry, and the Swedish companies have now become a part of large international groups. They strive to develop standardized assembly systems, which include the aspiration towards one single standardized assembly system for all production units in a company group, irrespective of in what country the production takes place.

To us it does however appear inappropriate to introduce this type of assembly system on a market with high product differentiation (i.e. that the products have to differ because of customer demands), substantial variations in demand over time and relatively short product life cycles. The aspiration to develop and apply a single international, or global, assembly system, which is independent of national conditions and tradition and that does not utilize competitive advantages like high competence and that furthermore is largely independent of product characteristics can be questioned on many accounts. It should also be added that international assembly systems mainly inspired by Japanese examples, now introduced in Swedish industry, have in many cases already been abandoned in Japan. New assembly systems with considerably more flexible production are now instead introduced, especially the electronics industry is a forerunner in replacing the assembly line (see example 1 in Appendix 1 and Asao 2001).

Management philosophies

The assembly line gives the management a favorable chance to survey the production and by that be able to manage it in a, under normal circumstances, simple way. Assembly line systems in most cases presuppose central and detailed control. In assembly line systems it is essential that the operators work is coordinated in detail for the production to function. This management philosophy is goes together with a view of the employee as a replaceable cog in a big wheel. Such control and coordination is not required in alternative assembly systems where self-governing workgroups, which in part take responsibility for this planning and control in the ways previously mentioned and that will be further mentioned, are utilized.

The choice between assembly line systems and alternative assembly systems thus is connected to what management philosophy one has when it comes to managing the work. Henry Mintzberg (1983), the organizations researcher, discusses different ways of coordinating and controlling the operations in an organization. Assembly line work is mainly controlled by what Mintzberg refers to as "direct supervision"[7] and "standardization of work processes". The employees "mutual adaptation" (like in self-governing workgroups) is trusted in alternative assembly systems and one also focuses on their competence and performance.

These are methods of coordinating and controlling the operations which are used in many organizations, especially those with highly-educated employees with high levels of knowledge and perhaps even unique products and services. The more a company, for example in the automotive industry, develop towards a knowledge intensive business (see Chapter 8) and away from mass production of standardized products, the more important it becomes to utilize more advanced management methods. If one on the other hand relies on "direct supervision" and "standardization of work processes" it becomes difficult to utilize the operators' competence and to thereby reach flexibility in the production.

Since alternative assembly system means increased freedom (increased scope of action)[8] for supervisors, management and operators, it brings about a different way of controlling and organizing the operations, resulting in that the management has to change. This management then largely becomes connected to mutual personal responsibility. If the need for such management is not perceived and then not developed, it will be more or less obvious to reinstate traditional assembly systems.

The arguments in favor of returning to the old revived assembly line do not entail the entire truth behind this development. In our opinion there are other, fundamental factors that are the reason for this development, which we now discuss below.

Knowledge regarding traditional and alternative assembly systems

The assembly line is commonly used, well-known and tested. Management, supervisors, production engineers do however often lack knowledge and experience from alternative assembly systems.

In this context education of production engineers should definitely be paid attention to and developed further in order to raise competence and to convey new research findings to the Swedish industry. One problem today is that skilled engineers are offered more interesting jobs within other areas than mechanical engineering. Furthermore the competence and interest in production at the management level in large Swedish companies appears to have been reduced. When production systems are to be altered consulting companies, whose suggestions one lack the competence to critically evaluate, are often contracted. The approach to production appears to be as something that creates problems —— something that one can get rid of by for example outsourcing, i.e. letting other companies take responsibility for defined parts of the business —— rather than being something which creates strategic possibilities[9].

The lack of competence and experience when it comes to alternative assembly systems is present at all levels within the companies. First of all the knowledge regarding the advantages and possibilities of alternative assembly systems is insufficient. Secondly the theoretical understanding of why alternative assembly systems in many respects are more efficient than assembly line systems is missing. The theoretical knowledge of the different types of time losses presented in Chapter 4 and 5 is often insufficient. Thirdly the knowledge on how production systems with alternative assembly should be designed to function efficiently and thereby enable the company to be profitable is inadequate. Fourth there is lack of knowledge about and experiences of how production systems with alternative assembly are managed, and what conditions are required for it to function well.

One has occasionally believed that it is enough to make the operators find the job interesting and challenging to get a well-functioning production system. The positive effects of the operators comfort and motivation —— among other things the effect that employee turn-over is reduced —— is assumed to pay for the supposedly more expensive way of producing.

Experience does however show that self-governing workgroups, particularly the cases where they have a more extensive and qualitatively different work and increased self-control, requires specific production technical prerequisites such as for example adapted salary systems and rules that make the operators rights and duties clear.

Since the production technical motives of alternative assembly systems have become blurred the companies have not been able exploit the potential of these new production systems and economically benefit from them. Operators have instead in some cases reaped the short term benefits of alternative assembly systems, while in other cases neither the company nor the employees have been able to take advantage of the possible benefits. These circumstances have decreased the management's interest of introducing or maintaining alternative assembly systems. The joint responsibility of employers and employees in gradually improving a company's competitiveness have at the same time become more difficult to realize because in reality one has never or very seldom indeed realized that the alternative assembly systems in its foundation involves technical as well as organizational changes.

Alternative assembly systems with parallel product flows are fundamentally different from assembly line systems and it has required development work in such areas as work organization, supply of information and material and education including specific measures to facilitate learning of the assembly work for it to function as intended. When such production systems have been introduced they have paid the price for being different either by shouldering large development costs or by running into unexpected problems, since certain basic, critical prerequisites had not been met[10].

In the latter case the result may become a production system lacking necessary rules and agreements which in turn established some undesirable norms. It has often instead of self-governing workgroups resulted in individual work from a gathering of individual operators. The result for the individual operator has often been an inferior working environment where the work load is high and unfairly distributed. The assembly line and a return to more well-known work organizational circumstances has from a labor union perspective been seen as an only resort to save the jobs.

Power and cooperation

Initiatives regarding alternative assembly have with a few, but important, exceptions been met with half-hearted support, and nowadays barely that, from management and middle-management.

It is not possible to disregard that in places where the employees knowledge and commitment is of crucial importance for the productions result it signifies a different balance of power between employer and employee than in traditional manufacturing, where the overview of the production process no longer is with the people performing the manual labor, namely the operators, and where their work is controlled by the assembly line. As we understand it "The Swedish model" for work life development means that employers and employees are focused on cooperation and accept their interdependence of each other and does not view their relation merely as game for power. If the employers do not share that point of departure, and the power game gets the upper hand, it is natural to regard alternative assembly systems and the change in balance of power as a menace to its own interests.

Middle-management may also feel threatened if self-governing workgroups are introduced since part of the work that they perform becomes unnecessary or can be performed more efficiently by the collective of employees. It is natural that executives as well as other employees prefer a work organization where their own competence is required and they do not risk ending up unemployed.

Production technical work in self-governing work groups are in many companies seen as being in opposition of production technical work in other parts of the company. In order to restore the production technical competence in the companies they believe that the workgroups need to be abolished and replaced by an assembly line, where the production technical work is centralized within the company.

The labor market situation

During the 1970s and 1980s, the two decades when alternative assembly systems were introduced in the Swedish automotive industry, the unemployment rate was low and employee turnover was high. This was the case in connection with the planning of Volvo's factory in Kalmar in the beginning of the 1970s as well as with Volvo's factory in Uddevalla at the end of the 1980s.

The design of these two factories was undoubtedly influenced by a desire to create attractive workplaces to make it easier recruit employees and reduce employee turnover. The Swedish labor market has however since the beginning of the 1990s been plagued by massive unemployment, and the automotive industry has not had any trouble recruiting labor. There is reason to believe that these conditions have contributed to the reinstatement of assembly line systems within the Swedish automotive industry.

1.3 Some reasons in favor of introducing alternative assembly systems

Alternative assembly can, as will be discussed further on, yield lower usage of resources by increased productivity in the assembly work, diminished administrative superstructure and increased efficiency in usage of space.

The productivity in the assembly work at times appears to be the most important facto in choosing the assembly system, but the actual assembly work for example for a car makes up at the most 5% of the total product cost. The large costs are connected to product development and distribution including marketing. This distribution of costs is similar in many other businesses. In excess of the lower usage of resources that alternative assembly system yields it is also important to call attention to the possibilities it presents, mainly the advantage to be able to react quickly in variable markets, what is referred to as flexibility.

Since each product flow can produce without affecting the other flows it is considerably easier to alter the production volume in production systems with parallel product flows, by for example working over-time or working with fluctuating manning. It also becomes easier to simultaneously produce different product varieties, to introduce alterations of products and to introduce entirely new products[11].

The time from product development until the product is introduced on the market can also be reduced in comparison with the assembly line. It is connected to the improvement of the conditions for paralleled organized product development (what is referred to as concurrent engineering where several product development activities are organized so that they can be performed virtually simultaneously). In production systems with parallel product flows and a low degree of automatization the running in of products can also be done in less time than in technically complex assembly line production systems. The ability for the developers to practically communicate with the production staff (production engineers, operators etc.), who often have better information on how to improve the production process, is also important in this context.

In assembly line systems more coordination and planning of the work is required than in assembly in parallel product flows. The prerequisites to reducing the time from customer order to the start of assembly, and by that the delivery time, is better in the latter case. Product throughput time in the assembly factory can also be reduced by using parallel product flows.

There are better conditions to manufacture products where less has been invested in product development and by difficult to assemble in assembly in parallel product flows than in assembly line systems. This must not be confused with low quality products, but it is about the ability to efficiently manufacture products that are not mass produced. Note that in order to function efficiently the assembly line requires extensive construction and preparatory production.

In alternative assembly systems where self-governing workgroups assemble entire products the conditions for direct communication between workgroup and customer regarding ordered products is improved. This is especially important in dealing with professional customers, such as government agencies and transport and logistics companies.

The advantages alternative assembly systems results in from a company point of view have, since these advantages are not commonly known or recognized, been discussed in some detail above. That alternative assembly systems lead to benefits for the employees is however hardly news and we will only briefly discuss this.

As mentioned above and which we will get back to later important advantages in alternative assembly systems are a more extensive, qualitatively different work and increased self-control. Furthermore the possibilities for development at work including improved psychosocial working environment and ergonomics are greater. It is possible for both new employees and more experienced employees to contribute to production and cooperate, which results in stability in the production system. The individuals in a workgroup can with the help of overlapping competencies assist each other.

The operator's value on the labor market outside the factory in which he or she works is completely different since he or she works in an alternative assembly system. This appeal depends on that the knowledge and skills that are developed is of general value in a completely different way than is the case for work along the assembly line. This advantage may on the other hand become a disadvantage for the production system as a whole if the organization does not make use of the competence and it instead results in high employee turnover.

The most important aspect for the employees is however that the work in alternative assembly systems can become meaningful in a different way than what was possible along the assembly line. It is a question of a qualitatively different work which makes use of other qualities than merely, in a narrow sense, the manual skill of the operators, a professional work rather than serial work.

*

To sum up alternative assembly systems results in possibilities to expand the companies business by increased competitiveness based on other (and for Sweden more important) competitive means than merely low cost of production. A quandary when discussing these types of advantages is that they are not as plain and predictable as for example cost reductions in relation to a budget.

Principally important advantages such as fewer points of planning within the company as a whole and prerequisites for a more customer focused production should be possible to convert into new competitive strategies that create considerable added value. These strategies are however not yet formulated and it may be difficult for the companies to profit by the added value created. The potential advantages for the companies as well as the employees are however considerably greater than what is possible by traditional cost reductions. High profitability and low production costs are not the same things; to confuse them is a costly mistake.

We do certainly not suggest that alternative assembly systems are always the best assembly systems. The context and environment do naturally influence the preferable type of assembly system. If labor with high competence is lacking and/or if a production system with large volumes have to be introduced in a brief period of time the only option is often assembly line systems.

1.4 Layout of the book

This book is made up of eight chapters, In Chapter 2 we discuss different types of product flow patters, since the understanding of these are one of the cornerstones of this book. Different aspects on work organization are presented in Chapter 3.

Subsequently the reasons that production systems with parallel product flows have higher productivity then the assembly line are described. We bring up different types of time losses (Chapter 4) and how these time losses can be calculated and reduced (Chapter 5).

In Chapter 6 the current conditions along the assembly line are presented. How assembly work that departs from the product that is about to be manufactured allows for a longer work cycle time is also described. If the right prerequisites are presented the consequence is a qualitatively different work, than the one being performed along the assembly line. How information needs to be structured to allow for a qualitatively different work is discussed in particular. The supply of material and material exposure also needs to be reformed to provide the right prerequisites for the kind of assembly work discussed in Chapter 7.

In the final chapter (Chapter 8) some general considerations regarding alternative assembly systems with what is referred to as holistic assembly work are presented. The principle behind the layout of the book is apparent from Figure 1.1.

To organize the book in this manner means that general and elementary knowledge and experiences are presented in the first chapters. By reading Chapters 1-3 the reader can achieve an understanding and an ability to see connections between assembly systems and work organization, or technical and human aspects of alternative assembly.

Chapters 4-5, which explain time losses, can occasionally appear abstract. Chapters 6-8 dealing with structuring of information and material for holistic assembly work may also appear abstract and specific for the automotive industry. They are however necessary to in a profound way understand the background and the principles behind alternative assembly systems. Readers interested in the subject and that wish to become more engrossed and understand how alternative assembly systems should be designed, and why they should be designed like that, are advised to read these Chapters as well. In Appendix 2 definitions and word explanations are also collected to facilitate for those who wish to read the Chapters separately.

The experiences presented in the book are, with a few exceptions taken from the auto-

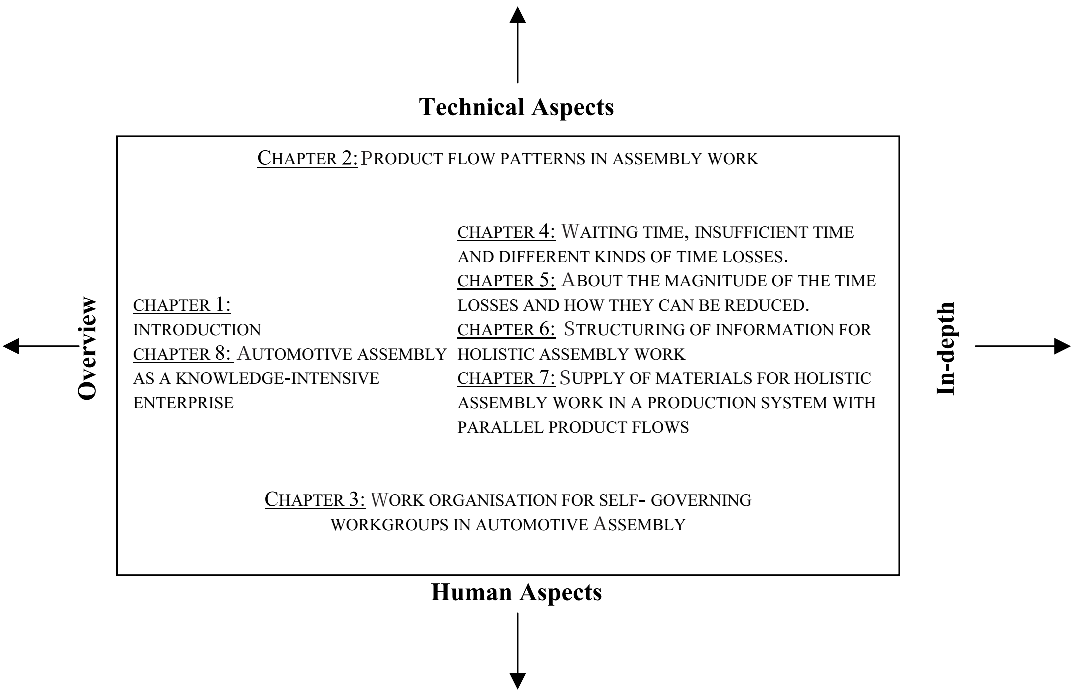

Figure 1.1　Schematic image of the layout of the book.

motive industry, and Volvo in particular. We consider the principles that are formulated to be generally applicable in assembly of large and complex products such as trucks and cars, but they can to a varying extent also be applied to other assembly, for example of electronic goods (see example 1 in Appendix 1) but also in other industries.

2. Product flow patterns in assembly work

2.1 Some important terms

Tools, equipment and operators in a factory are centered in certain areas commonly referred to as work stations. At each work station there is space for at least one product in process being processed or assembled and separated from products in process at other work stations. Each work station is often manned by one operator but two or more operators may also share the same work station. Another possibility is that two or more operators share the work at two or more work stations. We refer to these as station groups, a term introduced in this book because the industry lacks an appropriate term to describe this.

In flow oriented production, as often is the case in the automotive industry, the goods gradually completed follow a limited number of predetermined routes though the factory and consist of a one or more product flows. Since products in process are transported to and from work stations one could state that product flows connect work stations and station groups and by that form specific product flow patterns. A number of station groups and/or work stations interconnected through product flows together form a production system.

In factories there are often areas, referred to as buffers, where products in process for different reasons are temporarily stored. Like there are products flows to and from work stations there are product flows to and from buffers. The possible buffers are also included in a comprehensive depiction of a product flow pattern.

An abstract image of a production system or part of a production system that (at least) depicts work stations, buffers and operators in relationship to product flows is called a schematic layout. Such (a layout) is an important tool in design and analyses of production systems.

In this context it should be emphasized that a so called physical layout, similar to a construction drawing showing different areas and fixed installations in a factor, is insufficient as a basis for design and analyses of a production system since it does not show how the production system functions.

2.2 Different types of product flow patterns

In a production system with a serial product flow pattern there is often a single joint product flow and all products pass through every work station or station group (see figure 2.1). The joint product flow in this case is

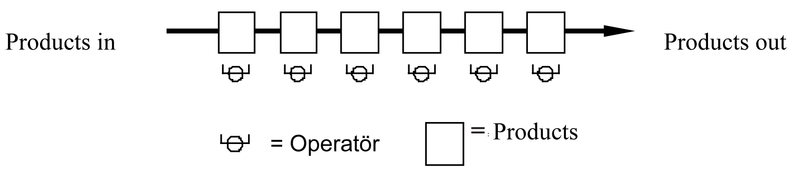

Figure 2.1 Schematic layout of a production system with a serial product flow pattern.

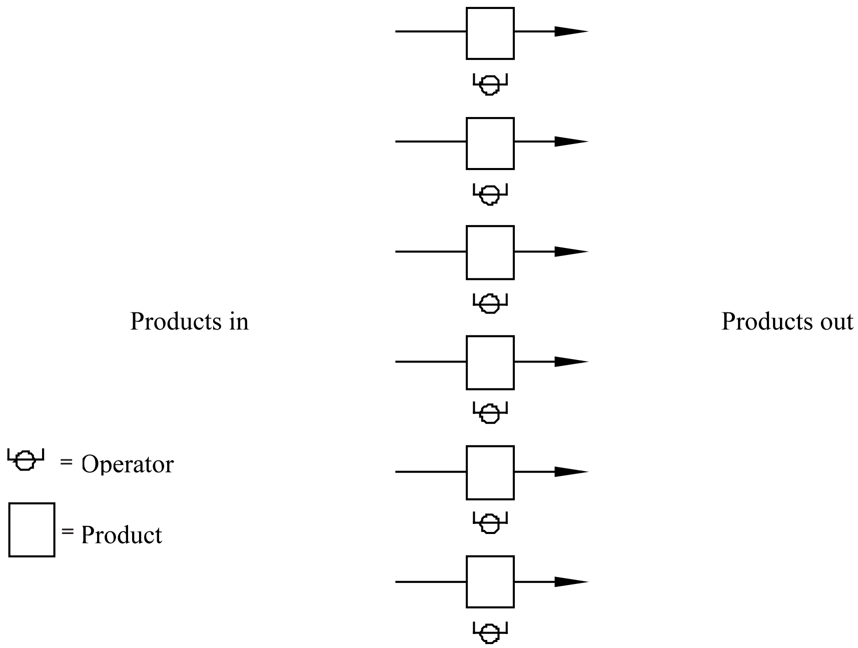

Figure 2.2　Schematic layout of a production system with a parallel product flow pattern.

a so called serial flow, like an assembly line, where products pass two or more serially connected work stations or station groups. The work cycles that the operators perform are typically short, repetitive and the transport frequency of products hence is high i.e. one or more products are moved several times.

A product flow can be paced or un-paced. In a paced serial product flow the product is continuously moved or it is automatically moved after a certain period of time has passed. In an un-paced serial product flow it is gradually moved either by the operator manually moving it or signaling that the product is finished, after which the product is moved by some kind of transport equipment.

