Prerequisites for Development of Products
Designed for Efficient Assembly

- a study about making knowledge productive in the automobile industry

Chair of Production Systems
Department of Production Engineering
ROYAL INSTITUTE OF TECHNOLOGY
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Prerequisites for Development of Products Designed for Efficient Assembly
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Chair of Production Systems
Department of Production Engineering
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ABSTRACT

This thesis deals with the development of the competence to create assembly efficient products. The assembly-related knowledge that is resident within an organisation is of inestimable value and should be used, refined and developed in order to obtain assembly efficient products. The question is how competence development can be promoted organisationally. This thesis has adopted the working hypothesis that modularisation promotes competence in the development of assembly efficient products. This position is based on the literature regarding competence development, competence-promoting organisations, and concurrent engineering.

The empirical research reported in this thesis is a long-term case study carried out at Volvo Car Corporation. In the licentiate thesis that preceded this doctoral thesis, it was suggested that assembly work should be based on modules. The further topics researched in this thesis include examination of a modularisation process, examination of the communication interface between the assembly organisation and the product development organisation, the effects of modularisation on the assembly process, and an investigation of the development of two assembly efficient products.

The product of the research is a model representing the organisational prerequisites for developing competence in the creation of assembly efficient products. The key elements in the model are a transparent organisational structure, clear intention in the organisation, and accommodation of cross-functional exchange. Modularisation is a means of creating a transparent organisational structure that makes it possible for members of the organisation to understand the context in which they work, which is a basic requirement for developing competence. A structure for cross-functional cooperation should be put in place to facilitate cross-functional exchange and learning. To succeed in developing assembly efficient products, an organisation must also clear signal that this is its intention. Visions, goals and strategies must express this ambition. Only then will the members of the organisation have the mindset that enables them to use their full potential to develop competence in creating assembly efficient products.

**Keywords:** competence-promoting organisation, transparent organisation, modularisation, assembly efficiency, automobile industry
Many people contributed to the research presented in this thesis. Here I would like to take the opportunity to thank some of those who were frequent contributors.

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Lena Moestam Ahlström
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1. INTRODUCTION

This thesis deals with issues relating to product development from the perspective of manual assembly. It focuses on how to use and develop competence in developing products designed for efficient assembly. The studies were performed within the automobile industry.

1.1 Background

Work, capital and natural assets have traditionally been considered the prerequisites for production. While this belief is still valid, the meaning of ‘work’ has changed. It has ceased to refer only to a direct physical contribution to the refining of materials and has come to include how we learn and are able to improve performance in each and every work task in the product realisation process. This change has increased the need for competence, as well as the need to understand how to promote the development of competence. Competence, as used here, refers to the ability to perform work tasks skilfully and to actively contribute to company progress.

Consideration of manufacturing\(^1\) aspects in product development is important in order to improve the performance of the product realisation process. There is a need to improve productivity and quality in respect of both the actual product development work and, at a later stage, in the manufacturing phase (see, for example, Clark and Fujimoto, 1991). By drawing on manufacturing knowledge in the design phase, the product can have a better design right from the start (and thus a higher quality), reducing the need for iterations during the product development work (and thus improving productivity). From a manufacturing point of view, a product designed for manufacturing enables

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\(^1\) This thesis regards ‘manufacturing’ as a subset of ‘production’. Production is defined as activities and operations such as product design, materials selection, planning, manufacturing and quality assurance. Manufacturing is defined as the act or process of physically making a product from its material constituents. Hence, manufacturing is a subset of production, and assembly is a subset of manufacturing. The expression ‘product realisation process’ is used to refer to the production system.
productive manufacturing and facilitates the achievement of the desired quality of output.

Assembly is one part of the manufacturing process, and the reasons for focusing on design for efficient assembly are the same as those supporting design for manufacturability in general – improvement of productivity and quality.

This thesis sets out to identify the prerequisites for improved performance in the development of products designed for efficient assembly and how to develop competence in this particular area. Empirical research was done at the Volvo Car Corporation. This organisation is continuously changing its working methods in product development in order to improve its performance in the product realisation process. A key concern is the creation of better conditions for cross-functional cooperation so that all requirements will be considered from the start of product development.

1.2 Industrial context

In 1994 Volvo Car Corporation started to develop a new product concept that differed from earlier concepts in many ways. The new concept was based on a broadened product portfolio, with cars designed for differentiated groups of customers ranging from pre-family to family to post-family customers. All these cars were to be developed in a considerably shorter time than ever before in the history of the company. The chosen strategy was to produce a number of models using a platform concept. All cars on the platform were to have a modular structure, so that a large number of components could be shared and different cars could be manufactured in the same flow. The most obvious benefit of a modular structure is the ability to produce many variants at a low cost.

To establish this system it was necessary to find ways to realise concurrent engineering. Volvo Car Corporation chose to do this by forming ‘module teams’. One explicit goal of this new method of organisation was that each of these teams should be organised around modules with the aim of enabling communication and knowledge transfer between product development and manufacturing. The product development work was to be performed by collocated teams in a cross-functional setting that included all the different areas of expertise needed in the product realisation process.
The cars on this platform were developed in an overlapping sequence. During the development of the first of these cars, new working methods were evolved and put into practice. There was a concern that the products should be assembly efficient, and thus engineers and assembly workers from the assembly plant were involved in the development project from a much earlier phase than usual. The aim was to use knowledge and experience from the assembly plant in the development of the new product in order to ensure that the design was adapted to the assembly process.

Despite these efforts to improve communication between product development and the assembly process and to focus on the development of assembly efficient products, there are still many problems with the process. The modularisation of the product has only partially yielded the expected benefits in terms of improved communication between product design and the assembly process. This communication interface is still generally rather complex and often confusing. In order to improve the conditions in which existing competence resources are used and to develop assembly efficient products, the prerequisites for the development of competence need to be examined. A systematic approach is needed to achieve sustainable improvements in performance.