In a production system with a parallel product flow pattern the transport frequency is however low and work cycles are long. A specific product only passes a few work stations or station groups. In extreme cases the product constantly, throughout the entire process stays at one work station or station group. The assembly work will then because of the prolonged work cycle be less repetitive (see figure 2.2)

In addition to serial and parallel product flows there are different variants and types of product flow patters that occur in practice. One such variant is called a semi-parallel product flow pattern (see figure 2.3). This product flow pattern is, inter alia, recognized by production sectors with "waists" with high transport frequency alternating with production sectors with parallel product flows. In the "waists" is often production equipment, such as an industrial robot gluing wind shields to a car, placed which one for e.g. cost reasons believes should not be multiplied[12].

There is an additional type of parallel product flow pattern which should be given

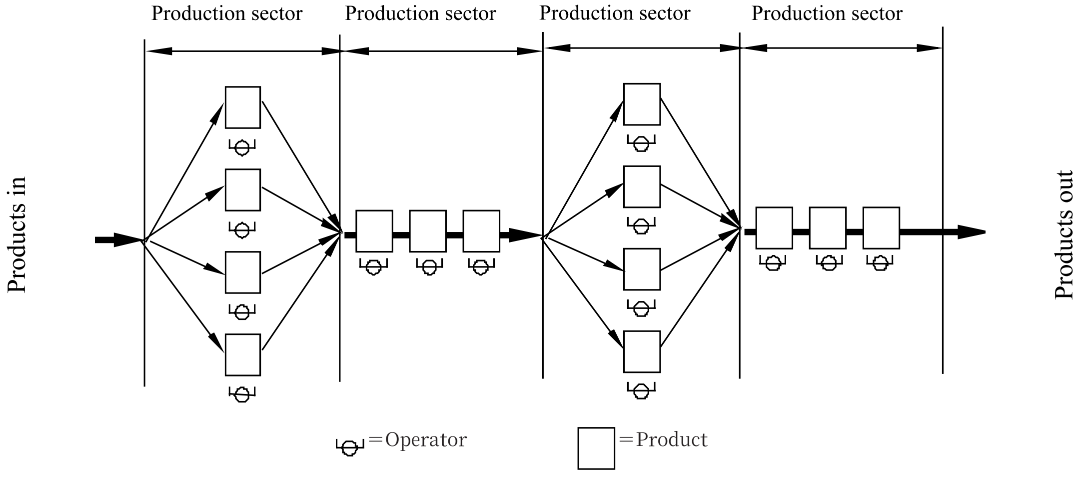

Figure 2.3　Schematic layout of a production system with a semi-parallel product flow pattern.

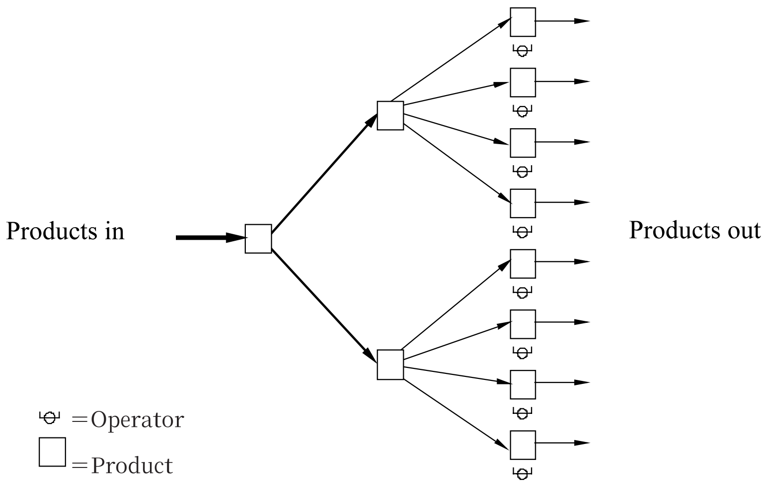

Figure 2.4　Schematic layout of a production system with an organic product flow pattern. Note that the manual labor has been concentrated to the periphery of the product flow, while more and more automated equipment is placed where the transport frequency is higher.

attention. A distinctive feature of this pattern is a gradually declining transport frequency and it is referred to as an organic product flow pattern. The product flow gradually spreads like the branches of a tree (see figure 2.4). In a production system with such a product flow pattern the automated equipment is placed in the sectors of the product flow which have a high transport frequency. This equipment can then be jointly used for several product flows, while the manual work is placed in the low frequency sectors of the product flow (which are in the periphery of the branches). In Volvo's factory in Uddevalla the product flow pattern was organic while the product flow pattern in Saab Automobiles factory in Malmö was semi-parallel.

2.3 Consequences from choice of product flow patterns

The chosen product flow pattern is of fundamental importance in a production system. It affects productivity, the efficient use of space, flexibility, long-term production planning, inventory management, supply of information and material, organization of work, content of work, ergonomics, work satisfaction and more. Some of these connections are summarized in table 2.1 and 2.2 below. It should be pointed out that the connections in these tables are a matter of principle and that the advantages that a parallel product flow pattern can generate are not automatically attained —— it is also necessary that other essential prerequisites are met.

Table 2.1 A fem dimensions connected to production systems with different product flow patterns.

Dimensions that are connected to production systems with different product flow patterns:	Serial product flow pattern:	Parallel product flow pattern:
Interdependencies within the productions system (Chapter 3, 4 and 5):	Stronger dependence	Weaker dependence
Materials supply and materials planning and scheduling*	Centralized	De-centralized
Tools, equipment:*	Technically advanced and specialized	Simple and general
Work cycles (Chapter 2):	Short	Long
Division of labor (Chapter 2 and 3):	Far-reaching (high)	Not far-reaching (low)
Work content (Chapter 3):**	Fragmented and standardized	Extensive, qualitatively different (so called holistic assembly work)
Learning principles (Chapter 6):***	Additive learning, i.e. one learns small independent parts that are added up.	Holistic learning, i.e. one start out from an understanding of the whole and then learn parts that fit in with the whole.
Self-control for operators and workgroups in relation to the technical system (Chapter 3):	Less extensive	More extensive
Self-control for operators and workgroups through administration of the own work (Chapter 3):	Less extensive	More extensive
Requirement of production technical knowledge with management and executives (Chapter 1):	Lower	Higher

*) Is not discussed in this book but refer to for example Engström and Medbo (1992).

**) Note that productions systems with parallel product flow patterns have occurred with additive learning, i.e. where the assembly work has not been holistic. What we in Chapter 8 refer to as second generation alternative assembly systems are however based on holistic assembly work.

***) Regarding this dimension only the direct application of what is called holistic learning in the way this learning principle is applied in assembly work is discussed. We are then talking about holistic assembly work (see for example Nilsson 1992A, B and 2003). The research and development work regarding holistic learning that the authors conducted has been in collaboration with Professor Lennart Nilsson at the Department of Education at Göteborg University.

Table 2.2 Some different types of achievements and outcomes for production systems with different product flow patterns.

Achievements and outcomes for production systems with different product flow patterns	Serial product flow pattern:	Parallel product flow pattern:
Time losses, i.e. system-, handling-, variant-, and balance losses (Chapter 4 and 5):	More extensive	Less extensive
Product quality (Chapter 1):	Lower, especially for products where one has not put a lot into product development	Higher
Buffer needs and total need for space (Chapter 3):*	Higher	Lower
Delivery time (Chapter 1):	Longer	Shorter
Throughput time in the factory (Chapter 1):	Longer	Shorter
Time from start of product development until the product reach the market i.e. time to market (Chapter 1):	Longer	Shorter
Flexibility regarding production quantity, product variation, product changes and product introductions (Chapter 1):	Lower	Higher
Requirements of product design (Chapter 1):**	More extensive	Less extensive
Overarching organizational superstructure (Chapter 6):	More extensive	Less extensive
Possibility for development at work (Chapter 8):	Less extensive	More extensive
Ergonomics (Chapter 1):***	Problematic. High level of repetitiveness and little self-control requires special ergonomic contributions.	Good possibilities to get satisfactory ergonomics through low level of repetitiveness and large self-control.

*) The need for less space in a parallel product flow depends e.g. on that the more times the product is moved the larger space is required for e.g. stopping and starting where it is not possible to work on the product also the need for space for transport and handling equipment, including return lanes in case track bound trucks are used. In addition space for buffers and equipment for moving the products between the work stations is needed.

**) Note that extensive construction and preparatory production work is needed to develop a product that results in work operations with little variation in work time.

***) Is only summarily covered in this book, also see for example Johansson et al. (1993) Kadefors et al. (1996) or Engstrom, Johansson Hanse and Kadefors (1999).

3. Work organization for self-governing workgroups in automotive assembly

3.1 Self-governing workgroups in alternative assembly systems

Assembly work is often, not at least within the automotive industry, conducted along an assembly line. This way of production facilitates visual control of the operators work. What happens during work and how it gradually proceeds is apparent from the movement of the products and other visual signs such as the tilt of the pneumatic hoses. The manager who passes the work area can immediately make sure that the work progresses as it should —— that his factory is producing and appears to be efficient.

However if the work is organized so that several operators with an extensive work contents cooperate on one or more products, a bystander can often not understand what is going on. Some operators may be standing talking while others work intensively. It may not appear very efficient, but such assembly work can despite this be considerably more efficient than work along an assembly line.

To cooperate in a workgroup around several products at once, with a work organization that means joint responsibility for production quantity and product quality but control of the own work, is however a known way to produce in all industries. One sometimes talks about self-governing workgroups, which especially during the 1970s was a popular notion. With self-governing one meant that the workgroup independently had agreed upon goals to fulfill and at the same time had the chance to fulfill these goals. The advantages for the employee with this type of work organization is a more independent job with both work expansion and work enrichment —— one is given more freedom in exchange for increased responsibility. From the management side it is an advantage to decrease the number of planning levels within the company, and by that gets an increased flexibility in combination with a reduced overarching organizational superstructure.

3.2 How to create and utilize the scope for variation of production pace

In both traditional and alternative assembly systems one usually works with a quantitative production goal, which means that a certain number of products have to be completed within in a specific time frame. When one has a paced product flow the production ideally progresses so that a constant number of products are completed per time unit. If for example the production goal is to assemble 80 cars in eight hours ideally the cars are moved along the assembly line at a steady pace, and a new car is completed every sixth minute. The line that for a work station or station groups illustrate how many products have been completed in comparison to how much time has passed will consequently be a

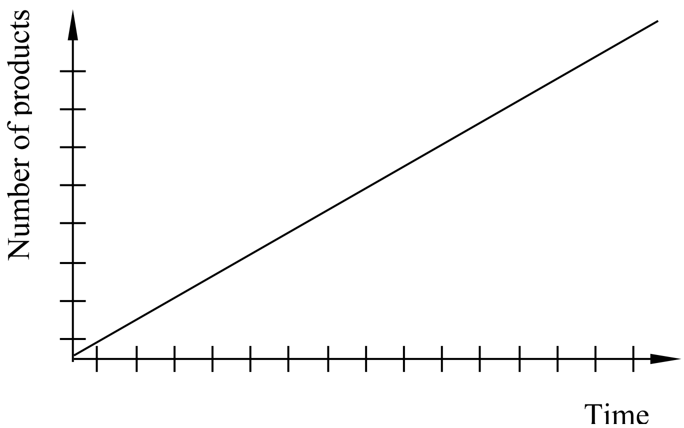

Figure 3.1 Diagram where the diagonal line indicates how many products that have been completed in a certain time at a steady rate of production.

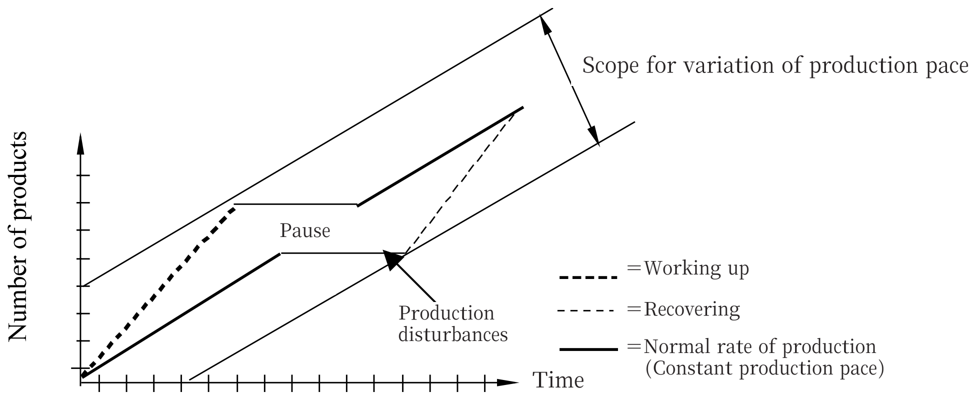

Figure 3.2　Diagram where the two lines indicate production with varying rate of production, partly working up followed by a pause, partly a production disturbance followed by a recovery of the lost volume of production (catching up).

straight line, as is shown in figure 3.1.

In practice it is however for different reasons not possible or even desirable to produce at a completely steady rate of production during an entire work day. It requires a certain scope for variation of production pace, which can be used partly to give room for production disturbances and product variations that lead to a time variation in the production, and partly to give room for self-control in relation to the rate of production for individual operators or workgroups.

In figure 3.2 the scope for variation of production pace is the field between the two diagonal lines. The lower line shows as an example where the production has stopped for some time because of a production disturbance but subsequently recuperated. The disturbance can in this case be accommodated within the scope for variation of production pace, which result in that time losses because of dependences between operators does not occur as is further discussed in Chapter 4 and 5. The upper line shows a somewhat simplified example of how an operator or a workgroup work faster in order to be ahead of the planned production and subsequently use that time to take a pause from work[13]. Working up and the pause can be accommodated within the scope for variation of production pace.

This scope for variation is in the latter case utilized by the operators to get some level of self-control. One extreme where the scope for variation of production pace is more extensive, is work at, as it is called disengaged work stations. At these the work is neither controlled by machines (e.g. the work and the pace is not determined by a machine or equipment performing work), nor is the work controlled by how work stations upstream or down-stream in the product flow functions. (For a disengaged station group the same relationship is true)

If material is available to a sufficient extent, the possibility to work ahead at as it is called a disengaged work station is in theory infinite. There are often great possibilities to finish work ahead of time, not only because of the possibility to work ahead but also because of - which is discussed in Chapter 4 and 5 —— the time losses at a disengaged work station are smaller than at an assembly line. This is often not taken into account when the quantitative production goals for a disengaged work station are set.

The other extreme when it comes to the scope for variation of production pace is as mentioned an ideal assembly line (see figure 3.1). In practice there has to be a larger or smaller scope for variation for the operators' rate of production also at an assembly line, and by that a certain scope for, inter alia, production disturbances and/or working up.

Thus there is a certain possibility to work ahead also at the assembly line if it is possible for the operator to move along the flow of products and work at several different products. The operator work towards the flow of products direction by performing his work at work stations placed before the own work station in the product flow. In this way some assurance against future disturbances is attained.

To work along the product flow with access to several products at the same time is within certain Japanese automotive industry something that is part of the established way to assemble, and unregulated work ahead is not allowed. Instead one has for example within Toyota planned for the existence of a variation in the work time, as it is called, actually needed (see Section 4.3). For each operator there are along the assembly line eleven markings on the floor. The operator is normally expected to start working at marking number 3 to then be done with the work when he reaches marking number 7. The operator and his colleagues can thereby directly survey the progress of the work within the work cycle (one can see at which marking one self and ones' colleagues are at). Additionally there are for example information boards (displays), sound and light signals that help the operators to understand how the production is proceeding. To in this way immediately elucidate different types of disturbances to subsequently call for direct action are principles that lean production contributed to constructively make people aware of.

At disturbances the distance between the first and the third marking and between the seventh and last marking are utilized. Further there are possibilities to call for help from colleagues, and in extreme cases to en-

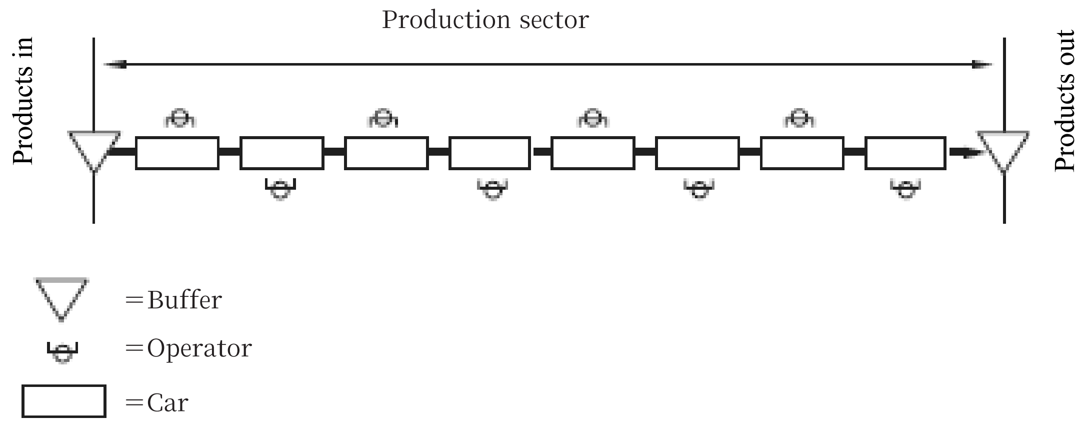

Figure 3.3　Example of principle design of a production sector at Toyota, where workgroups are surrounded by buffers and the operators have access to several products at the same time and follow the products on a rolling walkway. One has, in comparison with the Swedish assembly factories, a low operator density and thereby decreases the time losses, as they are referred to.

tirely stop the product flow within each production sector.

Also note that the number of products available to work on in relation to the number of operators, i.e. that the operator density (the number of operators per product) is of importance for the scope for variation of production pace in the way that the scope for variation is larger when the operator density is decreasing (see figure 3.3).

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In the Swedish automotive industry it is relatively common that an operator, in the case there are unoccupied positions alongside the products up-stream in a product flow, individually work ahead. The operators that have the right components and beforehand can interpret the production plan and variant specification can in some cases move long distances up-stream in the product flow.

To individually work ahead along the assembly line is however an act that is not condoned by the management, inter alia, because then one often does not follow the by the department for production preparation in detail prescribed way to work. Instead one might move material and tools and equipment with the consequence that one disturbs the work at other work stations at the risk of deteriorating product quality. On the other hand it has been shown that one of the few personal rewards that exist in individual work along an assembly line is to attempt to get as long continuous pauses as possible after working up. The operator is so to say competing with himself. (Karlsson 1979).

A few aspects regarding buffer functions and utilization

A different way of creating the scope for variation of production pace in both paced and un-paced product flows is to introduce buffers for work in process between the production sectors. Variations in buffer volume can then be utilized to smooth out the variations in the rate of production within the production sectors.

In order for the operators to be able to work up or catch up with production after a disturbance or after production sequences of an unusually time-consuming product variants, or to at all obtain self-control, it is however not only necessary to have access to buffers but also continuous information regarding how work performance is in comparison to the production plan. When a production system is designed so that a certain area on the shop-floor is utilized in order to be able to save a defined number of products in process, the products together with the empty buffer spots signals the buffers status in an immediate and tangible way. When the buffer spots are not immediately visible for the operator or the workgroup it occurs that buffer usage is shown through a number displays showing how these buffer volumes vary.

Depending on whether the scope for variation of production pace that is created by the buffers is used to parry production disturbances and to compensate for product variation or to give the operators increased self-control one talks about technical and social buffers respectively.

Examples of technical reasons for variations in the buffer volumes are, as mentioned earlier, that products require different amounts of time or that the material is missing, that a tool or some equipment is malfunctioning etc. Because of such technical disturbances it becomes important for the operator or workgroup to temporarily be able to increase the pace of work to thus when needed catch up with the lost production because of technical disturbances. The buffers that are shown in figure 3.3 are such technical buffers.

On the other hand the buffer volumes may also be utilized to temporarily work faster then required to maintain the planned production volume.

If for example the workgroup is ahead of the planned production one can take longer continuous pauses. In a self-governing workgroup one member can, based on agreement with his co-workers, temporarily leave the workgroup. In these cases the buffer volumes are used for social reasons.

If a buffer down-stream from an operator or workgroup has been emptied one can not immediately parry a production reduction since the operators or workgroups downstream will not immediately receive a product to work on (see figure 3.4) This illustrates that there is a competition between utilizing buffers to parry technical disturbances and utilizing them to work up and get pauses in the work. Rules and technical control systems for the workgroups pace of work in relation to buffer usage must therefore be well-developed. There are cases where a certain share of the buffer have to be utilized to give room for a lower rate of production at assembly of more time-consuming product variants.

It should be underlined that the possibility to work faster than normal is essential. A rule of thumb is to have the possibility to at least 20% over-capacity (excluding disturbances) to when needed catch-up the lost production (see Engström and Karlsson 1982 who give an account of the list of requirements on the production system that was previously utilized at Saab Scania).