1.3 Academic context

This thesis draws upon work done in the field of concurrent engineering and combines it with theories of how to create a learning (or knowledge-creating) organisation, with a particular focus on the development of products designed for assembly efficiency. It also examines the issue of modularisation. In this thesis the effects and potential of modularisation are examined in relation to organisational learning in the development of products designed for efficient assembly.

The thesis draws on a tradition of combining industrial work science and engineering research in the Division of Manufacturing Systems of the Department of Production Engineering at KTH. The leading representatives of this tradition are Professor Gunnar Sohlenius and Associate Professor Ann Kjellberg. Sohlenius’ work can be described as a search for a ‘philosophy of

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2 In this thesis modules are examined from the perspective of assembly efficiency. The most important feature of a module in this context is that it is a sub-assembly that is delivered to the main assembly line as one pre-assembled unit.
manufacturing’ (Sohlenius, 2000). Kjellberg’s research has been focused on learning and competence development in production systems (Kjellberg, 1996b). Their collaboration is based on a theory that combines learning and cooperation with quality and productivity in industry (for example of their joint work, see Kjellberg, A. & Sohlenius, 1993; Sohlenius et al., 1994; Kjellberg & Sohlenius, 1995).

According to Sohlenius, the western tradition of separating product design from manufacturing has resulted in a lack of knowledge of how to combine these two. This problem is illustrated in The Machine that Changed the World, published by Womack et al. in 1990. This book revealed the outstanding performance of the best Japanese automotive companies and also depicted the differences between the working methods of these Japanese companies and their European and American competitors. The book acted as a wake-up call to the automotive industry in Europe and the USA and was followed by many radical improvement programmes.

Womack et al. showed that the best Japanese automotive companies developed their products in strong project organisations that practised simultaneous engineering. Product development work was performed in cross-functional teams that included competence about all requirements of product development from the beginning. This approach has come to be known as concurrent engineering. At that time, product development work in European and American companies was carried out in projects that were passed from one functional department to another as the development process proceeded (Womack et al., 1990).

During the 1990s insights into how to improve performance began to affect the product development process in the automobile industry all over the world. There have been numerous research projects related to concurrent engineering.

One important challenge facing concurrent engineering is how to integrate manufacturing aspects into product development in order to design a product for efficient manufacturing (including assembly). This challenge has been addressed by researchers such as Clark and Fujimoto (1991), Susman (1992) and Magrab (1997). The technical characteristics of products designed for efficient assembly have been studied (see Susman, 1992, and Magrab, 1997) and methods have been developed to guide product development work towards realisation of such product characteristics (see, for example, Boothroyd et al., 2002, and Eskilander, 2001).
Clark and Fujimoto (1991), Wheelwright and Clark (1992), Syan and Menon (1994), Smith and Reinertsen (1998) and Magrab (1997) have all written about the value of establishing cross-functional teams working in parallel in product development work. This method of organisation shortens the lead-time in product development and reduces the need for iterations in the process.

Researchers have identified modularisation of the product as one technique that can be used to decompose a product into systems that can be developed in parallel (Smith & Reinertsen, 1998; Shirley in Susman, 1992; and Sanchez, 1996). Smith and Reinertsen (1998) and Sanchez (1996) have specifically identified modularisation as a basis for finding suitable work entities for cross-functional product development teams.

Modularisation of products has also been reported to give benefits in the assembly process in terms of reduction of manufacturing lead-time, reduction of assembly time and improved output quality (Erixon et al., 1994). Furthermore, modularisation makes it possible to isolate product modifications to a set number of modules in the assembly process, thereby avoiding complex effects in the entire assembly system (Magrab, 1997).

This thesis undertakes a further investigation of the use of modularisation to identify prerequisites for the development of assembly efficient products. It builds on the assumption of the benefits of cross-functional teamwork in product development. Nonaka and Takeuchi (1995) have studied the process of knowledge creation in product development. Their results, and other literature related to organisational learning, forms another, complementary, point of departure for this thesis.

Knowledge of the technical characteristics of assembly efficient products and of engineering research in that area is important when designing a product for assembly efficiency. However, the scope of this thesis goes beyond the purely technical perspective on assembly efficiency that dominates most of the engineering research.
1.4 Purpose

The purpose of this thesis is to explore the prerequisites for enhancing the development of assembly efficient products in order to develop a model of how to promote learning and competence development in this specific area. It focuses on organisational prerequisites, including organisational structure and working methods.

The areas studied include organisational aspects of product modularisation and the role of methods of engineering design in successfully developing products designed for efficient assembly.

1.5 Definitions, scope and limits

Learning and competence

The concepts of learning and competence are discussed at length in section 2.1 ‘Learning and the development of competence’. At this point, however, it is necessary to make some statements that will define the scope of this thesis.

Competence is required to develop assembly efficient products. Competence refers to the ability to perform a work task with skill, handle deviations, and actively contribute to the development of efficiency. Important questions in this thesis are how the required competence can be defined, refined, used, and developed and what are the prerequisites for this process.

Figure 1.1 is a schematic representation of the prerequisites if a company is to develop the competence to develop assembly efficient products. It is based on Stockfelt’s (1987) statement that competence requires opportunity, willingness and knowledge.
In order to develop products designed for efficient assembly, it is important to know the special technical characteristics of such a product. Technical knowledge is thus an essential foundation (level 1). The organisation must also have the goal of working towards assembly efficient products. That is, certain organisational prerequisites must be in place to support the development of assembly efficiency (level 2). Finally, there must be people who want to work toward this goal, for in the end it takes individual commitment and willingness to actually realise such an ambition (level 3).

Organisational prerequisites are of special interest since organisational support will both enhance willingness and the effort to gain knowledge about the area. Organisational prerequisites will thus be the focus of this thesis.

While technical knowledge is touched on, this research has not set out to investigate technical aspects of assembly efficiency. Rather, it has been assumed that since Volvo Car Corporation is a large company with a long history of producing cars, it already has a lot of technical knowledge about how to achieve assembly efficiency within the organisation. The aim is to investigate how to use this knowledge and how to enable organisational members to refine and develop their knowledge.