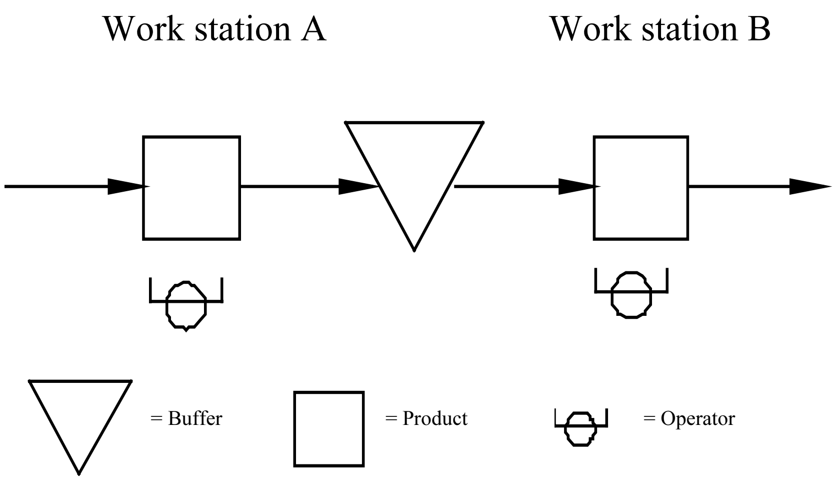

Figure 3.4　If the buffer between the work stations contains products in process the operators at work station B can continue their work although the work at work station A has stopped because of a disturbance. If however the buffer has been emptied during a pause at work station A the work at work station B is also affected by the production disturbance at the work station. A similar phenomenon can also occur between workgroups which is not illustrated in the figure.

Technical and administrative self-control

An additional way to create the scope for variation of production pace is to split up a longer un-paced product flow into several short parallel product flows. A production system with only parallel product flows consists of a number of disengaged work stations or disengaged station groups. The scope for variation of production pace for operators to workgroups will in this case, as has been called attention to above, be essentially unlimited, which means that the time loss can minimized and self-control maximized[14].

When it comes to self-control it is important to separate technical and administrative self-control. With technical self-control is meant freedom from the technical system, i.e. freedom from different kinds of technical dependencies such as being controlled by machines, that tools and equipment control what have to be done and how the work have to be performed.

Administrative self-control however means a freedom from being controlled by administrative routines, that is that the operator or operators can plan their own, and possibly their co-workers, work. To be able to obtain administrative self-control technical self-control must exist.

The self-control notion is fundamental to understand the underlying mechanisms in organizing self-governing workgroups. It is especially important to separate technical self-control on an individual level and technical self-control at the workgroup level. The difference between these manifest itself, inter alia, in that operators who cooperate can take longer continuous pauses than what is possible to get as a single individual.

The time when an individual or workgroup can take a pause should be possible to be used for something meaningful and therefore the buffers need to be relatively large. To make the work more efficient from a narrow production technical point of view by reducing the dependence between the operators, and thereby some of the time losses that the dependencies result in, however only requires a few places for the products in the buffer ―― further refer to the discussion in connection to figure 5.2, where it is apparent that the systems loss, as it is called, decreases considerably if there is one or two products in the buffer between the work stations.

In assembly in a production system with only parallel product flows, where the product is completed at a single work station or at a single station group, the need for buffers is largely lost. Therefore it is possible to jointly within a workgroup at any time decide to take a pause, or to temporarily both increase and decrease the pace of production in a way that is not possible at an assembly line. Consequently it is easier to meet the production goals in assembly with parallel product flows.

In production systems with parallel product flows the need for buffers is largely lost and thus no space needs to be set aside for such. This result in the usage of space being considerable more efficient in a production system with parallel product flows i.e. more products can be manufactured in the same factory space[15].

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To sum up, in this section we have emphasized that self-control at the workgroup level is an essential prerequisite for self-governing workgroups. Such self-control presupposes the scope for variation of production pace that in turn can be created in different ways.

Irrespective of how this comes about, for example with the help of buffers or by introducing parallel product flows, there are certain relatively generally applicable principles for designing, introducing and running self-governing workgroups. Such principles will be discussed in the continuation of this chapter.

3.3 Introducing and regulating self-governing workgroups

To introduce self-governing workgroups in an existing organization is a difficult task. This is true for affected operators as well as for the management and the supervisors.

Self-governing workgroups require, as mentioned above, changes of both technical and administrative prerequisites in an often not obvious way. Additionally will, inter alia, as a consequence of the delegated responsibility, traditional organizational boundaries be questioned. It is also not possible to get around the fact that a transition from a more traditional hierarchical work organization along an assembly line to self-governing workgroups will result in both winners and losers. Usually it is important that some of the affected are interested and can see more or less direct advantages from such a change. Parts of the personnel are hesitant. These are personnel that require education to be convinced and get a positive attitude towards the change. Lastly some remain who somewhat accurately fear that they will be worse off after the change. This is commonly personnel who have been adjusters, production leaders, resource personnel and supervisors along the assembly line. This state can in a principle sense, inter alia, be seen as a matter of fairness. Is it fair to let part of the personnel stop the others from getting a considerably improved job through, inter alia, increased responsibility and authority.

To change the work organization towards self-governing workgroups in an existing organization, where there are many internal deadlocks and sore spots to touch, is however not easy. It is, in our experience, not without reason that the mayor breakthroughs concerning new or changed organization of work, together with necessary changes of the technical and administrative prerequisites, generally have occurred outside already existing factories, often relatively far away from the actual main factory and also the head-quarter. It is well-known that possibilities for principally different solutions are opened when new production facilities are to be built. For example it is easier to make demands for group work and how this group work shall be organized when the majority of the personnel are to be recruited.

A phenomenon that is used as a way to shape the work organization is to consciously create a norm structure within the workgroup, in order to establish and maintain common norms of performance and common values, which eases cooperation between the operators. Such norms and values, where, inter alia, work performance can be based on work studies, shall have an effect to make the workgroup function as an independent point of planning with well-defined self-control, where there is an added value of cooperating with the workgroup. It is also important to ensure oneself that the desired norms and values remain with the workgroup. Therefore one should strive to have a relatively low, or at least controlled, employee turnover. Continuous controls are also required to ensure that some workgroups do not become elite groups while others become impoverished.

At start-up and the running-in period of new production systems pace training should be conducted periodically with intermediate evaluation which is considerably easier to realize in a production system with parallel product flows than along an assembly line where a corresponding procedure is on the verge of unreasonable.

Such pace training aspires to attempt a certain work pace, to then evaluate why one kept up with or not kept with the pace respectively. To not have to work extremely fast certain periods it is important to, in analogy with pace training in sports, be able to keep up with the predefined pace with the intermediate periods of rest (Nilsson 1986).

Regulation of the workgroups responsibility and authority is a specific problem area, which we only partly touch upon in this book. It is important that there are agreed upon and written down rules that define (i.e. regulates) the workgroups internal relationship, as well as how it have to function in collaboration with other workgroups and functions within the company. For example it is not acceptable to leave worn down tools and production equipment or not to restore buffer volumes when leaving the work place for the day so that the next shift, or those coming the next day, will have trouble to quickly pick up the work pace. There should also be regulations rules regarding cooperation, working up etc.

Except shaping the rules for the workgroups function, the technical and administrative prerequisites must be shaped so that they support, yes even accentuates these rules.

3.4 The size and internal distribution of work in workgroups

The issue of what is an optimal size of a workgroup virtually always arises when the organization of work is discussed. For automotive assembly self-governing workgroups of 5-10 operators is suitable. If the workgroups size is increased above this number communication is made difficult and the solidarity within the workgroups is weakened. This also requires that the placing of buffers and the design of product flows are performed so that the members of the workgroups work within a distance that enables eye contact.

If not possible to form such small workgroups, sub-groups should be formed. Such sub-groups must have a natural point of delivery of the work to other sub-groups. The delivery can be defined by the product being moved, that the operator gotten approximately half-way through the job, that a certain component can be assembled or that a certain operation has been performed etc. Such defined events must be able to be identified from a distance by all within the workgroup when working at their regular work stations or positions by the product.

Within a workgroup it is in many instances appropriate to pair the operators into groups of two with common work and responsibility. This is also true even if the workgroup has to be larger than the recommended 5-10 operators. The principle is to have one's regular partner to usually work with while at the same time being part of a workgroup with a spatial domicile with room to take a pause in close proximity to the work station.

The pairs formed, should generally be busy assembling, which is necessary to keep the production running. At the same time one of the operators should be less busy. He or she shall be responsible for technical and administrative prerequisites for the workgroups tasks and when needed support and assist the other operators. He or she has as a task to both before and during the process check tools, equipment and material, order replacements for discarded components etc. At the end of the day the workgroup together must restore the premises to the condition it has to be in for the next day or shift.

Work rotation within self-governing workgroups has as a purpose to increase the workgroups inner flexibility and also increasing competence and understanding of the surrounding world as well as how conditions within the company affect the workgroup. Inter alia it is important to achieve overlapping competences among the operators. To get overlapping competences will, according to the theory that taken responsibility carries with it greater freedom, bring about apparent advantages for the workgroup as a whole. As a consequence the operators should rotate between different kinds of tasks. If all members of the workgroup function as a "trainee" for example as a contact link between the personnel and the management the workgroup will as time passes get a comprehensive understanding of the external conditions for the job and also the possibility to have an influence on the external conditions.

During the start-up and running-in period of a production system the management must however occasionally lock the roles within a self-governing workgroup in order for the individual operators to achieve adequate competence. As a rule the operator must first feel at ease with certain specific tasks, know that he or she can perform a certain job at a certain pace and by that contribute to the collective achievement of the workgroup. After that is time to learn how to perform other tasks.

A good principle when designing self-governing workgroups is to make sure that there are several tasks that are appropriate for beginners to immediately learn. Such an example at Volvo's factory in Uddevalla was the assembly of doors, which was integrated into the workgroup. A car usually has four doors, which new employees first learned how to assemble. As a consequence beginners can trade other tasks with more knowledgeable operators during training periods before he or she can master the other tasks included in the workgroups' production commitment.

Another such task is to first learn how to collect material, for oneself or other members of the workgroup to then learn how to assemble, as it previously was done in Volvo's buss factory in Borås. An additional way to school beginners that proved successful was, as was done in Scania's buss factory in Katrineholm, to start working within the workgroups that were in charge of control and final adjustment, to then start to learn to assemble, being aware of the consequences of mistakes and the knowledge of feedback as well as detailed knowledge of product quality[16].

There is lot to be said for the principle to technically design production systems in a way that teamwork and thereby increased competence get an intrinsic value[17]. This is however in opposition with an increased individualization, which during the past ten years has become increasingly common in Swedish industry, which for example is reflected in current forms of salaries that increasingly tend to be based on individual competence and individual work performance.

4. Waiting time, insufficient time and different kinds of time losses.

Looking at the assembly line from the simplest possible starting point, as a product flow that passes two or more serially connected work stations or station groups[18], it is obvious that different kinds of waiting times for the operators occur, but also that the work time actually needed for the operator is not always sufficient.

In a automated serial product flow (without buffers) where the product is continuously moved, waiting time within the work cycle occurs if the duration of the work cycle at a work station is longer than the work time actually needed to perform a task (sometimes also referred to as operator time, required time, scheduled time), which means that the operators get a short pause before next work cycle commences. If the duration of the work cycle however is shorter than the time actually needed insufficient time, as it is called, occurs with the consequence that the operator must discontinue the work prematurely (he or she must send a product along that is not complete).

However for an un-paced serial parallel flow (without buffers), where the products are gradually moved, waiting time occurs when someone at the previous work station needs more time than expected for his work. Waiting time also occurs if the operator at a work station situated immediately after the operator's own has not had time to finish. The operator at the previous work station cannot send the product on and therefore cannot start work on a new product.

If one in design of a production system do not consider the waiting times that may occur, the operators must overachieve, i.e. work harder to reach the expected production quantity alternatively it is never possible to reach it as we discuss in greater detail below, or the product quality becomes low and one gets considerable after adjustments; whichever depends on whether one has a paced or un-paced serial product flow.

The occurrence of insufficient time in the product flow results in that many production systems have resource personnel helping out when the work time cycle for different reasons is insufficient. Alternatively supplementary assembly control and adjustments occur downstream in the product flow.

Consequently waiting time and insufficient time basically depends on that in a serial flow there is a time dependence between the operators while simultaneously the time an operator needs to perform his work varies. How this affects the need for resources in different kind of production systems can be understood through analysis of the time lapsed in the form of different kinds of time losses. These time losses are usually divided into balancing losses, variant losses and system losses as described below in this chapter[19].

To asses and compare efficiency of different production systems one can calculate their usage of resources in the form of work time. Differences between the work time actually required and the absolutely necessary work time that adds value to the product we refer to as time losses.

One way to analyze such time losses has been suggested by Wild (1975) in this book we utilize a similar method. In table 4.1 is, as an example, the need for resources shown in the form of working time in assembly of a typical Swedish car in a production system with serial and parallel product flow patterns respectively. The terms in the table are explained in the coming Section.

Table 4.1　Need for resources for assembly of a typical Swedish car in a production system with serial and parallel product flow patterns respectively. The table states theoretically defined time losses and real, observed time losses from a Swedish factory from the 80s with a traditional assembly line as well as a Swedish factory from the 90s with parallel product flows. The time losses are stated as percentage of the work time free of loss.

	Serial product flow pattern		Parallel product flow pattern	
	Theoretically calculated	Observed	Theoretically calculated	Observed
Balancing loss [%] :	5	30	1	5
System loss [%] :	25	80	5	20
Handling loss [%] :	6	25	4	15
TOTAL TIME LOSS [%] :	36	135	10	40
TOTAL USAGE OF RESOURCES [%] :	136	235	110	140

We have in table 4.1 chosen to use the "zero system calculation" as it is called. The method means that the time used, from the time the operator fixates the component in the position to be assembled until it is assembled, is regarded as work time free of loss, since it represents the absolutely necessary time that adds value to the product. Shorter work time than that is not possible; walking time at the work station and time for handling tools and equipment is not included. Material and tools are placed in the operators hands just at the moment it is needed. This is the absolutely necessary working time that time losses are calculated in relation to in the table and hence that is equal to 100%.

In the table above we see that the time losses are added to the absolutely necessary time[20]. For example we see that the observed usage of resources in the factory with parallel product flows is nearly identical to the theoretical lowest usage of resources with a traditional assembly line, see also Chapter 5.

Note that in all real production systems time losses exist. To in this way define a theoretical ideal situation, lead to that the efficiency in production systems with different design can be compared. Production system where for example the product flow pattern is designed differently can then, as done above, be related to the same theoretically ideal state[21].

4.1　Balancing losses

Balancing losses are caused by that in practice the work at an assembly line cannot be divided into equal parts that each and every one represents an equally long theoretically defined work time[22]. That it is the case depends, among other things, on that the product and by that the assembly work cannot be divided into infinitely small parts. In addition the product must be assembled in a certain order, which results in that it is not possible to combine work operations anyway one would want.

The operators hence will have an uneven work-load, and if we assume that no operator has a scheduled work-load exceeding 100% certain others will have less than 100%. The variation in theoretically defined work time per product between work stations results in the work-load at the work stations on average being less than 100%. On example of this is shown in table 4.2. In the example 92% of the work time cycle is scheduled, while the remaining 8% are assigned to balancing losses.

In the table above we can see that the work

Table 4.2 Examples of variations in theoretically defined work time between three work stations resulting in balancing losses.

Work station:	Theoretically defined work time [seconds] :
Work station 1:	107
Work station 2:	87
Work station 3:	101
TOTAL THEORETICALLY DEFINED WORK TIME:	295
Work cycle time:	107
Percentage share of theoretically defined scheduled work time for the entire product flow:	92%*

*) 295/(3×107)=92%

station requiring the longest work time, 107 seconds, is work station number 1. This work station will, no matter where it is placed, thus set the minimum limit for the time used for work on the other work stations, i.e. it sets the work cycle time. To calculate the share for the theoretically defined scheduled work time for the product flows three work stations one looks at the proportion of the total theoretically defined work time for the three work stations (above we see that it is 295 seconds) in relation to how long the work time will become if all work stations have the same work time as work station number 1, which was the one that had the longest theoretically defined work time. This is then 107 seconds multiplied by 3 (since there are 3 work stations), which is 321 seconds. We then see that 295 seconds constitutes 92% of 321 seconds.

4.2 Variant losses

Different product variants (for example that there is different equipment for cars assembled along the assembly line) require different work efforts and therefore result in varying work-load at the work stations. Variant losses, that in some sense are included in balancing losses, are time losses caused by variation in product varieties. If we suppose that no operator has a scheduled work-load of more than 100% the variant losses result in waiting time. The more product variants that are manufactured at the same time the larger are the variant losses. How large the variant losses become differs from time to time, since the number of products manufactured of different product variants varies depending on the customer's order.

There is one important principle difference between these two kinds of time losses defined here. Variant losses depends on and increase with the variation in work time that depends on that different product variants carries different tasks along with it, while the balancing losses for a given production system with a fixed work cycle time are constant, and will be there even if the product variants are completely eliminated (see example 2).

4.3 System losses, handling losses and training losses

System losses

Traditional production technique commonly use work times that are theoretically defined, and based on work studies, to thereby be able to distribute the work between the work stations. One does then largely ignore the significant effects of variation in work time that occurs when operators perform a repetitive task, which causes system losses. This type of loss is, in comparison to the other losses we discussed, the one that usually is the most extensive at an assembly line.

When an operator performs repetitive work, the work for different work cycles at a specific work station (the time actually needed) will take different amounts of time occupied although the tasks are the same. This depends on that one inevitably work at a different pace at different times. It is also true that different operators at specific work stations require different amounts of time to perform the same work. That is, the amount of time actually required varies between work cycles. Thus, there are differences in work time per product in addition to the differences described in the two previous sections, i.e. balancing losses and variant losses[23].

External disturbances that operators are subject to also have an affect, such as shortage of materials, tools or equipments resulting in different needs of work time, they are located in different places or malfunctioning, that components for some reason does not fit etc. No matter the causes of how this variation in work time arises it contributes to create an additional time loss, namely system loss. This variation arises both between operators and between work cycles, as illustrated in example 3 in appendix 1.

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Consequently in accordance with what is stated above the work time actually needed always differs for different work cycles irrespective of how experienced and trained a specific operator is. An average for this work time can then be calculated. When one calculates averages one often expects it to be about as many long as short values; one will then get a symmetric distribution, often a normal distribution as it is called.

In manual labor however the distribution

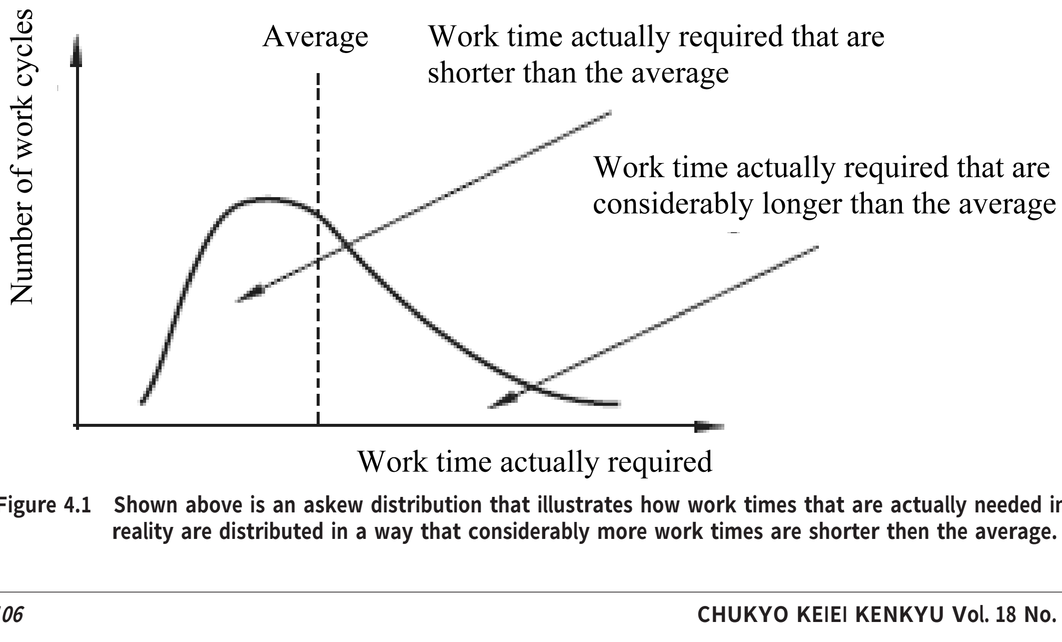


Figure 4.1　Shown above is an askew distribution that illustrates how work times that are actually needed in reality are distributed in a way that considerably more work times are shorter then the average.

of work times always becomes askew since the work performed always takes some time, while, inter alia, disturbances some times result in the work taking a considerable amount of time. This means that considerably more work times, that actually are needed, are shorter than the average value[24]. In the diagram in figure 4.1 we can see a line illustrating the usage of time for different work cycles. The average value is represented by the broken vertical line.

We can see that it is foremost the long work times that deviate from the average, not the short work times. Hence in this context one cannot set the work cycle time based on the longest time actually required (this has been marked at the right in the figure). Therefore one has to deduct the very long work times that sometimes may occur.