This research has also not set out to investigate all the psychological aspects of individual commitment and how to create willingness. It has focused on identifying the organisational prerequisites that enhance willingness on a
general level, rather than on such issues as salary, personal relationships to managers and other aspects on the basic personal level.

**Organisational prerequisites**

In this thesis organisation is regarded as the coordination of work efforts in order to achieve a common goal. Organisational prerequisites are basically the prerequisites for enabling each individual to understand their part in the company network of activities. Such understanding is related to competence in the development of assembly efficient products since an understanding of context is seen as basic to developing competence.

The initial statement of purpose for this research referred to an examination of organisational structure and working methods. ‘Organisational structure’ is here used to refer to the formal character of the organisation as a whole, including such things as organisational charts, departmental boundaries, the rough division of work tasks, and explicit goals and routines. ‘Working methods’ refers to how activities are actually performed, meaning who cooperates with whom, how they cooperate, what information is shared and how that information is perceived.

**Assembly efficiency**

The concept of assembly efficiency is related to the conditions for achieving efficiency in the final assembly of cars. Efficiency is a measure of the effort that is required to achieve a desired output. The understanding of ‘assembly efficient products’ in this thesis has an empirical starting point. It refers to the technical characteristics of a product that make it ‘good’ from an assembly perspective, that is, that make it meet the demands of productivity and quality in the assembly process. Simply put, a product with high assembly efficiency provides the assembly process with a good base for achieving high performance.

The concept of assembly efficiency has components that are directly measurable, but others are more qualitative in nature. Measurable components of efficiency in the assembly process are assembly time and cost (including indirect labour, investments, and tying-up of capital in general), lead-times, quality yields, and process stability (freedom from disturbances in the assembly flow).
The more qualitative aspects of assembly efficiency include the product’s ability to meet the prerequisites for an individual assembler to do good work. The product must thus be designed to give a good physical and psychosocial work situation. Only then is it possible to develop sustainable efficiency. A poor ergonomic situation causes costs and has a detrimental effect on the quality of output. The assembly of any one component must be evaluated in its assembly context. The working position and work movements must be studied so that physical strain is kept at a commendable level. Further, as far as possible assembly of components should be performed in its entirety to facilitate understanding of the context of the work. Understanding the work context is an important prerequisite for correct assembly and is also important when it comes to making improvements.

Assembly efficiency must constantly be improved, and therefore the improvement process itself is highlighted in this thesis. It is assumed that members of the organisation working with assembly, either directly or indirectly (like manufacturing engineers or production leaders), or with product realisation/industrialisation possess irreplaceable knowledge about assembly efficiency that can be used to refine the process in order to achieve top performance. Understanding the work context is a prerequisite for being able to contribute by suggesting improvements.

1.6 Methodological approach

The empirical base for this thesis was a study of Volvo Car Corporation and the actions taken there to achieve assembly efficiency. The data from Volvo Car Corporation have been analysed, compared with research literature and extensively discussed. The aim of these investigation and analyses has been to grasp general principles that can promote the systematic development of assembly efficiency.

The research methodology for this thesis is primarily qualitative in nature. Creswell (1994) identifies a qualitative study as an inquiry process producing an understanding based on building up a complex, holistic picture, formed by words and conducted in a natural setting. This contrasts with more traditional quantitative study, which is based on testing a theory composed of variables, measured with numbers, and analysed with statistical procedures. Quantitative studies typically test theories and hypotheses in a cause-and-effect order.
In a qualitative methodology, categories emerge from informants, rather than being identified a priori by the researcher (Creswell, 1994). This approach provides rich, ‘context-bound’ information that can lead to patterns or theories that help explain a phenomenon. In a qualitative study the rules and procedures are not fixed, but rather open and emerging.

Creswell’s description of qualitative research corresponds well to the approach adopted for this thesis. The approach could also be described in terms of a hermeneutic circle. Helenius (1990) describes this circle in terms of interpretation and understanding: one starts with a certain understanding, and the aim of research is interpret what is happening in order to understand it better. Thus understanding is both the point of departure and the goal. Föllesdal et al. (2001) describe the hermeneutic method as starting with a hypothesis, collecting material, re-evaluating the hypothesis, collecting more material, re-evaluating the hypothesis again, and so on. The process is characterised by continuous movement between hypotheses and the research material.

This research for this thesis began with the hypothesis described in chapter 3, ‘Research method’. In the course of the research, this hypothesis has evolved and been refined into the model that is presented in this thesis. The model can be described as the end-hypothesis in the hermeneutic procedure leading to this dissertation.

Creswell (1994) insists that in a qualitative study it is important to be consistent with the methodological assumptions of the qualitative paradigm. Consequently, this thesis starts with research questions rather than with a general hypothesis. The subsequent research process has been an attempt to understand what is observed rather than an attempt to find the figures or variables required to prove or reject a hypothesis. Further elaboration on the actual research procedure is found in chapter 3, ‘Research method’.

1.7 Structure of thesis

This thesis is divided into 11 chapters. This first chapter has presented the purpose of the thesis, giving the practical background from industry and the theoretical background of related research.
Chapter 2 sets out the theoretical frame of reference for this research. It outlines the assumptions and guiding theories that underlie the research and contains a statement of the research questions.

Chapter 3 describes and discusses the methodology used in this research.

Chapter 4 describes organisational development at Volvo Car Corporation in order to explain the industrial context for this thesis.

Chapter 5 recapitulates of the results from the licentiate thesis that preceded this doctoral thesis.

Chapter 6 presents a picture of modularisation at Volvo Car Corporation, based mainly on interviews.

Chapter 7 contains an investigation of the communication interface between the final assembly process and the product development organisation.

Chapter 8 describes a study analysing the effects of a split of a module in the final assembly shop.

Chapter 9 examines the process whereby two assembly efficient products were developed.

Chapter 10 summarises the results of the empirical investigations and interprets these in terms of the theoretical frame of reference. A model captures the main results in this thesis.

Chapter 11 discusses the implications of the results.
2. FRAME OF REFERENCE

This chapter sets out the assumptions and guiding theories that underlie this thesis. It does not attempt to review all the available literature in the field, but rather concentrates on models that have proved especially fruitful for this study.

The first section of this chapter presents relevant literature on learning and the development of competence. Section two presents some literature on the special type of learning organisation that is in focus in this thesis and deals with concurrent engineering. Section three summarises the most important elements in the frame of reference, leading in to the final section where the research questions are introduced.

2.1 Learning and the Development of Competence

This section first explains the increasing need for competence in industry. Concepts of competence, learning and knowledge are then examined and finally theories about how to organise work to promote learning and competence development are discussed.

2.1.1 Changing industrial requirements for competence

In a large company, division of work is necessary for efficiency. In the mass-production era, work specialisation became the key to success for many companies – witness the introduction of the moving assembly line by Henry Ford early in the 20th century. This approach was based on Fredrik Winslow Taylor’s ideas about ‘scientific management’ (Taylor, 1911). Taylor was convinced that in the interests of efficiency each person in an organisation should specialise in a specific task. On the shop floor, the work tasks should be designed in such a way that a person with no prior education or training could perform a task efficiently after a short instruction and training session. Time and motion studies should be conducted to identify the most efficient way to perform tasks on the shop floor.
Conditions in manufacturing companies in the automobile industry have changed considerably since the start of the 20th century. There has been a dramatic shift in the view of learning, knowledge and competence, and this shift has led to new demands in regard to the organisation of the work.

During the 1980s and 1990s, industry in the western part of the world became aware of the value of the Japanese concept of kaizen, that is, continuous improvement (Imai, 1993). In this period the Quality movement got an influential role in management of organisations. One of the major emphases of the quality movement was the need to engage all members of the organisation in improvement activities. Bergman and Klefsjö (1991) believe that the core message of Total Quality Management (TQM) is to constantly strive to fulfil the requirements and expectations of customers at the lowest cost by engaging everyone in continuous improvement work.

This shift from strictly limited responsibility in the production process to being asked (and even required) to engage in improvement work has been described by researchers such as Kjellberg and Kvarnström (1996), who state that ‘a skill-intensive manufacturing paradigm is now coming into being’ (p. 1).

Many authors claim that we have become a knowledge society. Drucker (1993) writes that we have left the post-capitalist society and entered a new society where the basic economic resource for production is, and will be, knowledge. He claims that the function of an organisation is to make knowledge productive. Nonaka and Takeuchi (1995) argue that organisational knowledge creation will become the key to sustaining competitive advantage in the future.

Argyris (1999) surveyed a vast number of academic and industrial publications about ‘learning organisations’ and identified common central ideas for such organisations. These include concepts of organisational adaptability and flexibility, a readiness to rethink means and ends, realisation of human potential for learning in the service of organisational purposes, and creation of organisational settings as contexts for human development.

Drucker (1993) claims that every contemporary organisation has to be skilled at ‘creating the new’. He identifies three systematic practices that organisations need to be skilled at: continuous improvement in everything they do (kaizen), development of applications of their own success
(exploitation), and innovation. Kjellberg (1999) focuses on the challenge to organisations to mobilise inventiveness, and describes a three-stage shift in the understanding of competence. In the first stage, commitment was mobilised by focusing on holistic work content. In the second stage, the goal was to mobilise shared mindsets by focusing on visions, goals and strategies. The goal of the third stage is to develop innovation capability by focusing on creating possibilities to understand organisational premises in general. Kjellberg refers to this third stage as ‘the responsiveness era’.

Synthesis

Taylor’s ‘scientific management’ was one approach to creating competence in industrial work. Each worker became very skilled, very competent, at performing one task. The big difference today is that the experience and knowledge of each co-worker is seen as an important asset when it comes to improvement and as a source of innovation. This change in attitude led to a need to re-evaluate the division of work. If people are to be able to improve, exploit and innovate on behalf of the organisation, their work must be organised in way that give every member of the organisation the best possible circumstances for becoming competent.

2.1.2 Competence, learning and knowledge

In order to understand what is required to develop competence, it is important to grasp the concepts of competence and competence development, as discussed in the literature.

Kjellberg defines competence as the ability to perform the proper action at the right time (in Kjellberg & Kvarnström, 1996). This definition is useful in relation to this thesis in that there is a clear connection to the demands of working life. This definition stresses action, and not just any action but the ‘proper’ action at the ‘right’ moment.

Figure 2.1 summarises Kjellberg’s view of the circumstances that contribute to competence. She emphasises the contribution of surrounding conditions in the organisation to the forming of competence. Formal knowledge and experience are fundamental to competence, but individual attributes, issues of organisation and working methods and the values existing within the organisation are also of great importance.
Kolb (1984) presents an extensive model of experiential learning. In his model experience is seen as the source of learning and development. Kolb uses experience in its widest meaning, referring to everything we experience in our daily life with all our senses and how our earlier experiences affect how we perceive new experiences.

Kolb focuses on the transaction between internal characteristics and external circumstances in the learning process. In Kolb’s terms, knowledge creation is the result of transactions between personal knowledge and social knowledge. Personal knowledge comes from subjective life experience. Social knowledge consists of the objective accumulation of previous cultural experiences, transmitted by cultural networks of words, symbols and images. Knowledge results from the transaction between these objective and subjective experiences.

The starting point of Kolb’s theory is the learning by experience cycle, shown in figure 2.2. Kolb states that effective learning requires four different kinds of abilities: concrete experience abilities, reflective observation abilities, abstract conceptualisation abilities, and active experimentation abilities. For individuals to learn efficiently, they need to be able to involve themselves in new experiences with an open mind (concrete experience). They need to be able to reflect on and observe their experiences from many perspectives.

**Figure 2.1 The competence complex by Kjellberg**
*(in Moestam Ahlström & Kjellberg, 2001)*
(reflective observation). They need to be able to create concepts that integrate their observation into logically sound theories (abstract conceptualisation). They must also be able to use these theories to make decisions and solve problems (active experimentation).