Because of this it is common to in practice distribute the work after an average but add a percentage on the envisaged work cycle time so that it becomes slightly longer than the average work time. Consequently when product flows are designed and proportioned the fact that work time cycles require different amounts of time is largely disregarded by the companies.

When the work cycle time for a specific work station is insufficient the consequence often is that the subsequent work stations are disturbed or that the operator is not able to carry out complete assemblies.

If the product flow is not stopped the remaining assembly work must be carried out by resource personnel[25] along the product flow and/or special adjusters in a separate division. To detect what has not been fully assembled along the assembly line, extra inspections of every product is required. The adjustment work sometimes carries extensive dismantling along with it to be able to reach and fix what has been overlooked before and that possibly has been built in during the subsequent assembly work. This need for adjusters also creates needs for other kinds of measures, for example such mistakes cause extra material management and administration —— this because components sometimes are damaged in dismantling and must be replaced quickly, which for instance requires that they can be ordered in a fast and efficient way.

A time loss of partially different kind is connected to the need for replacements in a serial flow. In such a flow all work stations must constantly be fully manned, otherwise it is not possible to even start producing. If for example the operator or the operators at one work station are absent the work there ceases, and with that the work at the other work stations in the same product flow will also be forced to cease. Consequently there has to be replacements for operators in case of illness, training, meeting, visits to the lavatories etc. Since the need for replacements varies their time will not always be fully used. Replacements are therefore also commonly calculated into the system losses.

Handling losses

Apart from the time losses that have been discussed above there are also other important time losses in production systems. One important loss of that sort is handling losses. It refers to time when the operator handles tools and also material during the course of the work and moves himself between different positions at the work station. This loss varies quite a lot depending on how carefully one has designed the work station and the supply of materials.

To exemplify the extent of handling losses figure 4.2 shows such losses for a production

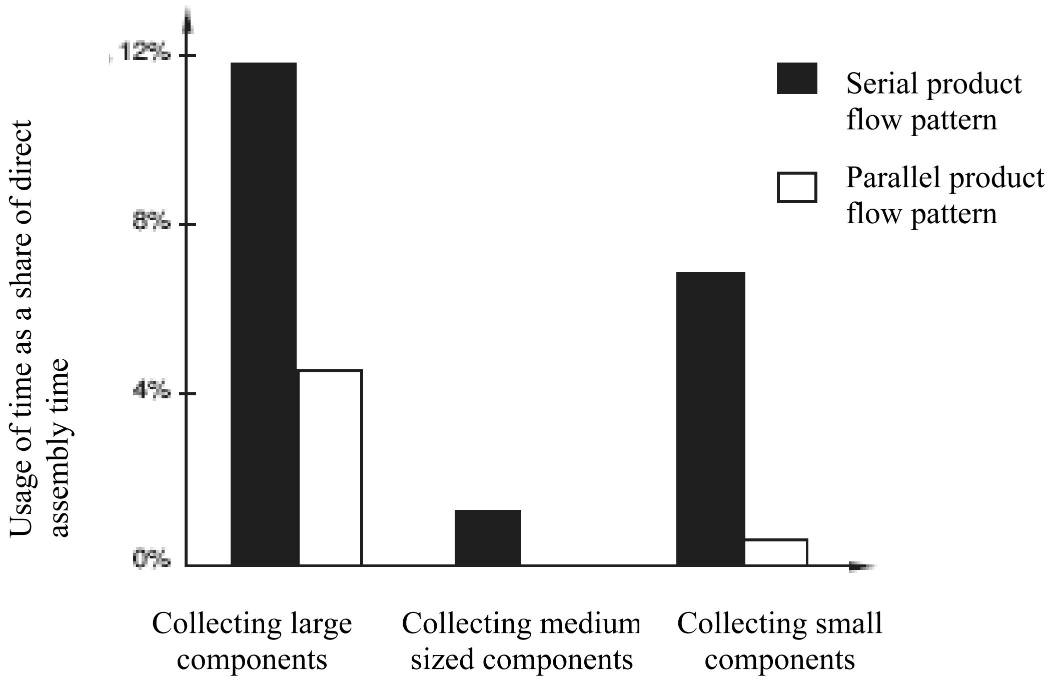


Figure 4.2　Comparison between observed usage of time according to video surveillance for handling losses in two production systems with different design, namely serial and parallel product flow patterns respectively in a studied production system. The handling losses have been calculated as a share of the work time actually required for the product.

system with a serial product flow pattern. There the handling loss is also compared to a production system with a parallel product flow pattern. In both these cases it is the same product that is being manufactured.

The considerable difference in handling losses between the two production systems depends on the completely different ways that material is supplied. In the serial product flow pattern the material is supplied in a traditional way, while it in the other production system comes in a batch for each product. We will get back to this in Chapter 7.

Training losses

With training losses we mean time lost because the operators require time to learn the job and cannot immediately perform at full pace. In otherwise equal circumstances the training losses naturally increase when the content of the work increase quantitatively, so that the training losses to the contrary to some of the other covered time losses (namely balancing and handling losses) tend to increase when the work cycle time increases. This connection is however often less important than one might think, since the training losses to a large extent is also effected by other factors such as staff turnover and information and materials management for the assembly work. The latter is discussed in greater detail in chapters 6-7.

5. Regarding the magnitude of the time losses and how they can be reduced.

In the previous chapter a number of time losses that occur in work in a serial flow were defined, and in connection therewith we brought up the reasons for such time losses occurring. Here we will take a closer look at the factors that influence the magnitude of the time losses. Knowledge of such factors creates opportunities to reduce the time losses, which naturally is of interest.

5.1 The magnitude of the balancing losses

Within many companies extensive production technical resources are put into reducing balancing losses. For this purpose there are different mathematical decision rules and computer program that are used to under defined conditions distribute the work as evenly as possible between the work stations. However often one does not care about other types of time losses, particularly not system losses. Either they are not known or they are considered not easily effected, since often they cannot be dealt with unless the entire production system is rebuilt.

Here we will not go into further detail regarding the different mathematical methods of evenly distributing time between work stations, but instead point out a more basic factor, namely the work cycle time's influence on the balancing losses. Theoretical calculations, also supported by practical experience, have resulted in generalized lines in accordance with figure 5.1 that show how much the balancing losses under ideal conditions at least will amount to. As is apparent the balancing losses increase the shorter the work cycle time is, since it is more difficult to evenly distribute the tasks between operators when the work cycle time decreases.

That the line shows dispersion, i.e. that is made up by a field, depends on the products

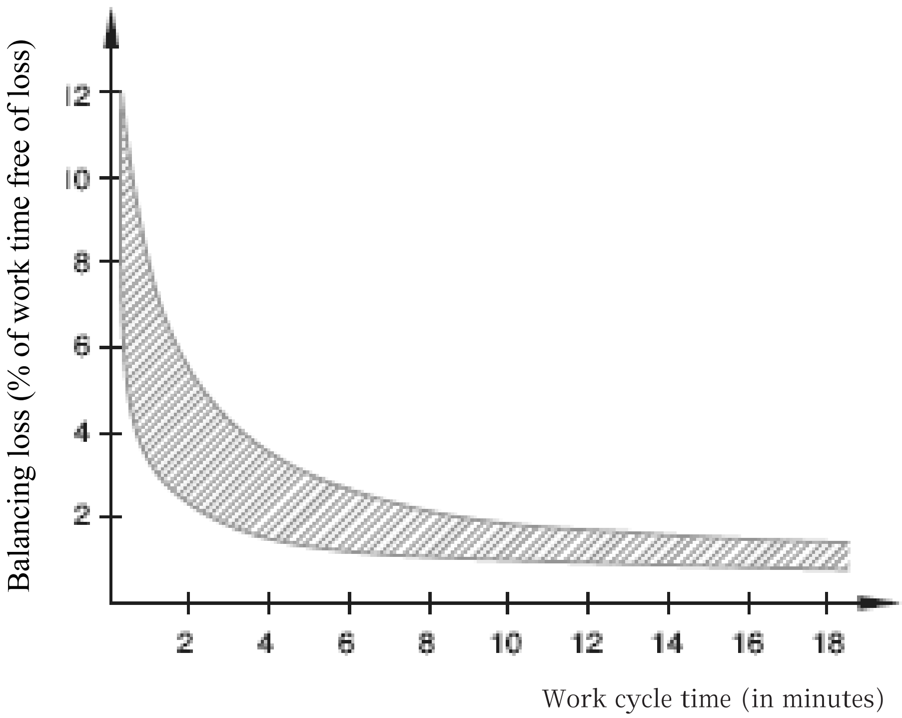


Figure 5.1 Diagram of how theoretically calculated balancing losses are altered when the work cycle time changes (Wild 1975).

being different. It is easier to evenly distribute the work at work stations when the work is made up by several smaller tasks, which often is the case when the product is made up by several small components. However if the product being assembled has few, large and/-or heavy components, it becomes more difficult to obtain a high and even work-load. In the latter case, one then follows the upper part of the field to estimate the balancing loss.

The longer a flow of products is, i.e. the more work stations it contains[26], the shorter the work cycle times become, which consequently means that the balancing loss increases. However if all work on a product is performed at a single work station, as the case may be in a production system with parallel product flow patterns, no balancing loss occurs, no matter the length of the time of the work cycle.

5.2 The magnitude of the variant loss

The variant loss in a serial production flow pattern has been discussed in the previous chapter. In a production system with parallel product flow patterns, where the entire product is assembled at one work station, there is no variant loss since the product is allowed to remain until it is assembled and it is possible to get a new product when required.

Variant losses can also be reduced if there is a possibility to level out between the product variants, i.e. if surplus of time created in work on a less time consuming product variant can be made available for work on a more time consuming product variant. This can be done in different ways such as using buffers between the work stations (which we will get back to) or applying sequence balancing as it is called, which means that more and less demanding product variants are mixed in the flow of products. If there are workgroups where one simultaneously works on several different products the possibility for such leveling out also increases.

5.3 The magnitude of the system loss

There are, as we saw in Section 4.3, a variation between work stations as well as between work cycles regarding the time actually needed to perform the work. Both these types of variations cause system losses. Note that this is true irrespective of how experienced and trained the operators are and even if there is no variant or balancing loss.

In a serial product flow, where the products can not pass each other, it is at every instance the work station where the assembled product requires the longest work time that sets the pace for the product flow, like when one is stuck in traffic it is the slowest car that sets the pace.

That the system loss increases the more work stations there are in a serial flow can be resembled to the more cars there are at a traffic light when it is red, the longer it takes for every car to drive off when it becomes green. (Besides the risk of there being a driver who starts slower than the others increases the longer the line of cars is.) The more work stations there are in product flow, statistically the larger the difference between the average work time and the longest work time becomes, i.e. the larger the time loss.

Figure 5.2 shows an example from Wild (1975) that system losses increase when the number of work stations following each other in an un-paced production flow increases. The more serially connected work stations without buffers the larger the system losses and thus the less the production capacity. However when there are buffers be-

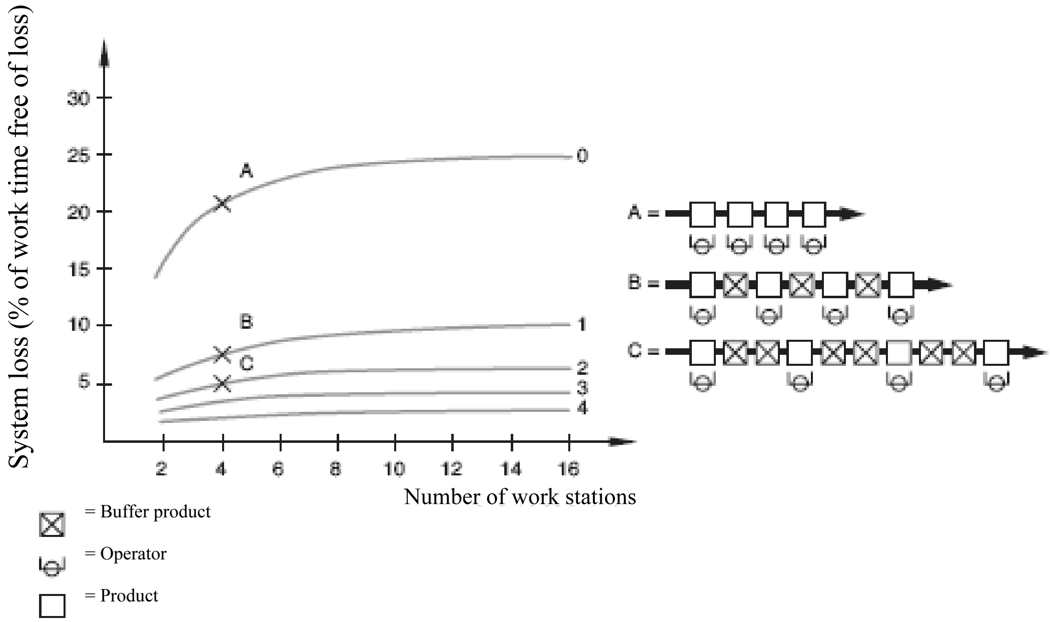


Figure 5.2 Diagram of theoretically calculated system losses (Wild 1975). The diagram illustrates how the system losses are related to the number of products in buffers and the number of work stations. The different lines represent buffers of different sizes placed between the work stations (from "0" in case no buffer exists up to "4", which shows that as many as four products can be in the buffer).

tween the work stations leveling out becomes possible, so that the system losses decrease[27].

As can be see in the diagram in figure 5.2 the system loss is large where one has no buffers and that it increases the more work stations there are. If we look at the line that illustrates an un-paced serial product flow without buffers the system losses are large even when there are only a few work stations. The system loss also increase with the number of work stations (it is for example already 15% in an un-paced serial production flow that has two work stations following each other, but then levels out and is for example approximately 25% in an un-paced serial product flow that has 16 work stations). It is also interesting to note that there is a quite clear limit where the increase of the system loss de-escalates; we see that it is after approximately four work stations.

5.4 Methods of reducing balancing, variant and system losses

When it comes to design of product flows and work organization there are some more or less obvious ways to reduce the time losses covered above, primarily system losses which usually is the most dominant. It is, inter alia, possible to:

1 Replace a long serial flow with large time losses with many, short, parallel product flows so that not so many work stations become dependent on each other. Time losses in each and everyone of the short, parallel product flows become smaller - in an extreme scenario each product flow only consists of one work station and there are no time losses whatsoever because of queue formations. We noticed that in connection with the discussion at table 4.1.

2 Introduce self-governing workgroups where two or more operators work together. This means that one can use the flexible division of work between the operators, inter alia, by having coinciding competences to be able to help each other. Consequently it becomes possible for the operators to in different ways compensate for the waiting time that occurs or find more efficient ways to work. The workgroup in this way acquires an elevated inner flexibility

3 Enlarging the work within a workgroup by integrating pre-work stations and/or increasing the number of products immediately available for work, which means that the direct work, as it is called, is enlarged. In this way there are more available work positions than operators, which can be utilized to gain the sought after inner flexibility. The possibility to make use of work stations with preparatory work as extra work positions results in one being able to save pre-worked components in a buffer within the workgroup, which consequently further raises the inner flexibility[28].

4 Extending the work within a workgroup by also integrating the tasks that can be performed separate from production, which also means that the indirect work, as it is called, is increased, and by that the workgroups inner flexibility is increased. Indirect work that is performed for every product produced, is for example handling of materials, cleaning and administrative work. The indirect work can function as a buffer between individual products since the tasks can be flexibly changed between the operators. What is called indirect work, possible to perform at any time, fulfill the same function but also makes it possible to include the resource personnel, as they are called, in the workgroup to help out in different ways. It is often tasks such as certain maintenance and production technical work, but also some types of handling of materials.

5 Introduction of buffers between work stations, station groups or production sectors in a serial flow to render leveling out between work cycles possible, whereby some significant time losses are reduced in accordance with what has been discussed in this and the previous chapter.

6 Letting the operators at an assembly line themselves temporarily prolong the time of the work cycle, which also facilitates leveling out between work cycles. This occurs if tools and equipment makes it possible to work on products outside the own work station. To work outside the own work station can however result in the operators disturbing each other, since one does intrude on each others work stations, and the handling losses increase because of the longer distance to walk. Leveling out through working up is facilitated if the operators are scarcely placed, i.e. if operator density is low, just as if the operators' competences overlap in a suitable way, so that they more easily can perform each other's work and thereby increase the workgroups inner flexibility.

Besides it is also possible to reduce the variation in the work time that is actually needed through among other things to in different ways standardize the product and/or the assembly work. One can for example reduce product variants, introduce standardized work methods, improve the quality of components, carry out selective hiring of personnel etc. Alternatively the product design can be changed so that the need for adjustment and fitting work that often occurs during assembly to finalize the product is reduced. This means that one reduces the number of required components, assures oneself that the components are of the correct dimensions etc.

These methods to reduce the time losses through in different ways standardizing the product and/or the assembly work, does however entail direct and indirect costs which might be larger than the advantages gained by reducing the time loss. Efficient assembly line work consequently tends to require large product development costs that therefore have to be spread out on large production volumes. Alternative assembly systems with buffers and/or parallel production flows can however improve the total economy by reducing the product development costs (compare discussion in Section 1.3).

Finally it should be observed that the methods described above to reduce time losses to a large extent can be combined with each other, although the extra benefit of using an additional method is diminished when the time losses have already been reduced through usage of other methods.

5.5 The magnitude of the handling loss

The handling loss refers as has been explained in the previous chapter to the part of the work time during which the operator handles tools and material during the course of the work and also moves himself between different positions at the work station.

The magnitude of the handling loss in part depends on the work cycle time and in part on how the material is supplied, placed and exposed at the work station and also on how tools and equipments is chosen and arranged at the work station.

The shorter the work cycle time is the larger share of the work time is consumed by handling material and tools. The handling loss can become very high in extremely short work cycles (see figure 5.3). When the contents of the work increases and the duration of the work cycle is prolonged longer continuous periods of time will be possible to use to perform other tasks such as for example handling of materials. This state can be utilized so that the operators themselves can get material from for example nearby storage room (referred to as a material place). This can occur without the handling loss becoming too extensive. The supply of material can in this case be designed efficiently without automatization.

How the supply of materials is performed, and by that how the material exposure at the work station is organized also has great significance to the magnitude of the handling losses in a given work cycle time. If for example material to the operator is exposed in the form of a batch of material for each product good conditions for a small waste of material and good product quality is created and furthermore training for an extensive work contents is facilitated (see figure 4.2 in Chapter 4).

5.6 Closing remarks

To sum up above we have shown that there are many possibilities to reduce time loss in

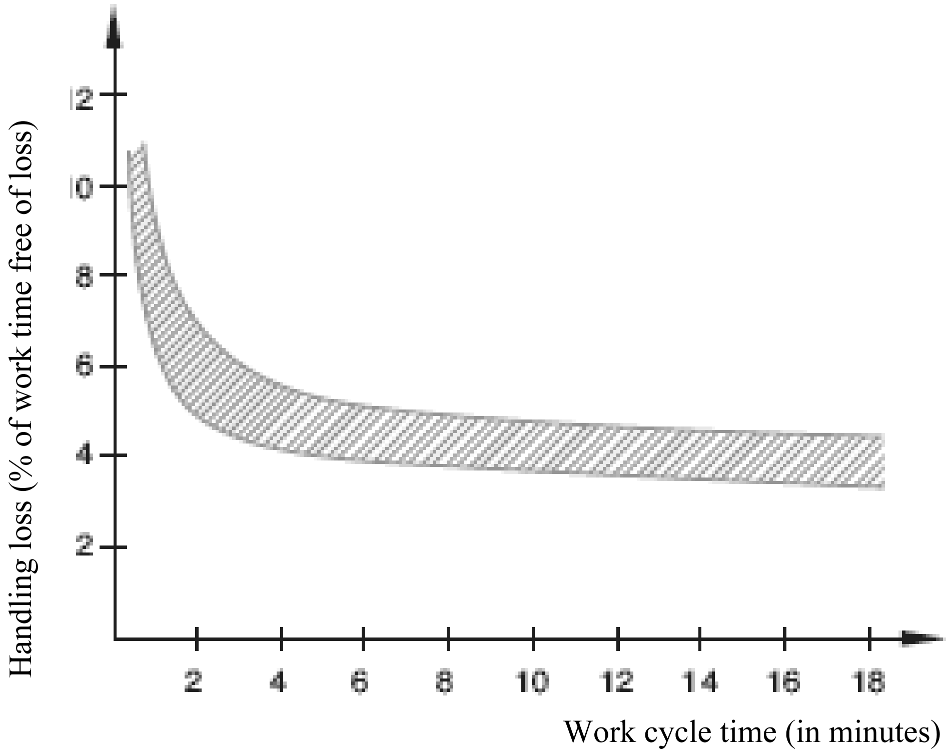


Figure 5.3　Diagram that shows how theoretically calculated handling losses change with increasing work cycle times (Wild 1975).

a product flow. We have among other things established that:

—System and variant losses are reduced the shorter the product flow is and/or if buffers are placed between the work stations or station groups. In the latter case there is from a technical point of view an upper limit to how much buffer sizes can reduce the time loss.