![Kolb's experiential learning model (Kolb, 1984, p. 42)](image)

**Figure 2.2 Kolb’s experiential learning model (Kolb, 1984, p. 42)**

Kolb’s model has two distinct dimensions: one vertical and one horizontal. The poles on the vertical axis are concrete versus abstract, while those on the horizontal axis are active versus reflective. The concrete/abstract ‘dialectic’ refers to different ways of grasping experience, by apprehension or by comprehension, while the active/reflective dialectic refers to different ways of transformation, by extension or by intention.

Apprehension refers to the felt qualities of an immediate experience, while comprehension is reliant on conceptual interpretation and symbolic representation. Apprehension and comprehension affect each other, for apprehensions is the source of validation for comprehensions and
comprehensions are the source of guidance in the selection of apprehensions. Intention is transformation by internal reflection, a process of deploying attention. Extension is transformation by active external manipulation of the external world. According to Kolb, these different forms of grasping experience and transforming it are the basis of knowledge creation.

Figure 2.3 shows Kolb’s experiential learning model of adult development. It shows that integration of the adaptive modes leads to development of each of the adaptive abilities:
- Affective complexity in concrete experience results in higher-order sentiments.
- Perceptual complexity in reflective observation results in higher-order observations.
- Symbolic complexity in abstract conceptualisation results in higher order concepts.
- Behavioural complexity in active experimentation results in higher order actions.
The cone shape illustrates that the four abilities become more and more highly integrated at higher stages of development. Development of each of the four abilities proceeds from a state of passivism, defensiveness and dependence to a state of self-actualisation, independence and self-direction.

The development cone brings back the emphasis on acting in Kjellberg’s definition of competence. Higher levels of competence, as defined by Kjellberg, are developed towards the top of the cone in Kolb’s development model.

Stockfelt (1987) is another researcher who, like Kjellberg, focuses especially on the concept of competence. He writes about competent acting and what is required to develop ‘action competence’. Stockfelt points out that competence
Stockfelt emphasis the concepts of knowledge, willingness and opportunity as fundamentally important to achieving competence (see figure 2.4). He insists that acting can only be competent when the knowledge is relevant, when there is a willingness to use it or refine it, and when there is an opportunity to act. As regards working life, Stockfelt focuses strongly on opportunities. He stresses the importance of having or creating learning environments in working life and strongly objects to the fragmentation of work content in manufacturing industry. He maintains that such fragmentation limits opportunities for workers to understand the whole of which they are a part.

Moxnes (1984) stresses learning from experience in working life and points out the difference between just experiencing and learning from experience. Like Kolb, he uses the learning by experience cycle: concrete experience, reflection and analysis, abstraction and generalisation, and adjustment of action. He claims that the most difficult step in the learning cycle is the generalising movement from a single event to a general principle. ‘Some people see the principle at once, while others make the same mistake over and over again’ (p. 60, free translation).
Moxnes categorises the factors that hinder or facilitate learning from experience into four areas:
- personal area (e.g. self-image, pain, human needs, age, motivation, status)
- human-interaction area (e.g. the group, feedback, norms)
- organisational area (e.g. centralisation, structure, fragmentation, reward system)
- society (e.g. family, school, nation).

Factors within these areas interact and form the conditions for learning. Individuals with their abilities (the personal area) interact with other individuals in an environment that has both social play rules (the human-interaction area) and authority structures created by the organisation (the organisational area). Society affects all these areas.

Nonaka and Takeuchi (1995) have attempted to research the secret behind Japanese companies’ success and how these companies go about creating knowledge organisationally. They claim that the Western and Japanese world-views differ in their understanding of knowledge. Whereas Japanese companies view knowledge as primarily tacit, the Western world has a tradition of valuing explicit knowledge.

The concepts of tacit and explicit knowledge derive from Polanyi (1966), who made a distinction between these two forms of knowledge. Tacit knowledge is personal, context-specific, and therefore hard to formalise and communicate. Explicit or ‘codified’ knowledge refers to knowledge that can be transmitted in formal, systematic language.

To give a deeper understanding of the distinction between tacit and explicit knowledge, Nonaka and Takeuchi list the types of knowing generally associated with these concepts:
- Tacit knowledge (subjective): experiential knowledge (body), simultaneous knowledge (here and now), analogue knowledge (practice).
- Explicit knowledge (objective): rational knowledge (mind), sequential knowledge (there and then), digital knowledge (theory).

This list shows similarities to what Kolb describes as grasping by apprehension and grasping by comprehension (see figure 2.5). It is thus possible to compare tacit knowledge, as understood by Nonaka and Takeuchi, to what Kolb describes as concrete experience. Explicit knowledge is comparable to what Kolb describes as abstract conceptualisation.
Figure 2.5 Tacit and explicit knowledge related to Kolb’s learning model

In Nonaka and Takeuchi’s model of the knowledge-creating company, tacit and explicit knowledge are regarded as complementary entities that interact in the knowledge-creating process in four modes of knowledge conversion (see figure 2.6).
In the socialisation mode, tacit knowledge is shared in the form of experiences and mental models. Externalisation is a process of articulating tacit knowledge as an explicit concept. This conversion is triggered by dialogue and collective reflection. In the combination mode, different explicit concepts are combined, added and sorted to create new concepts. Internalisation is a process of incorporating explicit knowledge into tacit knowledge in the form of new mental models.

The forms of knowledge conversion described by Nonaka and Takeuchi can be compared to Kolb’s model of learning (see figure 2.7). Socialisation is then equivalent to individuals exchanging apprehended knowledge (concrete experience). Combination is individuals sharing knowledge that is grasped by comprehension (abstract conceptualisation). Externalisation can be seen as a form of transformation of knowledge within the individual from concrete experience to abstract concepts. Internalisation is transformation of knowledge from abstract concepts into new (or altered) mental models that effect how new concrete experiences are apprehended.
The utilisation of tacit knowledge deserves some extra attention since Nonaka and Takeuchi believe that this is where there is a potential for improvement in Western companies. Kolb states that experiences grasped by apprehension cannot be expressed without losing the richness of impressions; formulation of an experience always means a simplification. This statement assigns socialisation a special status. It becomes a way to acknowledge the value of the rich tacit knowledge resident within the individuals in the organisation.