—Handling and balancing losses are reduced when the duration of the work cycle is prolonged, which is the consequence if the product flow is shortened.

Thus there is, as we have shown, a production technical motive to use buffers between work stations in a serial flow, namely to reduce the time losses. Buffers also have, as have been discussed in chapter 3, a social significance by creating the possibility to increased self-control. By varying the pace of work it becomes possible to accumulate the pauses that arise in repetitive work so that the operators have longer continuous periods of time at their disposal, which for example can be used for what is called indirect work or for longer continuous pauses.

If one fully applies this reasoning it is however apparent that it is possible to reduce the total need for buffers considerably if one has parallel product flows. At the same time increased productivity is gained through the drastic reduction of balancing, variant, system and handling losses at the work stations. It is possible to calculate the advantages in the form of reduced time loss before a new production system is planned. This procedure is nevertheless according to our experience not very common in the Swedish automotive industry.

To sum up, in a workgroup where the operators have overlapping competences to perform the tasks the time losses will be possible to reduce. It is still significant that the productions systems with parallel product flows are properly designed. If there for example are too many dependencies between the operators because of too large workgroups[29] or if the operator density is too high large time losses may occur.

6. Structuring of information for holistic assembly work

A job with an extensive work content places entirely different demands on both individual operators and the workgroup than a job with limited work content does. By in a versatile manner making use of people's different talents, intellectual as well as emotional and manual the traditional division between manual and intellectual task is altered; in this context we talk about what is referred to as holistic assembly work.

Simply put holistic assembly work includes that one masters and continuously handles a number of phases: knowledge of materials, structuring, assembly, control and adjustment measures[30]. Thus the actual assembling is merely a part of the assembly work. Below we will first of all cover the structuring phase. Structuring means that the assembly work is based on how the product is constructed and also on how the components that it is comprised of are related to each other and the finished product.

An important prerequisite for design of production systems with holistic assembly work is what is known as holistic learning which among other things involves the work being organized so that the operator can see the products and the work (see for example Nilsson 1992B). This learning is significantly different from traditional what is referred to as additive learning as described in Section 6.3.

6.1 Divided work, unstructured information and badly-arranged material exposure in assembly line systems

At the assembly line the work contents at each work station is limited and repetitive. The operator can see one or a few minutes of his and possibly even a few of his co-workers work, on the assumption that these co-workers are at adjacent work stations and are not blocking the view. This view covers a very limited part of the total assembly work, which often includes ten to twelve hours for a car and forty to fifty hours for a truck.

For the operator these conditions mean that he or she often lacks the big picture and an understanding of the connection that the product and its components have. This view is further limited by the fact that the production engineers attempt to utilize the work cycle to a maximum, which causes components that are naturally connected to not be assembled at the same or at adjacent work stations. Instead the operators often have to assemble the components that are located in the immediate vicinity of his or her position along the product, which means that the components are not naturally connected. If for example an operator is working kneeling in a coupe of a car it is highly likely that he or she may assemble as many components as possible that are available in the immediate vicinity of the location on the product where he or she is. Hence these components, that represent a limited work content of perhaps a few minutes, do not have any meaningful reciprocal relationship, and thus cannot be understood in relation to the other already assembled components.

Small components along the assembly line are located in compartments sorted by item number, while larger component are delivered from the subcontractor in standardized unit loads with several identical components. At the same time some components are also placed in different kinds of packages, generally placed in accordance with the planned production sequence prescribed by the production plan.

This way to expose the material makes it impossible for the uninitiated to based on the material ascertain what is going on at other work stations than the one or few he already completely masters. The occurrence of product variants that require different components further renders it more difficult to get the entire picture.

Besides the work stations at an assembly line are generally speaking placed in a long corridor-like space running through the entire factory. Therefore the operators are sometimes working surrounded by long, almost endless, facades of material that rise several pallets up in the air. Such a layout makes it difficult or impossible to see what is going on at other work stations.

The work instructions that exist in detail describes a few minutes of work. To based on these work instruction get a comprehensive view of the entire product or the work performed on the entire product is impossible. To get a comprehensive view of several work stations is usually not possible either and it has not been the intention either. This state depends on that the work instructions are as fragmented as the work itself and only suited to describe the work in great detail. Are these work instructions collected in the form of paper print-outs they fill far too many binders to convey a picture of the whole process.

The same condition is true for the description of exactly what components that are to be assembled on different product varieties, often referred to as variant specification. This specification is often made up of a paper print-out (a form), which specifies the work that is to be performed within a certain production sector. To with the aid of these product specifications understand the product and the product variation is not possible. The components that are to be assembled are virtually only described by item number. Plain language designations i.e. comprehensible information in plain language and product varieties described in an understandable manner are seldom used[31]. (With a limited work contents the lack of plain language designations does not have any immediate significance, but creates considerable difficulty in the case where an efficient assembly work that is more extensive, and qualitatively different with larger self-control is sought after.)

6.2 Assembly work based on the product

To sum up, at the assembly line it is accordingly so that the product has components that for different reasons are connected to each other, and different product variants are in a systematic way different from each other, but the information as well as the material are unstructured and difficult to grasp, and the work is divided in a way that makes it impossible to grasp the connection and relationship within and between the products. How the work that is performed on the products actually fit together with the assembly of the products is a secret that is kept from the operator along the assembly line[32].

If the assembly line is not seen as a fundamental prerequisite for manufacturing within the automotive industry, but we instead in an unbiased way discuss how vehicles most simply and efficiently are assembled, what would the result be? We have to ask ourselves both what we want to achieve and under what conditions it is possible to achieve it.

For all production systems it is true that the expected production quantity, the total time the product requires and the time losses control how many operators and work stations that are required for manufacturing, and in manufacturing large quantities of for example cars we are talking about hundreds of operators and work stations. In assembly line systems it is obviously the total assembly work that have to be distributed among the work stations in a way that the assembly on all products are performed at all stations, i.e. a serial product flow is a given. That means that the number of work stations control how far-reaching the division of labor becomes, and the number of workstation in relation to the total time required for the product sets the work cycle time. The design of a production system hence controls the contents of the work; the assembly line creates fragmented work, time prevails over work. For each operator a certain period of time has to be filled to the brink with work.

It is however actually not necessary to have such fragmented work; Instead the product itself and the components it is made up of can directly decide the work contents and the work organization, i.e. the assembly work should be holistic. In auto assembly that implies that the car coach or the truck frame is selected as a starting point for totality in assembly since these are the only totalities available on the shop floor —— a stripped car coach or truck frame enters and a finished vehicle with all the components assembled exits the production system.

How is it then possible to relate the stripped body of a car or a truck frame with the completely assembled car or truck in a way that the components being assembled are possible to relate to each other in order to make the assembly work holistic? That is, how do we create different kinds of contexts on the shop floor?

One such way of creating such a context is to consciously assure oneself that there is always a correspondence in: (1) the way of exposing the material that is to be assembled, (2) how one works with assembly and (3) the description of the assembly work. These can also been seen as three different reflections of the product itself.

This implies that the material that is to be assembled have to be structured for it to be possible to expose in pedagogical manner, while at the same time conform to the work instructions, variant specifications etc. If the operator believes that he has the wrong material it has to be easy to in the work instruction find out whether he remembers wrong or he actually got the wrong material. The consequence of exposing material like this is an assembly work based on a whole different logic than the prevailing, and needs —— yes, requires altered technical and administrative prerequisites. Exposure of materials and the information communicated to the operators has to change —— how else is it possible to understand and observe the relations and contexts that are essential to the assembly work. With that a different supply of information and material is required.

A first necessary step is however to, so to speak, on the shop floor re-establish the "inherent logic of the product" to first make it possible to in a comprehensible way describe the product from an assembly point of view, to then structure the information and material in order for it to support the work (this logic does not exist for the operator at an assembly line and often not for the production engineers and preparatory staff). We will get back to how it is possible to describe the product in a logical, and from an assembly point of view, appropriate fashion in Section 6.3 below.

The organization of work should in this context be based on some kind of teamwork, where one preferably should be able to see what one's co-workers are doing or have done. Some form of division of labor is necessary in order to make it possible to in an appropriate way distribute the work within the workgroup. This division of work has to be based on work studies for it to be at all possible to divide the work between the operators and also be able to accomplish performance agreements within the workgroup. There also has to be a recommended way to work, and this should be described in detail.

Deviations, within certain boundaries, from the recommended way to work have to be possible for example in the case of a workgroup not being fully manned, having a temporary shortage of material or possible problems with tools or equipment or when different product variants are assembled. That for example the division of labor and the assembly sequence between different operations varies does not mean that the requirement on the result of the work, the specified product, changes.

From a learning point of view it is also appropriate that several finished and half-finished products can be observed by several operators at the same time and serve as physical work instruction, i.e. the products should be placed adjacent to one or more operators so that they understand what their work is preceded by and result in.

The assembly line should based on our experience be replaced by self-governing workgroups where several products are idly placed close to each other and the operators can during the course of the work alternate between the products. It has to be possible to communicate with each other during the course of the work —— if not always verbally one should at least be able to see each others facial expressions[33]. Besides a consistent linguistic usage (a nomenclature) that entails correct designations for the components, not merely item numbers, is most valuable. How else is it possible to communicate among themselves about the work in a workgroup, but also with other workgroups or other concerned parties within the company if they do not know what they are talking about?

It has to be possible to describe the work in a way so that it can be divided, and then in a fashion that is based on the product. The description of the work should reach from a stripped body of a car or a truck frame all the way to the finished product. Consequently the division of labor is a prerequisite also in alternative assembly systems, but it has a different basis than at the assembly line.

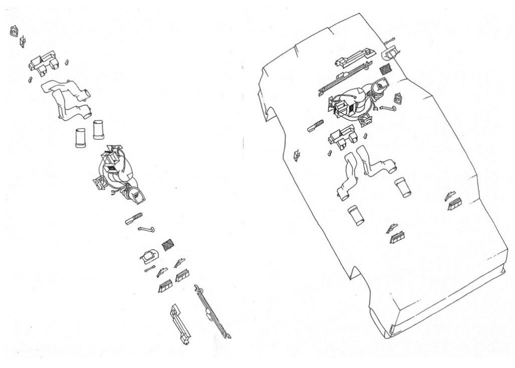
6.3 Holistic learning

To create the contexts that, in accordance with the previous Section, are a prerequisite for holistic assembly work means that it is necessary that the material is structured to create and enhance relevant connections. It is all about creating order, to comprehend and organize ones own and others work, and further more economize ones thinking. This in turn is an important prerequisite for what is called holistic learning.

To learn assembly work, especially if it is rather extensive, the operator first needs to have a comprehensive idea of what it is all about. The foundation of all learning is that humans create internal mental conceptions, structures, which facilitate learning. In what is referred to as holistic learning one departs from an understanding of the whole to then understand and learn the details. It is by starting out from the totality possible to relate details to one another in time and space. In assembly work it means that the individual tasks and components can be related to one another and to the product as a whole, which facilitates the individual operators learning as well as the cooperation within a workgroup.

By utilizing holistic learning it is possible to with relative ease learn an extensive work contents. In assembly of a car holistic learning has resulted in work cycles with a duration of one to two hours (which corresponds to almost a fourth of a car) up to 10-12 hours, i.e. assembly of the entire car. This can be compared to the work contents of one or a few minutes that is common along the assembly line. In almost all cases within the industry what is referred to as additive learning is used to train the operators at the assembly line. This principle of learning means that operator gradually learns more details as time passes. In car assembly that results in an upper limit of a 20 minute work cycle with as mentioned above an economically realistic learning time.

The assemble work in holistic learning thus becomes qualitatively different in comparison to additive learning since there the details are piled on top of one another. Figure 6.1 illustrates the difference between the



Additive learning Holistic learning

Figure 6.1 The figure illustrates the difference in the structuring of material (for air condition equipment) based on additive (to the left) and holistic (to the right) learning respectively. In accordance with the holistic learning the assemble sequence is decided based on the components organized in a holistic fashion (to the right). Different assembly sequences are then resembled to alternative routes on a map, which for example facilitates assembly of separate product varieties.

Figure 6.2 Above to the left is a hierarchical structure that for example describes a company's organization or a product shown. Above to the right it is shown that this structure also can be resembled to a pyramid. At the top of the pyramid is some kind of totality, at the bottom the smallest constituent part, in between smaller and smaller gradually distributed constituent parts.

holistic and the additive learning.

6.4 Hierarchical structures for holistic assembly work

Since information and materials that are to be assembled have to be organized in an appropriate fashion it is necessary to utilize and develop some kind of structure for this. A certain kind of structure is the hierarchical structure that starts out in a top and then gradually branch off into smaller constituent parts. Consequently with the help of a hierarchical structure it is possible to simultaneously separate the totality and its constituent parts (see figure 6.2)[34].

The products that are to be manufactured are described in similar way to a company's organization. The entire product is seen as a totality that then is hierarchically divided into smaller constituent parts. From the top of the pyramid, which the total product structure constitutes, the product is divided into defined systems and components that then gradually can be further decomposed down to the smallest screw and plate. Functional requirements, tolerances, modules of the product etc. that concerns the product will represent different cuts of the hierarchical structure. Commonly one talks about what is called a product structure and then have precisely a hierarchical structure that describes a product in mind.

Hierarchical structures that describe the product is of crucial importance to make work division and surveying possible, irrespective of if it is a matter of construction work, preparatory production work or assembly along an assembly line or work within a self-governing workgroup. Note that a product, as well as a production system, is possible to describe in several different ways with different hierarchical structures that are appropriate for varying purposes.

Is product information in the Swedish automotive industry today structured in fashion that supports a holistic assembly work, with a for assembly appropriate hierarchical product structure, where it is possible to swing from totality to constituent parts and from constituent parts to totality respectively? In short, the answer is no[35].

Hence what is required, especially to support holistic assembly work, is a reconstruction of the "inherent logic of the products" in order for it to be restored on the shop floor. In other words a hierarchical assembly orientated product structure which describes the product in a way that makes it possible to structure the components that are to be assembled in a fashion that makes it possible to take in and understand the product is needed. This structure forms the basis for the design and description of the work[36].

To create such a hierarchical assembly oriented product structure the components that are part of the product have to be structured in specific way, i.e. form separable groups of material, Main groups as well as sub-groups of components, have to in a hierarchical way be separable from other components and simultaneously be able to receive a relevant designation (see figure 6.3). When one sees the components the designations should make sense, and based on the designations one have to be able to visualize the components.

For example in assembly of cars we found that the requirement of separability meant that the first main group (wires for electricity, air and water) ended up including long thins components that were immediately separate from the components in the other main groups. In the other main group (drive line) it was mostly larger components connected to driving shafts and the engine. The first main group can be resembled to a nerve system comprised of different sorts of wires and relays etc. while the other main group is connected to power production and power

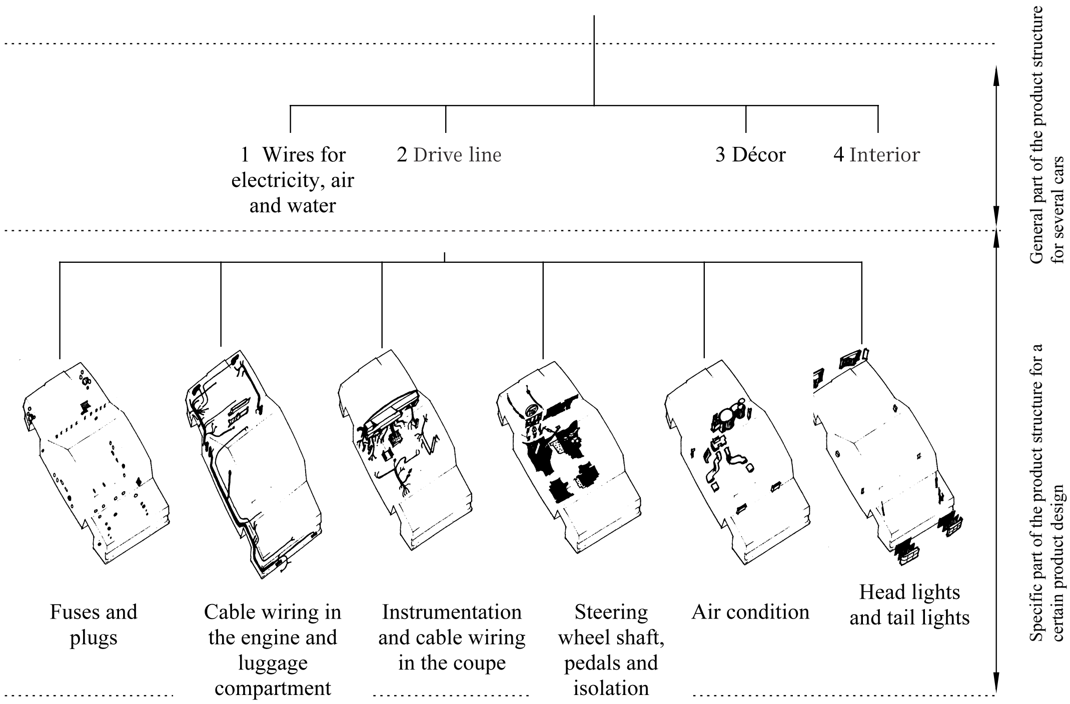


Figure 6.3 The hierarchical assembly oriented product structure that has been developed and realized in practice for cars divide the car into what is referred to as main groups: (1) wires for electricity, air and water, (2) "drive line", (3) decor and (4) interior.

transfer, to once again use a human as an analogy it is more to be resembled to the system of organs such as heart and lungs[37].

6.5 Holistic assembly work and common sense

Production along an assembly line is characterized by being extremely fragmented work with the purpose to, in a narrow sense, utilize the operators manual skills, while simultaneously the labors exchangeability is maximized so that it with a limited training period is possible to quickly be able to perform at full pace.

When we deal with as a complex product as we speak about here it is according to our experience not sufficient to merely change the flow of products and the supply of material to successfully reform the assembly work. If the work content is increased considerably a radical change of the way to learn the assembly work and the way to describe the product is also required. In a work time cycle exceeding about 20 minutes in duration in car assembly and about 40 minutes in duration for truck assembly are among other things extra-ordinary measures regarding the way to from an administrative point of view describing the product required.

Nevertheless it is not correct to equate work at the assembly line and all the work performed the industry. Assembly line systems as it is utilized within the automotive industry are an example of one of the technically and organizationally most complex industrial enterprises there are, precisely because the manual labor is so extremely fragmented.

In smaller places of work and within small businesses the automotive industry will therefore seem too complicated and by that distant. In a way it is all about common sense, logic and obvious things. The product and its components, as well as descriptions of the product, have to be possible to get a comprehensive view of if it is to be possible to accurately design and learn the work. That the operators have knowledge of the correct designation of the components that are to be assembled may seem banal for someone working in a smaller place of work, especially for a skilled employee, but it is as have been described above not obvious for work along the assembly line in the automotive industry.

Some methods of work are more or less obvious and necessary in small scale production, but have been lost in large scale assembly line production. Yet it is not about these methods of work not being rational or not being possible to use for large scale production. On the contrary it is possible and brings about many advantages to use similar methods in large scale production, but of course adapted to the specific conditions of large scale production.

7. Supply of materials for holistic assembly work in a production system with parallel product flows

As we have seen production systems with parallel product flows are attractive from several points of view. The supply of material is however often considered a problem for such production systems. That is also the case if one does not develop and substantially alter the supply of material in comparison to traditional supply of materials (what is called continuous supply to the assembly line).

The supply of materials has to provide the operator with the correct material. He or she has to be provided with or be able to get the components that are to be assembled, and the material should be exposed in an appropriate manner so that the operator's tasks are facilitated. As discussed in Chapter 6, when it comes to holistic assembly work this presuppose that the "inherent logic of the product" on the shop floor is first restored. Subsequently the information and material is structured as to support the work.

However in Sweden considerations regarding how the product is purchased largely influence the supply of material. The consequence of which, inter alia, is large packages with a substantial need for space in the factory and as a result also unnecessary handling and moving of material at the work station. In addition it is not uncommon that the operators get ergonomic stress problems.

In this chapter we will show how the supply of material to parallel product flows have to be designed in order to ease the operators work. To start with we will describe how traditional supply of material to an assembly line is conducted and also what consequences this has for the assembly work. Then the supply of material in a parallel product flow will be discussed and exemplified[38].

7.1 Traditional supply of material at the assembly line in the automotive industry

It is relatively easy to design a production system for assembly of smaller products (for example cameras and computers), especially with low production quantities and if there are few variants. To supply of material for larger products is however more difficult. For really large products such as cars, busses or trucks in large quantities it is directly problematic, since the quantities of material required are so extensive (since the number of product variants also increase evermore because of the differing customer requirements the supply of material is becoming increasingly complex).