When it comes to creating knowledge organisationally, Nonaka and Takeuchi speak about the interaction of two types of knowledge spirals. The first spiral takes place in an ‘epistemological’ dimension across the four modes of knowledge conversion – socialisation, externalisation, combination and internalisation. The other spiral takes place in the ‘ontological’ dimension, where knowledge developed at the individual level is transformed at the group and organisational level and passed back to the individual again. These two
spirals interact over time in a dynamic process that creates organisational knowledge.

Nonaka and Takeuchi identify five enabling conditions for knowledge creation organisationally:

1. Intention – There must be organisational intention and it must be known in the organisation. Such an intention is typically expressed in the form of strategies. Organisational intention is important to achieve collective commitment, which in turn is fundamental to human knowledge-creating activity.

2. Autonomy – Each individual in the organisation should be allowed to act as autonomously as circumstances permit. This is important to achieve flexibility in acquiring, interpreting and relating information. Autonomous individuals function as a part of a holographic structure, in which the whole and each part share the same information.

3. Fluctuation – Fluctuation in an organisation means that the members of the organisation start questioning existing working methods, routines and attitudes. This occurs spontaneously when an organisation is facing real crises. It can also be generated when management sets challenging goals and thereby creates a sense of crisis.

4. Redundancy – Redundancy is access to information beyond what can be considered the immediate operational requirements of members of the organisation. Sharing of redundant information promotes sharing of tacit knowledge through a process of intrusion. Sharing extra information helps individuals to understand where they fit into the organisation. Redundancy works as a self-controlling mechanism to keep the organisation heading in the right direction.

5. Requisite Variety – Members of an organisation can cope with many contingencies if they possess requisite variety of information and have free access to information. Requisite variety then means that the organisational members can combine different information quickly and flexibly.

Synthesis

The models described above are both overlapping and complementary. While Kjellberg, Stockfelt and Moxnes focus on the individual’s relationship to the surrounding world, Kolb analyses the learning process within the individual. Nonaka and Takeuchi draw attention to tacit knowledge and how it can be
used, while Kjellberg, Stockfelt and Moxnes looks at learning from a more general point of view.

Kolb’s model gives a valuable description of how our different abilities affect how we learn. Relating Kolb’s ideas to knowledge about how to achieve assembly efficiency, his model can be used to analyse the learning profile of the different professions that are involved in developing assembly efficient products.

The models of Kjellberg, Stockfelt and Moxnes are fairly similar. They all point to the need to create a learning-promoting environment in order to achieve learning and develop competence. Stockfelt emphasises the need to create opportunities organisationally, and Kjellberg and Moxnes elaborate on these opportunities. Kjellberg focuses on the organisation, what working methods are used and what these methods imply about the values in the organisation. Moxnes writes about the same topic, but he categorises them in terms of the decision structure in the organisation and the rules for social interaction.

Kjellberg’s and Kolb’s models have been combined to produce a manageable model of individual competence development. In figure 2.8, the spiral towards the apex represents individual competence development towards a state of self-actualisation, independence and self-direction. The arrows surrounding the spiral represent factors affecting the process of developing competence. An individual’s attributes, experience and education can be seen as personal inputs into this process, while the governing values, work organisation and working methods are external inputs.
Nonaka and Takeuchi’s models differ from the others presented here because of their focus on how knowledge can be transferred from one person to another in an organisation. Their work is extremely important in relation to the theme of this thesis, since the focus will be on how existing assembly knowledge in an organisation can be better used, that is, transferred to the people who develop the product.

2.1.3 Organisations enhancing competence development

The search for a flexible, dynamic and vital organisation of production systems has led several researchers to look at human beings and living organisms in general. They have been impressed by the ability of living organisms to adapt to changing environments. These researchers have identified patterns that they believe can serve as models for industrial organisations striving to develop the same qualities as living organisms. Two of these models are known as holonic manufacturing systems and the fractal factory.

**Figure 2.8 Individual competence development based on Kolb (1984) and Kjellberg (in Moestam Ahlström & Kjellberg, 2001)**
The word ‘holon’, as in holonic manufacturing system, is a combination of the words ‘holos’, the Greek word for whole, and the suffix ‘on’ meaning particle or part. The concept holon was suggested by Koestler (Koestler, 1967) to describe the basic unit of organisation in biological and social systems. Every unit of organisation, such as a single cell in an animal, comprises smaller units (such as molecules) and at the same time forms part of a larger unit (such as a muscle). A holon is an identifiable part of a system that has a unique identity, yet is made up of subordinate parts and in turn is a part of a larger whole.

The strength of holonic organisations (such as living organisms) is that they build complex systems that are efficient in the use of resources, highly resilient to disturbances and adaptable to changes in their environment. The stability of holonic organisations stems from a combination of autonomy and cooperation. The holons can cooperate to achieve a goal or an objective, yet they have a degree of independence and handle circumstances and problems on their particular level of existence without asking higher level of holons for assistance.

Theories about the fractal factory (Warnecke, 1993) have also been inspired by the vitality and dynamics of nature. The term ‘fractal’ comes from the field of mathematics, where it is used of models that provide realistic mathematical descriptions of complex natural phenomena.

In relation to manufacturing industry, Warnecke defines a fractal as an independently acting corporate entity whose goals and performance can be precisely described. Fractals can be seen as factories within the factory. Warnecke points out the importance of performing all services, or work tasks, in ‘their entirety’, but at the same time they should be performed as independently as possible.

Self-similarity and self-organisation are important characteristics of a fractal organisation. In an industrial setting, self-similar refers primarily to the goals of the factory and the fractals. They all operate towards the same overarching goals and are integrated in the goal-formation process. Self-organising means that each fractal must be free to organise itself and to decide how the work tasks are to be performed.
Warnecke sees the fractal factory as means to make better use of human resources in industry. Freedom of action and access to information are seen as the most important attributes to motivate the work force.

Kjellberg (1996b and Kjellberg & Kvarnström, 1996) have investigated programs for organisational change in Swedish industry during the 1990s. Some of the characteristics identified in these programs are associated with increased areas of responsibility for working teams. Kjellberg describes this change as an increase in working content in a way that enables people to play a greater role in company business. Figure 2.9 is a graphic representation of some her findings. The image draws on the Swedish concept of boundaryless flow organisations (Helmrich et al., 1994).

![Figure 2.9 Process-oriented work organisation by Kjellberg](image)

The general idea is that activities within the company are divided based on process flows rather than on the traditional divisions between functional departments. Each process is directed towards a special group of customers or specific customer values. According to Kjellberg, this kind of organisation improves the conditions for learning since it enables people to take part in and understand more of the company’s operations and customer demands.

Nonaka and Takeuchi (1995) propose an organisational model with self-organising teams in cross-functional settings in what they call a ‘hypertext’ organisation with ‘middle–up–down’ management. Such an organisation can provide the five necessary enabling conditions for organisational knowledge creation mentioned in section 2.1: intention, autonomy, fluctuation, redundancy, and requisite variety.
In a hypertext organisation there are three different but interconnected layers, related to different contexts within the organisation. The layers are the business system, the project team, and the knowledge base. The business-system layer, which has a hierarchical structure, is where normal routine operations are carried out. In the project-team layer, multiple project teams engage in knowledge-creating activities such as new product development. The third layer, the knowledge-base layer, does not exist as an actual organisational entity but is a layer where organisational knowledge generated in the other two layers is recategorised and recontextualised. This layer is embedded in corporate vision, organisational culture and technology.

A hypertext organisation views bureaucracy (the conventional hierarchic organisation) and task forces as complementary. Bureaucracy is effective in bringing about the knowledge conversion modes of combination and internalisation, while a task force is suitable for the knowledge conversion modes of socialisation and externalisation.

The key characteristic of a hypertext organisation is the ability of its members to shift contexts. They can move among the three contexts in order to accommodate the changing requirements of situations both inside and outside the organisation.

In ‘middle–up–down’ management, middle managers are seen as ‘strategic knots’ that link top management with front-line managers. They are the bridge between the visionary ideas of the top and the often chaotic realities confronted by front-line workers.

*Synthesis*

The theories presented above offer interesting models for the design of a competence-promoting organisation. A recurring feature in these theories is the need for extensive information in order to understand the context for action, including information about goals and the general direction of the organisation. Other recurring features are the benefits of autonomy and of teamwork involving people with a variety of skills.

These theories point to a need to create autonomous organisational units with work allocations with sufficient scope to allow an understanding of company activities and to give each unit freedom of action. The organisational unit
needs to be small enough to be manageable as a team in which the team members can work closely together and complement each other in performing their common task. These organisational units need to be connected to each other through a clear and simple interface that makes it easy to understand how they are related to each other and how the organisation is constituted. Since understanding is a basic prerequisite for developing competence, the enhanced ability to understand the work context in such an organisation strengthens what Nonaka and Takeuchi call the knowledge base layer in a hypertext organisation.

2.2 Concurrent Engineering

This section will first set out the benefits of concurrent engineering. This introduction will be followed by information about methods and tools in concurrent engineering. The third subsection focuses on engineering principles and tools related to assembly efficiency, and finally the literature on modularisation and platforms is discussed.

2.2.1 The benefits of concurrent engineering

The term concurrent engineering was coined in the USA in 1989 (Sohlenius, 2000) to refer to a method of working in which the various engineering activities in the product and production development process are integrated and performed as much as possible in parallel rather than in sequence.

Sohlenius states that the main goal of concurrent engineering is to shorten lead-times. It is also said to improve the quality of work. ‘Concurrent Engineering aims at using the opportunities for improvement as early as possible by integrating the product and process development so that the cost for regret is minimized’ (Sohlenius, 2000, p. 85).

Sohlenius’ statements are supported by the findings of Clark and Fujimoto (1991). They conducted an extensive study of product development performance in the automotive industry, measuring lead-time, quality and productivity. Their results clearly indicate that tight integration of upstream and downstream activities in the product development process is of decisive importance in achieving overall high performance in product development.
Clark and Fujimoto describe product development as a process with four major development stages: concept generation, product planning, product engineering and process engineering (see figure 2.10).
Figure 2.10 The horizontal relationships represent problem-solving cycles, and the vertical relationships denote refinement of knowledge or information assets (Clark & Fujimoto, 1991, p. 27). Note that ‘production’ in Clark and Fujimoto’s nomenclature is equivalent to ‘manufacturing’ in this thesis.
In the concept generation stage, information about future market needs, technical possibilities, and other conditions are merged and translated into a product concept. The product concept defines the character of the product from a customer’s perspective. It is often expressed verbally, with some form of sketches and preliminary technical specifications.

Product planning translates the product concept into specifics for detailed product design, including styling, layout, major specifications, cost and investment targets, and technical choices. Engineers and designers at this stage employ physical models for styling evaluation and mock-ups for interior and layout evaluation.

Product engineering translates product-planning information into detailed product designs. Full-scale commitment of engineering resources begins at this stage. The problem faced by the product engineers is how to realise the product concept in real parts and components while also satisfying business requirements.

Process engineering translates detailed product designs into process designs and ultimately into actual shop-floor manufacturing processes. Process design in the upstream part of this stage includes overall plant design (material flows and plant layout), hardware design (tools, jigs, dies, and other equipment), software design (part programming), and work design (standard operating procedures).