At the assembly line the operator must chose the right component out of a facade of material. What material that is to be selected, for the individual product, is generally clear from some kind of variant specification with more or less cryptic codes or unit numbers on. Material is collected from the packages labeled with the codes in question. In some cases pilot lights, bar-code scanners or suchlike is utilized to guide the operator.

To make room along an assembly line with components that moreover comes in different styles sequence deliveries are often used[39]. Such an example is pre-assembled dashboards from the subcontractor that are delivered in packages placed at the assembly line in the factory. The dashboard for the respective car is packaged in accordance with the planned production sequence that cars arrive in on the assembly line. Beside this method has the advantage of making the operator's choice of material easier. The transport distance between the subcontractor and the factory is often only a few kilometers, but despite that the handling and transport work is usually extensive since it, among other things, is necessary to re-pick the material in rounds.

The present structural transformation within the automotive industry has significantly affected the conditions for supply of material to the production system for trucks and cars. The number of auto manufacturers has decreased through mergers and acquisitions, resulting in fewer companies with factories requiring an ever higher production volume to be economical. This has led to that different (car) models with fundamentally different design not seldom are manufactured within the same production system. The consequence is an increased number of components that are to be supplied to the assembly line with, among other things, lack of space as a result. Thus a common consequence is that even more types of components than before needs to be placed in the order of the planned production sequence (be laid in sequence).

The difference in product design between models results in that the commonly occurring aspiration to get a common production sequence is not always possible to realize. Besides different suppliers often exist for the same component or module, which makes a common exposure of precisely that material at the work station more difficult. External parties in the form of specialized logistics companies are often utilized, to collect and transport the material. Thus in total the work of handling, sorting, re-picking and transporting for the supply of material to the assembly line becomes very extensive. The original basis for the assembly line, to transport unopened packages straight to the work stations for exposure, is by that no longer valid[40].

7.2 Supply of material in parallel product flows through batching of material in material batches per product

How is it then possible to in an economically rational way supply the workgroups that work in a production system with parallel product flows with material? This was for a long time a pure research question. A relatively extensive research and development work, financed by what was then known as the Swedish Agency for Technical Development, commenced in 1978, when the ambition within Saab was to use parallel product flow also within final assembly of cars (see Engström and Karlsson 1982). Later this was realized through planning of Saabs now closed factory in Malmö, a factory that was an exact copy of the production system and the material supply methods that were a result from the previous research and development work[41].

During this research and development work stocktaking of components was carried through along a number of lines. It was shown that the number of components that were part of a car were surprisingly few. The surprise regarding the number of components was in part due to the way the product information from the company's construction and preparatory departments was structured. This state of things opened the possibilities to in an economically rational way supply self-governing workgroups in a parallel production system with material. It was among other things shown that the supply of material with extensive elements of manual labor could be more efficient than what had previously been assumed, especially if it was combined with automatization when it comes to supply of small components as was the case in Volvo's Uddevalla factory.

The requirement that the operators have to be provided with specified components at specific times is to a large extent possible to reduce in supply of material to self-governing workgroups with extensive elements of manual handling of material. For, among other things, this reason the need for advanced technical equipment for supply of material is decreasing. Instead it is an advantage to use several, simple sorts of transport equipment such as manual carts. The possibilities to adapt manual carts to separate production systems and products are substantial since they are simple to modify and develop, especially in comparison with automated equipment. The latter was the case when Volvo's Uddevalla factory was opened, in the shape of Volvo Cars factory in Uddevalla.

This results in flexible supply of material. For example one or more operators in a workgroup have the possibility to collect material for the other members of the workgroup in the intended storage room (what is called a "material place"). It is also possible to facilitate learning the assembly work by first learning to collect the material to then gradually learn to assemble.

When the duration of the work cycle is prolonged it is possible to walk long distances and manually collect material. It is possible without the handling losses increasing compared to what it would be in short work cycle assembly line systems, since these losses constitute part of the work cycle time which levels out the longer the duration of the work cycle; 5-6% of for example a 60 minute work cycle is a relatively long time (see figure 5.3), that very well could be used for handling of material.

To let the workgroup be responsible for the supply of material also means that the workgroup is given additional tasks that are possible to perform relatively freely, which in turn makes it possible to reduce the time losses and as previously discussed increase the self-control.

The majority of the components that are part of for example a truck or a car are small and light, as clips, plates, screws and nuts. Therefore there are advantages in giving special treatment to these small components. If these components are delivered to the operators packaged in small transparent plastic bags or boxes that contain the components that are needed to perform a certain task, 10-20 components per package, it will lead to a considerable gain in time for the operator and additionally will considerably facilitate learning the assembly work. The manufacturing of these packages containing small components can preferably be automated.

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In Volvo's factory in Uddevalla the principles and methods making the supply of mate-

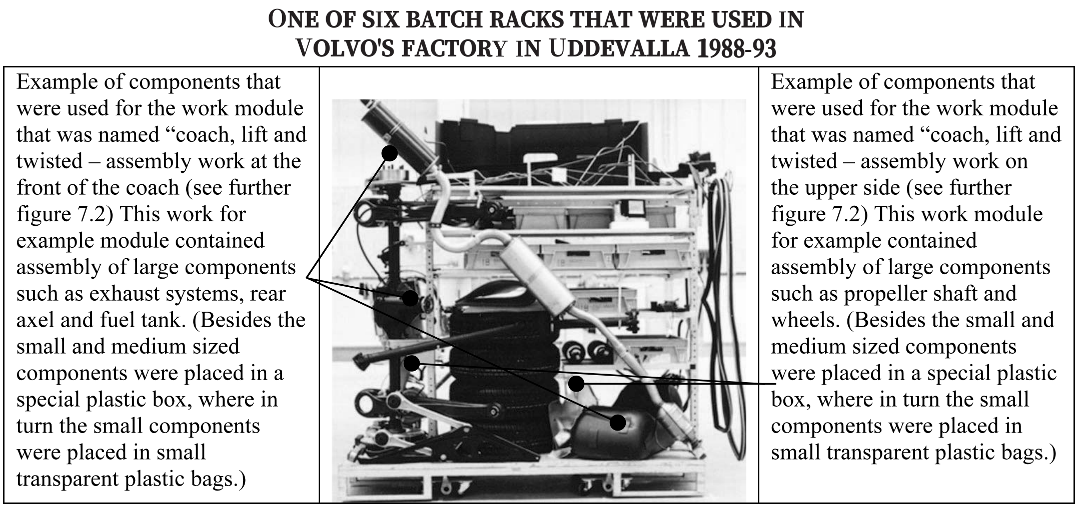


Figure 7.1 The picture shows one of six batch racks, as they are called, that formed the batch of material for car at Volvo's factory in Uddevalla.

rial in parallel production flows possible were further developed for assembly of vehicles in full scale. It was among other things the development of the batches of material that was decisive (the use of batches have later on been further developed and is also used within other production systems).

A batch of material can contain virtually all the material needed to supply an individual car in a workgroup. If the workgroup assembles the entire product it means that all the material that the finished product is made up of is part of the batch of material. That was the case in Volvo's factory in Uddevalla, where the batch of material for an entire car was made up of six batch racks as they are called, see figure 7.1. The important thing about these exact batches of material, which should be given attention, is not primarily that the material fit into these sex batch racks but that the material was structured in a pedagogical manner. Exactly what components that were placed together and in different boxes or shelves was significant to render holistic assembly work possible. Note that it is not necessary to bring material of

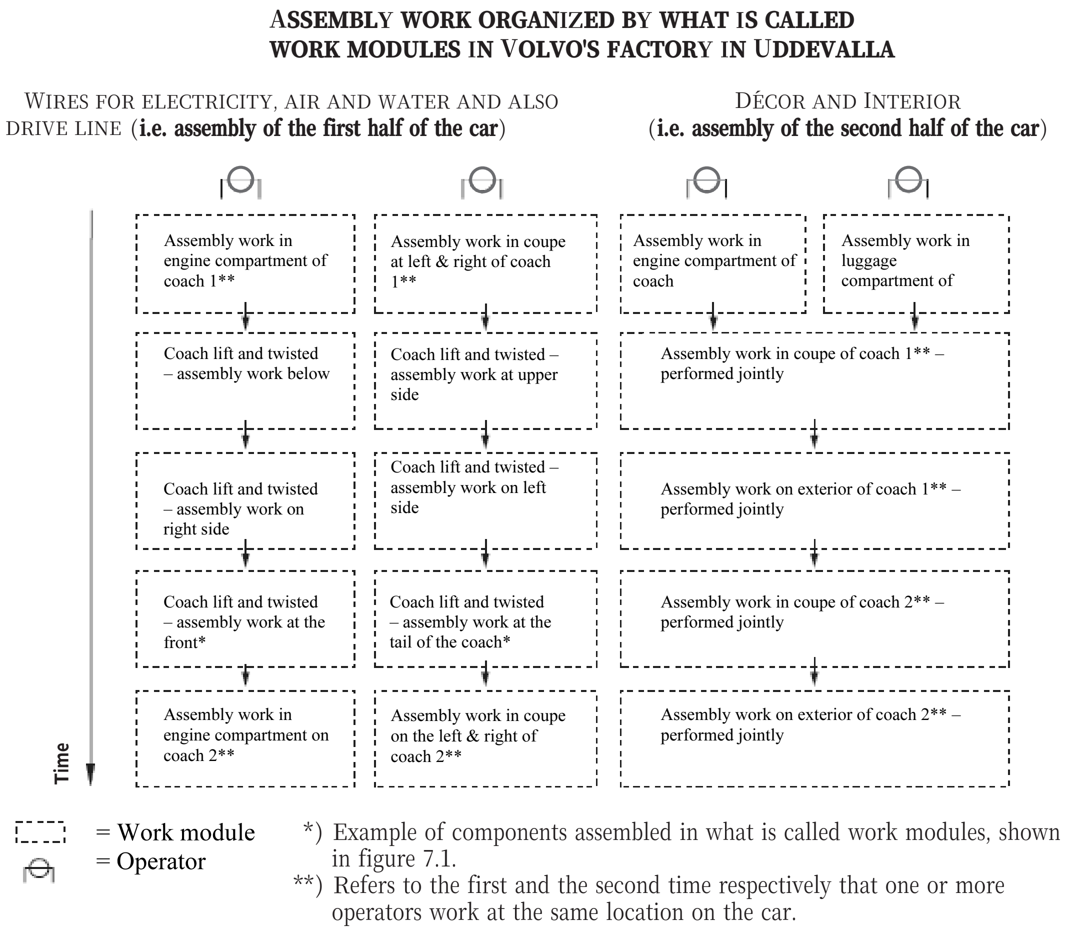


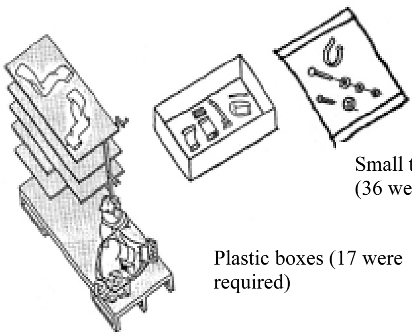
Figure 7.2　The operators assembly work in Volvo's factory in Uddevalla where the car was assembled by two couples of operators where every such couple assembled half a car. That is wiring and "drive line" and shown to the left in the figure and the decor and interior as shown to the right in the figure.

the same size together in for example the same plastic box.

Hence the material is exposed like a jigsaw puzzle with assorted pieces where the components that are part of it was or to a large extent became self-explanatory to the operator or operators. Therefore it is important that the components are divided into main groups and sub-groups in accordance with a hierarchical assembly oriented product structure, such as the one discussed in the previous chapter, in order for the operators to by that easily understand the product and the assembly work to be performed.

For holistic assembly work it is necessary to start out from an assembly oriented product structure (see figure 6.2). As is apparent in figure 7.2 in Volvo's factory in Uddevalla

BATCH OF MATERIAL FOR A CAR AT VOLVO CARS FACTORY IN UDDEVALLA 1997-2001



	Batch racks:	Plastic boxes:	
	Large components	Medium sized components	Small components in small transparent plastic bags
Number of pallets/package	6	17	36
Number of components per pallet/package and car	250	320	550
Usage of time per component for handling of material i.e. to in storage collect the material	26 seconds	11 seconds	3 seconds

Figure 7.3 Example of how the batch of material was designed for assembly of cars at Volvo Cars factory in Uddevalla. (note that the design of this is somewhat different from what was used in Volvo's factory in Uddevalla, as has been shown in figure 7.1, among other things the plastic boxes were piled on top of one another —— not placed in batch racks, so these could have a considerably more plain design compared to what was the case in Volvo's factory in Uddevalla.) The times indicated at the bottom row refer to the usage of time per component required to complete the batch for the three different categories of material.

this meant that two operators built the first half car while two others assembled the second half car (we have for the sake of understanding somewhat simplified this example by disregarding how the pre-work stations, that were integrated in the workgroup, were utilized). The batch of material was in this case designed so that the operators gradually collected plastic boxes with material and large components from the batch racks. The operator's assembly work was made up of a number of what is called work modules, where each such work module corresponded to a plastic box with material and some larger components. The plastic box and the small transparent plastic bags were also equipped with plain language designations[42]. In this plastic box there was also small components placed in small transparent plastic bags[43].

The plastic box that for the first time was to be used to assemble in the engine room was designated "assembly work in engine room on coach 1" and contained exactly the components that were required for this job. Next time an operator assembled in the engine room he or she fetched a plastic box called "assembly work in engine room on coach 2". These plastic boxes had the same (product and assembly related) designation in plain language no matter what product variant was manufactured. Certain work modules were performed by one operator while other work modules were common for two operators. In principle the batch of material was constructed so that each such work module corresponded to one plastic box of material.

The way to structure material pedagogically in the form of a batch of material described above means that product information from the company's construction and preparatory department is checked long before the actual assembly is commenced. It is simply necessary to keep the product information in order; otherwise it is not possible to collect a correct batch of material. It is necessary that the batch of material contains exactly the material that is needed to assemble the individual product; otherwise the operator will not be able to trust the batch of material as a physical work instruction[44]. The point is that physical work instruction is always available to the operator during his or her work, and moreover the operator actually has to use it, otherwise no product will be assembled. (One problem with traditional work instructions in the form of paper printouts is that they are not always updated and correct. Even if that is the case it is still not certain that the operator utilizes those.)

This way to assemble means that the operator constantly to the extent possible performs work preparation; material is to the extent possible collected to the assembly position alongside the product and thus then for a considerably longer period of time than for the work that is to be performed at that moment. (On an assembly line is often only material for the work that is to be performed during a work cycle collected.) There is also time gain to be made by having several components simultaneously in the hands in a way that is not possible at the assembly line, since, inter alia, small components often are placed in compartments sorted by item number.

7.3 Closing remarks

To sum up it can be established that there are two important reasons for batching of material for individual products in parallel product flows: (1) To ensure oneself of correct material contents in the product, in order for the finished product to be made up of correct components[45]. Furthermore to (2) utilize the material that is part of it as a necessary pedagogical support for the operator in performing and learning the work, i.e. it constitutes a physical work instruction.

It is essential that the supply of material through batching of material enables self-control for a workgroup. If this is to be possible, control of material has to be designed so that it is the workgroup and their needs for material that decides when material is delivered to the workgroup. That is why the workgroups themselves have to control the supply of material based on their respective production commitments and decide when the material is needed. The control of material thus has to be based on pulling demand (what is sometimes referred to as pull based planning). Note that self-control have to be possible within agreed upon boundaries, it can not be possible to work ahead or be behind by more than what is appropriate from the operators point of view and appropriate for the production system as a whole. It can for example not be possible to supply and expose so much material in advance that the workgroup is finished with today's production at lunch time. Such working conditions lead to, among other things, unacceptable psychosocial working environment conditions.

In the normal case supply of material to work stations should be done manually without automated handling and transport equipment. It provides both high accessibility and high flexibility. Manual supply of material to work station is simpler to adapt to the conditions at a certain work station. Nevertheless it is in some cases well-founded to automate the production of batches of material in itself, for example through automated collecting of small components. Very frequent transports of material in production systems should often also be automated.

From a general point of view the exposure of material has to be adapted to the operator and his or her assembly work. It shall not be necessary to walk long distances along a facade of material to collect components. The operator shall neither have to reach far down or pull out pallets or boxes to reach the components.

We have in this chapter shown that it in assembly in parallel product flows is relatively easy to accomplish exposure of material that is adapted to the assembly work and to the person as a versatile and knowledgeable actor in a production system. At the assembly line it is considerably more difficult to adapt the supply of material including the exposure of material to facilitate assembly work.

8. Automotive assembly as a knowledge-intensive enterprise

As partly has been touched upon in the introductory chapter and which, inter alia, has been exemplified in connection with discussions of buffer design in Chapter 3, within the international automotive industry there are today two trends concerning development of the assembly line.

The latest development is applied by Toyota, inter alia, in their factories in Tahara and Toyota City. This constitutes so to speak the second generation of lean production. It is characterized by, among other things, buffers along the assembly line and low operator density —— significantly lower than customary within the Swedish automotive industry (see figure 3.3 in Chapter 3). This is an example of conditions that have not been observed or conveyed in the debate regarding Japanese ways of production. The buffers have been introduced to avoid that production disturbances spread between the production sectors and also to raise product quality. The usage of buffers and the low operator density reduces time loss and is one of the explanations behind the efficiency of Toyota's production system[46].

With the exception that it in some Japanese factories has proven necessary to introduce buffers, it has relatively recently within Toyota been introduced what is called "autonomous complete processes", which involves keeping related components within different production sectors together, and if possible also on the operator level, so that a sort of totality is formed principally within each production sector. With that one has departed from as far as possible only striving to have a scheduled workload of 100% for every operator.

Simultaneously as this happened in Japan a copying of the type of production system previously in place at among others Toyota has taken place and is taking place outside of Japan. This way of production is known by the name lean production. For example in Sweden today a blend of new and old way of production, that has been inspired by what previously existed at, among others, Toyota during the 1980s, where the aspiration to have as small buffers as possible was a distinctive mark, is predominant. That is the first generation of lean production, which should not be confused with the second.

The second generation of lean production at Toyota undoubtedly has certain similarities with predecessors in the development of alternative assembly systems within the Swedish automotive industry, for example Volvo's factory in Kalmar or Volvo Trucks factory in Tuve, above all in that buffers were used quite extensively. The work contents is however only some or a few minutes and thus considerable less than the work contents that existed in the Swedish predecessor factories (see figure 1.1 in Chapter 1 for a few examples). Furthermore the buffers in the second generation of lean production are only technical, which means that the workgroups' self-control is very limited. Social buffers, which makes self-control possible, used to be common within Swedish automotive industry (see Chapter 3). Buffers with that function do not exist at all in the second generation of lean production.

Some of the principles of design of production systems that have been accounted for in this book have been utilized within Toyota during the further development of their previous way of production. The work performed in the rebuilt production systems is however still limited and divided into parts, although some time losses (principally system loss) are reduced with the help of buffers and low operator density. The totalities formed through the "autonomous complete processes" are foremost of relevance to the company, inter alia, through the advantages a global production way involves. Seeing as these "autonomous complete processes" are defined independent of a particular production system, they have been standardized within the company group, i.e. the same way to assemble cars is possible irrespective of in what country the local factory is located, which brings about that production volumes as well as different kinds of improvements, quickly can be spread between separate factories (see Nohara 2002).

Many of the methods and tools that are for example presented in manuals for education in lean production in Europe and the United States are suitable to use in design of production systems, irrespective of whether it is production systems with assembly lines or alternative assembly systems (see for example Quest World Wide Education Ltd 2001; Rothe and Shook 2003). These methods and tools are thus often general, and in reality not specific for just lean production, even if they in Sweden often are presented as such.

In Sweden it is common with performance agreements based on work studies between employees and employer. These set both a lower and an upper limit for the operators performance (what is called a MTM-agreement). Such agreements are without parallel in Japan. Within the Japanese automotive and electronics industry it has been shown that the economic advantages of a more efficient way of production virtually only led to the company benefiting. The operators have largely been excluded in the sense that the work itself has scarcely been developed and the rewards that exist are mainly related to salaries and salary related incentives. In Sweden it has on the other hand often occurred, which we covered in Chapter 1, that the companies more or less through unawareness handed the advantages of reduced time losses to the employees.

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When it comes to alternative assembly systems it is possible to distinguish between two generations of production, where the first focuses on the implementation of self-governing workgroups including developing suitable conditions for assembly work in such workgroups, as discussed in Chapter 3. The second generation is a further development that contains parallel product flows which facilitates great efficiency and holistic assembly work, which requires that information and material is structured in an appropriate manner, as discussed in the two previous chapters. Fully applied this way of production involves automotive assembly becoming a knowledge-intensive enterprise.

To structure information and batches of material per product based on a hierarchical assembly orientated product structure as described in Chapter 6, renders it possible to assemble large and complex products in an efficient way in a production system with parallel product flows. Firstly it becomes possible to avoid the lack of space that occurs in traditional supply of material for parallel product flows. Accordingly material does not need to be available in unit loads, where several identical components are placed in the same package; it is possible to batch the material per product. Secondly it becomes possible to with economically realistic training times learn an extensive work content, since the exposure of material functions as a means of facilitating learning it, the batches of material are structured appropriately.

If information and material is structured as we stated, and if the operators can view a sufficiently large part of the assembly work the "inherent logic of the product" will appear to them, and by that the learning of the assembly work is facilitated in a way previously not possible.

Consequently a paradox exists. The more extensive, correctly structured, assembly work one performs, the simpler it is to learn more. The more limited the work content is, the more difficult it becomes to grasp the work. Experiences from assembly line systems, as has been mentioned earlier, has given rise to the notion that a work cycle time exceeding 20 minutes in car assembly is unrealistic from a training point of view. This is true, but only on the condition that the work is really difficult to grasp, that the connections that form the "inherent logic of the product" are not apparent, as is the case in assembly line systems. That one for cars previously had an upper limit of 20 minutes work cycle time has led to that the only realistic product flow patters in car assembly has been a semi-parallel product flow pattern, since the work time the product totally requires for a Swedish car has been more than 12-14 hours[47].

The corresponding relationship is true for the supply of material. If, which earlier was the case, the information systems and the way to describe the product results in the assumption that there are an indefinite number of product variants and immense quantities of material, the handling of material to put the material in batches per product for assembly in a parallel product flows appears extensive —— yes, on the verge of absurd. With the traditional way to describe a car it is for example not possible to understand how the different product varieties are different from an assembly point of view and then neither from a material handling point of view.

Production engineers and others with experience from assembly line systems are inclined to assume that problems in learning an extensive work content, extensive material quantities etc. makes assembly line systems the only rational means of production of large and complex products such as vehicles, especially in large quantities. If the "inherent logic of the product" is restored these assumptions do however become invalid and the causal connection is in fact the opposite. The experiences from assembly line systems that suggests limited learning capacity of the operators, large quantities of material, an immense variety of products that is difficult to grasp etc. merely substantiates that the "inherent logic of the product" is ruined in assembly line systems. Here one is easily led to erroneous assumptions that obstructs or makes an efficient assembly work and efficient handling of material impossible.

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In principal an assembly factory within the automotive industry, with self-governing workgroups and parallel product flows (and with a supply of information and material as discussed above) functions in the way that the product information from the construction department is handled and verified in several steps. The local factory transforms the information from the construction department in order to make it assembly oriented. This transformed information is subsequently locally processed to be utilized for the supply of material, as well as for work instructions, variant specifications etc.

When the components subsequently are brought together for each product in connection with the making of the batches of material the information is verified in yet another step. The assembly of the product then becomes yet another confirmation that the information has been correctly structured. (Possibly are also product audits, test drives and other forms of final check-ups to be considered as an additional fourth step in this information verification.)

This reasoning shows that there are advantages in letting personnel who work with preparatory work, material supply and assembly work close to each other, preferably on the same premises. These groups of personnel essentially perform the same kind of work —— knowledge intensive work. It is true that the visible result of their work is different, and that these groups of personnel utilize and view different documents, batches of material or completely assembled products from their respective point of view. But below the surface it is all about handling of information, and the information being handled is common for all three groups of personnel, since it concerns the same material and the same products.

If automotive assembly is designed as a knowledge intensive activity the operation changes from involving large coincidental elements to becoming increasingly predictable. The high-quality information that is available from the (central) construction department is utilized all the way out on the shop floor and long before the material arrives at the freight terminal.

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To conclude we would like to point to the connection between technical and human dimensions when it comes to alternative assembly systems. From a technical point of view the fundamental dimension that characterizes the way of production is its product flow pattern, as discussed in Chapter 2. What at a superficial level most clearly characterizes the second generation of alternative assembly systems are from this point of view that the assembly is conducted in parallel product flows.

When it concerns the human dimensions a couple of the most essential distinctive features of the second generation of alternative assembly systems are that they are holistic and therefore require structured information and material. This is however something which requires special insights to separate and understand the meaning of.

Accordingly it is in our experience insufficient to merely in a limited sense focus on the technical aspects and work organization; it is also necessary to in an engineer-like fashion construct and on an industrial scale establish a tough pattern which facilitates humans understanding of both details and the totality of assembly work and simultaneously be able to see the big picture of their own as well as their colleagues work.

In the future boundless research and development work that cross boarders between certain scientific disciplines as well as different functions within a company is required in several regards. This is work that requires cooperation between practitioners within different areas and between scientists and practitioners, but also between scientists within different fields. A work that to as a large extent as possible have to be conducted directly on the shop floor.

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Appendix 1: Examples

Example 1: Product flow patterns and work organization in the Japanese electronics industry

In today's Swedish situation we find it interesting to note the Japanese electronics industry's interest in production systems with parallel product flows. They have introduced small workgroups and talk about "cellular manufacturing". This means that usually around 3-10 operators assemble the entire product, sometimes it occurs that an operator manufactures the entire product himself. These workgroups have in other words replaced the assembly line in assembly of small and medium sized products such as computers, printers and cameras, but also photo copiers and microscopes etc. To put it somewhat simplified there are three different basic types of these workgroups:

1 Several operators standing still and assemble a part of the product at their own work station along a flow of products. This can be compared to what we refer to as an un-paced serial product flow. One has divided a long serial product flow pattern into several short serial product flows with buffers.
2 Several operators assemble entire products by following the product between the different work stations.
3 One operator work at one work station and finish the entire product.

Figure 1　A small workgroup (what is referred to as "cellular manufacturing") in Japan where a workgroup of four operators assemble lap-tops. Note the display in the top right corner which shows the workgroups planned and performed production at this exact moment. Unlike Swedish production systems with parallel product flows in Japan it is obvious that the operators must have information about the workgroups' current performance in relation to the production plan.

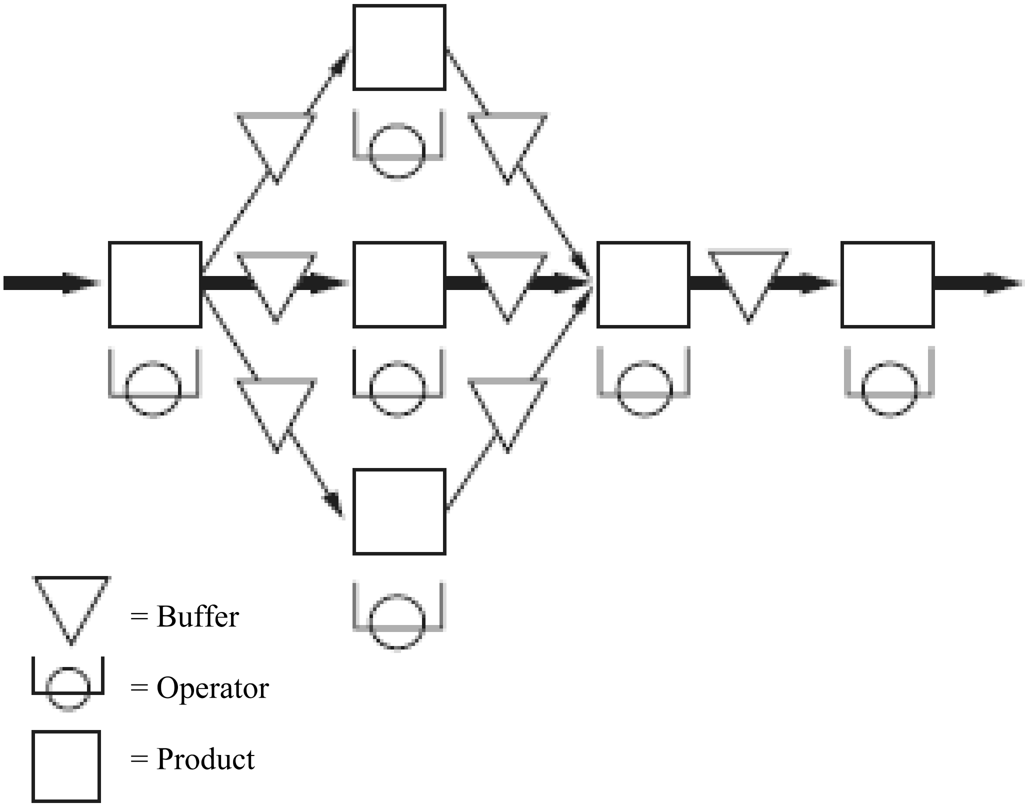

Figure 2 Schematic layout of a small workgroup for manufacturing of flat screens in Japan. Experiences from such small workgroups has shown that the start-up and running-in for manufacturing of new products takes place more rapidly than along a traditional assembly line. It is also easier to increase or decrease the production quantity. Furthermore a lower total need for man-hours is noted.

An example from assembly of flat screens is illustrative (see figure 1). The work is in this case performed in clean rooms. They have small workgroups of five operators, where the small buffers between the work stations consist of transparent plastic compartments with room for maximum three products (often it was one screen in each such compartment). These small buffers are located so that all the operators within the workgroup can see exactly what is in them (usually 1-2 screens). A characteristic of these small workgroups are that the operators are usually placed so close to each other that they have direct eye contact and all operators can immediately see what the others are doing.

A few examples of improvements in results which Asao (2001) reported after the transition to these small workgroups are as follows:

—In one of NECs factories the productivity in manufacturing of lap-tops increased by 30%, while the need for space decreased by 40% and the costs for tools and equipment decreased by 90%.

—In one of Canons factories the productivity in manufacturing of laser printers increased by 20%, while the need for space decreased by 50%.

－In one of Olympus factories the productivity in manufacturing of microscopes increased by 30%, and at the same time the lead times decreased by 70%.

It is however the increased flexibility, and then primarily the possibility to manufacture many different product variants to meet the very varied demand and short product life cycles, that has been decisive in relinquishing the assembly line, since it resulted in stock of unsold, obsolete products. Since the production equipment is not fixed to the ground the small workgroups that specialize in one or a few product variants can easily be changed. Workbenches and other equipment are often equipped with wheels. Changes in layout are usually done every month. Note that consequently, when it comes to assembly within the electronics industry, it is usually a matter work at a bench with relatively simple equipment.

Therefore a common feature for all these small workgroups within the electronics industry are the small buffers between the work stations, and that all these buffers are technical. They do not have any social buffers. Furthermore they often take over each others production commitments among the workgroups. This takeover partly occurs during times when there is a shortage of material and partly at the end of the work day in the case the planned production volume has not been met. For newly employed temporary staff (who are called "dispatched workers") who have worked such a short time so that it cannot be expected that they will keep the same pace as the fully trained operators keep, the permanent workgroups will help them to meet the planned production of the day.

Such temporary, not permanently employed personnel, frequently occurs in Japan. Approximately a third up to half of the personnel within the electronics industry are brought in from staffing companies[48]. Often one has short serial flows with buffers for them, but uses the other two mentioned basic types of workgroups for those who have worked longer at the company in question.

Another characteristic of the Japanese electronics industry, as well as for example the automotive industry in Japan, is that production goals and short-term and also long-term outcomes for the workgroup as well as for the production system as a whole are very clearly communicated. For example the communication takes place with the help of bulletin boards that are updated every break and displays which show the workgroup's continuous outcome in relation to the production goal. But also the overall goals for the year to come are clearly and continuously communicated, and agreed upon on a group level as well as on an individual level.

A conclusion from this example is that the Japanese development within the electronics industry in practice clearly shows several of the advantages of parallel product flow patterns. Precisely as in Sweden competent staff is a prerequisite for this, but unlike in Sweden the change has not been utilized to create better working conditions. The Japanese companies have fairly one-sidedly assimilated the profits that parallel product flow production system can yield.

Example 2: Balancing and variant loss, an arithmetical example

In table 1 below an example where the theoretically determined work time varies between both work station and product variants is given. Looking at the theoretically determined work times the scheduled work time is in this case 81% as compared to 92% as we saw in table 4.2 in Chapter 4 when only the balancing loss had been taken into account. The difference, 11 percentage points i.e. 92% minus 81%, can be attributed to the variant loss.

The total theoretically determined work time for assembly of the three product variants at the three work station in the example is 885 seconds. We can see that work station 3 has the longest theoretically determined work time for a certain product, namely 122 seconds for product variant 3. This work station with that product variant will set a minimum limit for the time used for work also at the other work stations and the other product variants. If work cycle times are as long for all the product variants at all the work stations[49] the time required for assembly is 9 multiplied by 122 seconds (since 3 work stations x 3 product variant equal 9). That is 1 098 seconds. We then see that 885 seconds constitutes 81% of 1 098 seconds.

Example 3: System loss, an arithmetical example

In the table 2 it is shown how the system loss is theoretically determined based on the work time actually required. It is read in the same manner as the table in the previous example.

The total work time actually required for the three work cycles at the three work station in the example is 897 seconds. We see that the longest work time is 146 seconds for work station 1 in work cycle 1, which will set a minimum limit for the time used for work also at the other work station[50]. The time used for assembly is thus 9 multiplied by 146 seconds (since 3 work stations x 3 product variant equal 9), i.e. 1 314 seconds.

Table 1　Example of variation in theoretically determined work time between work stations and product variants which result in balancing losses and variant losses. The production volumes for the three product variants are assumed to be equal.

Work station:	Theoretically defined work time [seconds] :			
	Product variant 1	Product variant 2	Product variant 3	Total theoretically determined work time per work station
Work station 1:	84	98	80	262
Work station 2:	113	103	102	321
Work station 3:	102	78	122	302
Total theoretically determined work time per work station and product variant:	299	279	307	885
Duration of work cycle:	122	122	122	
Share of theoretically determined scheduled work time for the entire product flow:	81%*			

* 885/(9 x 122)＝81%

Table 2　An example of variation in work time actually required between the work station and work cycles that result in system loss.

Work station:	Work time actually required [seconds] :			
	Product variant 1	Product variant 2	Product variant 3	Total work time actually required per work station
Work station 1:	146	71	75	292
Work station 2:	67	123	122	312
Work station 3:	106	72	115	293
Total work time actually required for the entire product flow:	319	266	312	897
Duration of work cycle:	146	146	146	
Share of the work time actually required for the entire product flow:	68%*			

* 897/(9 x 146) ＝68%

In the example above the share of work time actually needed for the entire product flow is only 68%. If the balancing losses and variant losses result in the operators being scheduled for 81% of the time according to the table in the example above the difference 13 percentage points correspond to the system loss.

Although table 2 above resembles the table that in the previous example described the balancing and variant loss, there are some essential differences. First this table is not about theoretical (standardized) work times but concerns the work times actually required. Second it is not about variation in work time between different product variants but about variation in work time between different work cycles. Third the variation between work station and between work cycles is assumed to be greater in this case than what is stated in the table in the previous example, seeing that more sources of variation are included when taking an interest in the work time actually required instead of the theoretically determined.

Appendix 2: Definitions and explanation of words

2.1 Definitions

	See chapter or Section:	Definition:
Additive learning:	Section 6.3	Such learning means, in a simplified way, to gradually learn details as time passes, and in that way attempt to learn an increasingly extensive work content.
Administrative self-control:	Section 3.2	Administrative self-control means a freedom from control by use of administrative routines. The operator or the operators can independently plan their own and possibly their co-workers job.
Alternative assembly systems:	Section 1.1 and Chapter 8	Refers to alternatives to the traditional assembly line.
Assembly line:	Section 1.1	Involves a common product flow where the product is moved from work station to work station (or from station group to station group) during the course of the assembly work. Sometimes we in the text also refer to "assembly line system".
Balancing loss:	Section 4.1 and 5.1	Time losses because of the difficulty to divide the work so that all operators have an equal amount of work (also see figure 5.1 in Chapter 5.)
Buffers:	Section 2.1	Space in the factory where the products in progress for different reasons can be temporarily stored.
Disengaged work stations:	Section 3.2	Refers to work stations where the work is not controlled by machines (i.e. the work or the work pace is not determined by a machine or equipment working), and the work is neither controlled by the work at a work station up-stream or down-stream in the product flow (For a disengaged station group the corresponding is true).
Dock assembly:	Section 1.1	Synonymous to production systems with parallel product flows. In the extreme case the product is at the same location, in what is sometimes referred to as a "dock", during the entire assembly work.
The scope for variation of production pace:	Section 3.2	The space to vary the rate of production, in part to make it possible to compensate for production disturbances, and in part to provide space for self-control for individual operators or workgroups.

	See chapter or Section:	Definition:
Handling loss:	Section 4.3 and 5.5	Refers to the time loss that depends on the operator handling tools and also material during the course of the work and moving himself between different positions at the work station (also see figure 5.3 in Chapter 5).
Hierarchical assembly oriented product structure:	Section 6.4	A hierarchical product structure which describes the product so that it becomes possible to structure the components that are to be assembled in a manner that makes it possible to overview and understand the product. This structure forms the basis for designing and describing holistic assembly work. (also see Figure 6.3).
Holistic assembly work:	Section 6.2 and 6.3	Simply put holistic assembly work includes mastering and gradually handling a number of phases: knowledge of materials, structuring, assembly, control and adjustment measures (see Nilsson 1992A and B or Nilsson 2003). This type of learning is considerable differentiated from traditional what is called additive learning (also see figure 6.1).
Holistic learning:	Section 6.3	Means that one departs from an understanding of the whole to comprehend and learn the details. In assembly work this mean that the individual tasks and components can be related both to one another and to the product as a whole, which facilitates the individual operators learning as well as the cooperation within a workgroup.
The inherent logic of the product:	Section 6.2	It means that the product that is being assembled has an inherent logic that can be utilized to structure information and material so that these correspond to and by that support what is called holistic assembly work. As an example can be mentioned that it is all about (a) connections between components within an individual product (but that are assembled at different times) and (b) connections between components in different individual products[51].
Insufficient time:	Introduction to Chapter 4	Insufficient time within a work cycle occurs if the duration of the work cycle is shorter than the work time actually required, with the consequence that the operator must discontinue the work prematurely, he or she has to send the unfinished product along. (Is however the duration of the work cycle longer than the work time actually required to perform a task, waiting time within the work cycle occurs.)

	See chapter or Section:	Definition:
Lean production:	Section 1.2 and Chapter 8	This concept is based on work along the assembly line as it was practiced in the Japanese automotive industry during the 1980s, especially at Toyota.
Operator density:	Section 3.2	Refers to the number of operators per product.
Organic product flow pattern:	Section 2.2	The product flow figuratively speaking gradually spreads like the branches of a tree (also see figure 2.5 in Chapter 2).
Paced serial product flow:	Section 2.2	Means that the production is gradually moved or is automatically moved along after a certain time. Within the industry this is sometimes referred to as a "paced line".
Parallel product flow pattern:	Section 2.2	A product flow pattern where the product flows run parallel (the product flows are separated). In the extreme cases the product remains at only one work station or station group during the entire assembly which is within the industry often referred to as "dock" or "dock assembly" (also see figure 2.2 in Chapter 2).
Product flow pattern:	Section 2.1	A production system has a product flow pattern that is described by how its product flows connect work station and/or station groups, and at that specific product flow patterns are formed.
Production system:	Section 2.1	A number of station groups and/or work stations connected by product flows together form a production system. A way to describe a production system is to state its product flow pattern.
Self-governing workgroups:	Section 1.1	With self-governing workgroups one refers to workgroups that independently have a responsibility that agreed upon goals are met and simultaneously has the prerequisites to meet these goals. For such a workgroup to function self-control is, among other things, required. Such workgroups are within the industry sometimes referred to as autonomous workgroups.
Semi-parallel product flow pattern:	Section 2.2	An intermediary form of serial and parallel product flow pattern. This product flow pattern is, inter alia, recognized by production sectors with "waists" with high transport frequency alternating with production sectors with parallel product flows. (See figure 2.3 in Chapter 2).
Serial flow:	Section 2.2	A product flow like an assembly line, where the products pass two or more serially connected work stations or station groups.

	See chapter or Section:	Definition:
Serial product flow pattern:	Section 2.2	A product flow pattern where there is a joint product flow, as an assembly line, and all of the products pass all the work stations or station groups (see figure 2.1 in Chapter 2).
Social buffer:	Section 3.2	Refers to buffers where the buffer volume is utilized for social reasons such as to provide self-control, based on the possibility to temporarily work more rapidly than what is necessary.
Station group:	Section 2.1	Two or more work stations where two or more operators share the work. We have introduced this definition into the text since a suitable term is not available within the industry. (Thus this term is specific for this book.)
Swedish model for work life:	Section 1.1	Intends to summarize the earlier initiatives within Swedish industry to replenish the working life as has been of immediate interest primarily during the 1960s, the 1970s and the 1980s.
System loss:	Sections 4.3 and 5.3	Time loss because of variation in work time actually needed between operators and work cycles (also see figure 5.3 in Chapter 5).
Technical buffer:	Section 3.2	Refers to buffers where the buffer volume is utilized for technical reasons to compensate that the products have different assembly times or for example that material is missing or some kind of equipment is malfunctioning.
Technical self-control:	Section 3.2	With technical self-control one refers to freedom from different types of technical controls, for example technical dependencies such as being controlled by machines, where tools and equipment decide what have to be done and how the work is to be performed.
Time loss:	Introduction to Chapter 4	To asses and compare the efficiency of different production systems one can compute their usage of resources in the form of work time. The differences between the work time taken into use and the absolutely necessary work time that adds value to the product we refer to as time losses.
Un-paced serial product flow:	Section 2.2	Means that the product is gradually moved through a product flow: the operator manually moves the product or signals that the product is finished, after which the product is moved by some kind of transport equipment. Within the industry this is sometimes also referred to as an "un-paced line".

	See chapter or Section:	Definition:
Variant loss:	Sections 4.2 and 5.2	This time loss is a kind of balancing loss occurring because different product variants require varying work effort and hence results in an uneven workload for the operators.
Waiting time:	Introduction to Chapter 4	A notion that occurs in two senses. (1) Waiting time within a work cycle occurs if the duration of the work cycle at a work station is longer than the work time actually required to perform a task, which means that operator gets a short pause before the next work cycle starts. (Is however the duration of the work cycle shorter than the work time actually required what is referred to as insufficient time occurs, with the consequence that the operator must discontinue work prematurely and he or she has to send the unfinished product on, see introduction to chapter). The notion of waiting time also occurs (2) in a general sense.
Work station:	Section 2.1	Tools, equipment and operators in a factory are concentrated to certain locations commonly referred to as work stations.
Work time actually required:	Introduction to Chapter 4	Work time that is actually required to perform the work within a work cycle, sometimes also referred to as operator time, needed work time or scheduled time.
Work time free of loss:	Introduction to Chapter 4	The work time free of loss is the absolutely necessary time that adds value to the product. Shorter time is not possible; walking time at the work station and time for handling tools and equipment is not included. Within the industry sometimes also referred to as "necessary net work" or "net assembly time".

2.2 Explanation of words

Assembly line system, refers to assembly along the assembly line.

Assembly sequence, refers to the more detailed order of how certain components are assembled on a certain product.

Batch of material, means a batch of material designed for assembly, sometime we also talk about batched material (see Section 7.2). Sometimes one also within the industry talks about "kitting" material ("kit" equals set of parts or materials to be assembled).

Exposure of material, refers to the way of placing and exposing material, i.e. the components that are to be assembled (see Section 6.2).

Hierarchical structure, means a sort of structure (pattern of constituent parts) that can be seen as starting from a peak and then gradually branch off into smaller and smaller constituent parts (see Section 6.4).

Indirect work, are tasks that can be performed separate from the production. This work is separated from direct work that is bound to the product and is necessary for the production to flow (see Section 5.4).

Large and small products, with small products are products smaller than approximately a refrigerator intended and with large products are such products like busses and trucks and cars intended.

Leveling out of work time, means that the operators individually or within a workgroup in different ways can compensate for differences in work time.

Machine controlled work, means work that is controlled by a machine or equipment working, and the work is neither controlled by the work at a work station up-stream or downstream in the product flow (For a disengaged station group the corresponding is true (see Section 3.2)).

Operator, refers to a person who performs work on the shop floor, other terms are for example fitter or employee.

Preparatory production work, refers to the work based on the construction department's work and the product information to prepare the product so that it can be manufactured.

Production commitment refers to agreements between operators and/or workgroups and the management regarding production quantity and product quality.

Production design, is synonymous with the design of the product.

Production engineer, means personnel working with production technical matters.

Product flow, is a flow of products which occur in a production system. In this book we differentiate between for example paced and unpaced product flows, but also between product flows and product flow patterns. The product flows connect work station and/or station groups, and form specific product flow patterns.

Product information, refers to information about the product. Sometimes we write product information from the company's construction and preparatory departments alternatively product information from the company's construction department depending on what is referred to. This product information refers to the groups, of companies, overall information about the product that the constructors, among others, develop in connection with the product being constructed. In some cases one could just as well have written "information about the product".

Production sectors, refers to defined parts (sectors) within a production system, one often talks about for example that an assembly line consists of different parts (sectors).

Production sequence, refers to the planned production sequence that the production plan prescribes.

Production structure, refers to a hierarchical structure that describes a product (see Sector 6.4).

Product variants, refers to different designs (variants) of a product. Within the industry one often talk about "heavy" and "light" product variants respectively, and then refer to more or less work-intensive product variants.

Product variation, refers to the variation that a product for different reasons has. This variation can depend on that the products are different from one another even if it is the same product variation, inter alia, since uniform products never are completely identical. This does among other things depend on that the dimensions of the included components vary. There is also a product variation that depends on different product variants (designs).

Qualitatively different work, is work that is qualitatively different than the one that occurs at the assembly line. (In assembly such work can be a consequence of what is called holistic learning and an extensive work content, since work among other things will requisition not only peoples manual skills within a limited work content; also see holistic learning and holistic assembly work).

Schematic layout, refers to an abstract image of a production system or part of such that (at least) shows work stations, buffers and operators in relation to product flows, i.e. a layout that shows how a production systems functions (see Section 2.1).

Self-control, means that an operator or workgroup, within certain defined boundaries can vary as well as control their own operations based on the given production undertakings, i.e. agreements on production quantity and product quality. When it comes to self-control one usually separates ⑴ technical and ⑵ administrative self-control (see definitions above and Section 3.2). Self-control in a general sense refers to autonomy and freedom to organize and perform ones work and also for example vary the pace of work.

Small components, refers to material such as screws, plates, nuts and clips.

Structure, refers to patterns (formation) of relations between constituent parts. We often talk about a specific sort of structure, namely the hierarchical structure, that starts from a peak and then gradually branch off into smaller and smaller constituent parts (with the help of hierarchical structure it is thus possible to separate totalities and their constituent parts simultaneously, see Section 6.4).

Traditional supply of material to an assembly line, means a continuous supply to the assembly line (see introduction to chapter 7 and Section 7.1).

Transport frequency of products, refers to how often products are moved in a product flow. With a high transport frequency one ore more products are moved several times, while at a low transport frequency it or they are moved a few times.

Volvo's factory in Kalmar, refers to Volvo Personvagnars factory in Kalmar.

Volvo's factory in Uddevalla, refers to Volvo Personvagnars factory in Uddevalla. Note that there have been two factories in Uddevalla that both had alternative assembly systems: ⑴ Volvo Uddevallaverken AB that was in operation 1988-1993. That factory had a parallel product flow pattern during the entire course of operation. ⑵ Autonova AB that had a semi-parallel product flow pattern. That factory subsequently changed owners and in connection with this came to be called Volvo Cars factory in Uddevalla. The alternative assembly took place here during the years 1997-2001. After that it was changed to assembly line systems.

Waiting time, is a concept that occurs in two senses. ⑴ There is waiting time in the general sense. The term waiting time also occurs in ⑵ a specific sense i.e. that waiting time occurs within the work cycle (see introduction to chapter 4).

Way of production, refers to how the production is performed, unlike the production system which means the system that is made up by among other things work station or product flows, where the production is performed.

Work cycle duration (work cycle time), the time within which an operator have to perform a task in a product flow. The duration of the work cycle depends on the production volume and the product flow pattern (the number of work station in a series). Alternative terms used within the industry are among others "work cycle" or "station time".

Work in advance, means that an operator or workgroup works in advance so that they are in front of the planned production (see Section 3.2).

Working up, means that one works in such a way that the operator can accumulate longer continuous periods of time, which can occur either by working faster ("sweat more") or changing work method ("work smarter", see section 3.2).

Work studies, refers to method studies and also measurement of work.

Notes

1 Translators note; Metall (The Swedish Metalworkers' Union) was a trade union in Sweden. It was formed in 1888 and had a membership of 379,000. In January, 2006 the Swedish Metalworkers' Union merged with the Swedish Industrial Union to form IF Metall.

2 Translators note: The book has not been translated into English. The original Swedish title is "Jag tror pa Sverige".

3 Similar initiatives occurred within the automotive industry as of 1971 at, among other places, Saab Scania (see Karlsson 1979).

4 Socio-technical refers to the fact that technical and human aspects in the production systems have to be designed in collaboration (see for example Emery 1972 or van Eijnatten 1991).

5 This was actually a semi-parallel product flow as explained in Section 2.2.

6 The assembly work can be facilitated when the product is constructed by putting time and money into product development. For products that are not produced in large quantities and/or where short "time-to-market" is important it is however suitable to invest less time and money in product development and to accept that the product requires longer assembly times.

7 In assembly line work the work is naturally to a large extent controlled by the movement of the line, which is a form of control that Mintzberg does not cover but which is a lot like "direct supervision" from a supervisor.

8 In Section 3.2 we discuss the scope for variation of production pace. In the same Section we also discuss technical and social buffers and technical and social self-control. All of these terms are different ways of describing an increased or decreased scope of action.

9 Outsourcing does however create other problems, such as the difficulty of evaluating companies that the production is outsourced to. Without production technical knowledge based on own production it is also difficult to develop products that are optimized to function in an efficient way. Within the automotive industry modulation has to some extent been a last resort in this situation, since the auto manufacturers by it have been able to outsource both product development and manufacturing to system suppliers, as they are called (they become responsible for defined systems in the vehicles being manufactured).

10 An example of a basic, crucial prerequisite is, as is covered in the next chapters, the prestructuring of the information the purpose of which is to facilitate the actual assembly work, which is required if one is supposed to learn an extensive work contents bringing about a qualitatively different work (see Engström, Jonsson and Medbo 2000 where the method developed to, among other things, design production systems including supply of information and material is presented).

11 During the years 1990, 1991 and 1992 the average cost per car for the yearly model change at Volvo's factory in Uddevalla was barely 25%

of what it was at Volvo's factory in Torslanda with its traditional assembly line (Engström, Jonsson and Medbo 1999).

12 That certain equipment for cost reasons constitutes a restriction which causes the product flow to focus to certain points is not self-evident. This because for instance in a situation with extensive work and teamwork it is quite possible to use several simpler tools (such as electric tools and torque wrenches instead of a pneumatic setter). Alternatively certain tools and equipment can also be shared between operators or workgroups. Further the need for tools with fixture functions is largely lost when members of the workgroups first adjust the assembled parts in relation to one another and then finally pull tight. In an assembly line a component must however be put in the right position at once, hence different fixtures are needed, otherwise errors are built into the product. The gain in equipment and factory space from the introduction of parallel product flow production systems is considerable (see for example Ellegård et al 1992).

13 Short pauses that partly appear randomly during the work without the operator working up can have a value from an ergonomic point of view since it makes it possible to recuperate but it tends to be experienced as meaningless or stressful by the operators, since he or she cannot decide on their own when the pauses will occur.

14 If the product flow pattern within a station group is formed in an unfortunate way the scope for variation of production pace may however become limited for one or more work stations within this group, with the consequence of significant time losses yet appearing at the same time as the self-control for the operators is limited.

15 For example in two cases that we studied the need for space for a serial product flow pattern without buffers was 0,6m^2 per car and year, while a parallel production flow pattern requires 0,4m^2 per car and year. The Japanese production system that utilizes buffers between the production sectors and low operator density however requires considerably more space. (Ellegard et al. 1992).

16 It should also be mentioned that this factory moves the buss chassis crosswise instead of lengthwise. It is then considerably easier to take in the entire product and all of the assembly work. Volvo's factory for busses in Borås previously worked in the same way.

17 Assembly work in production systems with parallel product flows has been evaluated from technical and psychosocial aspects and except for better efficiency the working environment was better then at the assembly line. This has been true for e.g. Volvo's factory in Uddevalla (see for example Engström et al 1995; Medbo 1999). Especially woman got on particularly well (Engström, Jonsson and Medbo 1996B).

18 To simplify the discussion in this chapter we only talk about work stations, but the same reasoning can be applied to station groups.

19 It should be pointed out that the discussion below of different kinds of time losses in a serial flow is kept general and therefore is not exhaustive.

20 If the work time free of loss for a car, in a serial product flow pattern, is calculated to 8 hours, the time losses (that in this example are calculated to 30%) are added to these 8 hours. The sum is then 10,88 hours.

21 When comparing the potential of improvement (that is the usage of resources over 100%) in production systems with for instance different product flow patterns one also avoids having to adjust to different product designs. Comparisons where one with rough estimates normalizes production data by using different types of correction factors are often not accurate. Small mistakes in estimates of the individual factors result in major deviations between entire factories because of the multiplying effect, and there are obvious difficulties to separate effect of product design and pro-

duction systems. (The IMVp study, i.e. International Motor Vehicle Program, Womack, Jones and Roos 1990 which was given a great deal of attention where 32 production systems for cars were compared did for example use this method.)

22 That people talk about balancing losses depends on that they strive to distribute (balance) the work so that the operators get a scheduled work load that is as even and high as possible.

23 Such variation is inevitable even in lean production. In such production the variation and the time losses are however reduced through among other things strictly regulated, standardized work methods, selective recruitment of personnel, illustrative and immediate remedial measures to fix for example different kind of disturbances in product flows and material management and also by applying teamwork that includes resource personnel to take care of variations. To in this manner immediately make different kind of disruptions clear to subsequently take direct action are principles that lean production contributed to constructively raise awareness about in the Western World.

24 This imbalance exists if the majority of the work is not controlled by machines. If however the operator is controlled by machines, meaning that the majority of the work cycle time is controlled by for example a tool or equipment finishing work, the distribution of time is more symmetric.

25 These resource personnel are often referred to as team leaders in accordance with the Japanese model.

26 To simplify the discussion we, just as in chapter 4, only talk about work stations, but the same reasoning can be applied to station groups.

27 The time losses in figure 5.2 do only take the variation in work time actually required between the work cycles into account, not between the work stations (Wild 1975).

28 It is primarily the preparatory work that represents relatively large amounts of time that are worth integrating into the workgroup. Preparatory work that requires expensive tools or equipment, or such preparatory work where one save a lot of time in assembling several components at the same time should be assembled elsewhere, perhaps in supply depots or at a suppliers. This is for example true for work such as simultaneously setting several smaller components into a fixture to then assemble further components to the ones already fixated in the fixture. Such an example is fastening lock knobs to the look bar in the door of a car.

29 Our analysis suggests that the dependencies increase significantly and alter character in workgroups that are larger than four to five operators.

30 Further see Nilsson (1992A) who accounts for a number of examples of questions that the operators should ask themselves in every phase of the assembly work (i.e. knowledge of materials, structuring, assembly, control and adjustment measures). This makes it possible to control the direction of the learning and simultaneously stimulate both manual and intellectual skills. One example of such a question that the operator should ask himself during the phase knowledge of materials is: What components are needed and where do these have to be assembled?

31 In the case plain language designations at all are used the operators on the shop floor can not be certain that these are accurate. Additionally it is not certain that that these designations are identical among the company's different functions. If the operator reads his work instruction or confer with a production engineer, who perhaps consults the information system that is used for different purposes it is not uncommon that the designations differ.

32 Fragmented work and lack of grasp of the big picture has, in Swedish automotive indus-

try, also proved to be true for production engineers, preparatory staff and designers. The consequence is that extensive extra work is required to ensure that the information and materials are correct.

33 A distance of approximately 11 metres is usually a limit for this to be possible.

34 A company's organisation, from the top executives, via the middle management, down to the supervisors and operators and the operators organisation of work, is an example of a hierarchy, in this case an organizational structure.

35 One reason for the negative answer is that in the Swedish automotive industry of today the product is described with the help of what is called a group wide hierarchical construction oriented product structure (Volvo 1989), the functional group registry as it is called, and not an assembly oriented product structure. From an administrative point of view this carries with it some unfortunate consequences. For the time being it is sufficient to say that a hierarchical construction oriented product structure is not very suitable even from the constructors' point of view. Another problem is that the hierarchical product structure that typically is used in product construction structures the group wide product information in a way that it largely remains with the construction department. The information sometimes even disappear on the way when the information in different ways is distributed to local factories, but this also occurs when it is converted locally for administration and supply of material.

36 The principles for supply of information and material that we show here we have also successfully utilized to improve and render information supply at traditional assembly lines more effective, as experiences from our collaboration with Scania proves (Portolomeos and Schoonderwal 1998).

37 Another starting point for structuring the components, which we have chosen to cover summarily, is that it have to be possible to understand the product variation. This is understood with the aid of to what degree the connection between the product and the material is obvious (see for example Medbo 1999).

38 We are not discussing aspects of material control here. It is however important that the control of material is designed as to support the chosen way of manufacturing. As an example it can be mentioned that the control of material in parallel product flows may well use the principles and methods from Japanese role models such as lean production, where actual needs in the production govern instead of estimated needs as is common in traditional mass production.

39 Sequence deliveries mean that the next component is selected from the unit batch or the package. Within the automotive industry today it is important that the systems suppliers as they are called delivers modules of the products or defined systems within the product in accordance with the planned production sequence from their factories to the auto manufacturers factory. (With defined systems within the product one refers to systems of components of different kinds that are part of a product, for example a braking system where several different components interact for a vehicle to be able to brake.)

40 Another reason for the supply of material becoming increasingly complex is that the product design is changed more often because of technical progress and customer demands. This result in a large number of alteration orders in the production, requiring extensive administrative work and that also renders supply of material more difficult. (There are real alteration orders in the sense that physical components have to be changed for the product to be correctly assembled i.e. in accordance with the specification. However there are also administrative alteration orders where it is all about that the information has changed somewhat and it is not related to the

physical product.)

41 That Saab Scania was interested in changing the final assembly of cars was because they had good experiences of self-governing groups from door manufacturing in the coach shop earlier (1971). After that (1975) parallel product flows with self-governing groups were introduced for grinding of coaches. The duration of the work cycle time was in the latter case 45 minutes instead of 2-3 minutes. This change led to that time losses were reduced while at the same time a better work with considerably larger self-control was achieved (Karlsson 1979).

42 In Volvo's factory in Uddevalla there was an advanced typography in the work instructions. For example small and capital letters, cursive text and displaced lines were used to describe the assembly work both in detail and totality. Further it was also possible to, as complement to the correct product and assembly related plain language designations, give selected components nicknames. The air duct to the dashboard was for example also referred to as a "submarine" since from the side this duct looked like a submarine. This nickname was noted within brackets and with quotation marks in the work instruction.

43 For the cars that we studied in connection with the design of production systems with parallel product flows it has demonstrated that these work modules will include about 15 minutes of work, but both shorter and considerably more time wise extensive work modules exist. How much material and how long the duration of the work time a work module represents thus depends on the division of labor and the product.

44 In several cases too long training times have been due to newly employed operators themselves collecting their batch of material without access to an unambiguous list. Then it is difficult to both exactly know what to collect and at the same time during the assembly work trust that the batch of material really is correct. On the other hand it is hardly possible to learn how to assemble if there is not any correct batch of material. (This condition can be resembled to students having to write their own textbooks —— a sort of "catch 22"-condition.)

45 If traditional supply of material for the assembly line (what is called continuous supply) is used, it is difficult to guarantee that the correct components really are available for assembly and that these are really used for the intended product.

46 The short assembly times in Japanese lean production that were reported in what is called the IMVP-study (i.e. International Motor Vehicle Program, Womack, Roos and Jones 1990) does however have another explanation. A lot indicates that the much discussed results of the IMVP-study largely were fictitious effects, which depended upon that one had not in a satisfactory manner considered, among other things, that different products require different amounts of assembly work; see Jonsson (1995) for a detailed discussion. Moreover these studies were conducted during the 1980s in different kinds of productions systems.

47 A semi-parallel product flow pattern, inter alia, requires spaces and can run into difficulty in correctly using the buffers. For example will, if special measures are not taken, the buffers re-assort the products so that the operators in the subsequent production sections do not beforehand know exactly what product variant they will receive.

48 There are examples of hired operators who have worked four or five years at the same company and even had supervising functions. That certain workgroups are entirely manned with temporary staff is common.

49 Here this assumption is made to simplify the discussion. Unlike an automated serial product flow the duration of the work cycle in a manual serial product flow can however vary between product variants depending on just

how time consuming they are. In our example the duration of the work cycle can be less than 122 seconds in a manual serial product flow, if product variant 3 is not assembled there at the moment. The effect is that the variant loss decreases, since the work time required for assembly decreases. The general principle is however still that the greater the variation in the theoretical determined work time is between the different product variations, the greater the variant loss becomes.

50 This assumption is again made to simplify the discussion. For a manual product flow the duration of the work cycle can vary over time, although it at every instance is the same for all work stations. In our example can for example the duration of the work cycle in a manual product flow be 146 seconds for the first work cycle, 123 seconds for the second and 122 seconds for the third. The effect becomes that the system loss decreases, since the time used for assembly decreases. The general principle is however still that the system loss depends on the variation in the work time actually required.

51 This means that for example a vehicle always has an organic build. That is, if one looks at the product from above the components included can be imagined to be organized by the imaginary centre line of the product. Some components come coupled along this centre line, while others are not doubled, this entirely analogous to for example how a human body is built (see for example Engström, Jonsson and Medbo 2004).