Clark and Fujimoto state that product development is a system of interconnected problem-solving cycles between different interest groups and that the characteristic of outstanding performance is a pattern of consistency in process, structure, attitude, and skills in integrated problem solving. The problem-solving cycle is described as a learning process (see figure 2.11).
Clark and Fujimoto stress the importance of understanding what effective integration means and what is required to achieve it. One example they give is the need to strike a balance between manufacturability and marketability. They claim that this can be achieved through the coexistence of concept-oriented process engineers and producability-oriented product engineers. Intensive communication, both formal and informal, is said to be the means to achieve this.
Clark and Fujimoto describe the challenge facing a downstream group as how to get a flying start on development before they have complete information and without creating so many constraints that the car loses its appeal. The downstream group must develop skill in finding and using ‘clues’ about the upstream work. These clues, combined with experience of previous patterns of upstream behaviour, become the basis for downstream action. Regular communication and cross-functional relationships that support early and frequent exchanges of preliminary constraints, ideas and objectives is essential.

Smith and Reinertsen (1998) focus on rapid product development, that is, on shortening the lead-time in product development. They point to early involvement of manufacturing issues in the product development process as having the potential to shorten development time both by overlapping activities and by reducing reworking.

The following are some techniques that Smith and Reinertsen identify as promoting the early involvement of manufacturing issues:

- Maintain continuous manufacturing presence in the development lab.
- Get product engineers onto the factory floor in order to give them direct experience of manufacturing and to help them build relationships with manufacturing people.
- Put assemblers on the development teams.

Smith and Reinertsen emphasise the prerequisites for effective teamwork in product development. They point to the importance of having a common objective for the team and suggest that cross-functional teams should be organised around a physical or logical subsystem of the product. Communication is seen as a central capability and collocation is considered to be an extremely efficient way of promoting this.

Sohlenius (in Sohlenius, 2000) have emphasised the need to view concurrent engineering as a multidisciplinary activity involving people with different backgrounds and perspectives. It is therefore vital to work according to the ‘total-integration principle’ (Kjellberg, 1992) to develop high quality solutions. Total integration refers to active and creative participation of all involved disciplines during all phases of development work, from planning to presentation of results. Furthermore, Kjellberg points out this total integration
must accompanied by an outspoken message that acknowledges and authorises the importance of a cross-functional work effort.

Synthesis

All of the work presented above emphasises the need for concurrent engineering in order to achieve high performance in the product realisation process. Integration is seen as the way to do this. However, integration is not easily accomplished. Clark and Fujimoto in particular set out the special kind of skill necessary to achieve effective integration. Close cooperation and intense communication between people with different competencies is an important component in the learning activity of product development in order to achieve high quality output.

2.2.2 Methods and tools in concurrent engineering

Several methods and tools have been said to be of help in realising a concurrent engineering approach. Wheelwright and Clark (1992) discuss quality function deployment (QFD), failure mode and effect analysis (FMEA), design for manufacturing (DFM), value engineering and Taguchi methods as being designed to enhance the ability of upstream groups to predict the consequences of their decisions for downstream activities. Syan and Menon (1994) focus on the use of QFD, DFM, rapid prototyping, and software tools in the realisation of concurrent engineering. Susman (1992) concentrates on DFM in order to integrate the issues of design and manufacturing.

Norell (1992) has studied the effects of design for assembly (DFA), FMEA and QFD in product development work in industry. She found that implementation of these methods led to improved conditions for cooperation between people from different functional departments in early phases of product development work. The methods led to increased knowledge about the product and improved conditions for holistic understanding.

Sohlenius has stated that there is a need to distinguish between tools, methods and fundamental principles in order to understand how different methods and tools can or should be used in engineering design (Sohlenius et al., 2002). The difference between these concepts can be illustrated by the example of driving a nail into a piece of wood with a hammer (Sohlenius et al., 2002). The hammer is the tool. The method is to grab the handle of the hammer and swing it so that the head hits the nail. The fundamental principle in this case is found
in the theory of mechanics and has to do with the rules of energy transformation. Sohlenius also concludes that axiomatic design (Suh, 1990) opens possibilities for making decisions focusing on quality and productivity.

Fagerström has proposed a model showing the basic parts and relationships in methods for development processes (see figure 2.12).

![Model Diagram]

**Figure 2.12** Fagerström’s model of the basic parts and relationships in methods for development processes (presented in Fagerström and Moestam Ahlström, 2001).

A model is a projection of the real world. The data collected in the model provide the basis, the information, for decision-making. The decision will, when carried out, have an effect in the real world. Models are typically either physical, mathematical or analogous. In development work, methods help the designer to create a model of what is essential in the real world.

In development work, models are used to formalise information for decision-making. Engineering design methods all contain models that help designers to focus on the specific issues addressed in that method. These models are often based on empirical or experimental experience, synthesised and expressed in the form of rules, tables or diagrams. All methods also contain a process model that describes the working procedure, that is, how to use the rules, tables and diagrams in implementing the method.
Synthesis

The engineering methods just mentioned are means of improving cooperation in product development work. The methods help development teams to focus on particular issues that can help them achieve a common view. A common view and a common language can decrease eventual conflicts between different interests in the team and contribute to increased cross-functional learning.

2.2.3 Engineering methods and principles for assembly efficiency

Boothroyd et al. (2002) refer to assembly efficiency as a measure to evaluate the design of a product with respect to its ease of assembly. They also speak in terms of the ‘assemblability’ of a product. The DFA method developed by Boothroyd et al. (2002) includes rules that help designers to judge the possibility for integration of parts. The method also contains models that help designers to evaluate the design efficiency of a product and consider whether redesign is called for. The two basic rules in the method are to reduce the number of parts and to design each part so that it is easy to handle and to insert or fasten.

Magrab (1997) uses a definition of ‘manufacturability’ that highlights some other interesting aspects relevant to assembly efficiency. By a product’s manufacturability he means its simplicity; the straightforwardness of its configuration; the degree to which it minimises labour, materials, and overhead costs; and its freedom from inherent quality and processing problems.

Magrab (1997) summarises the governing principles of design for assembly as follows:
1. Simplify, integrate and reduce the number of parts. Each separate part is an opportunity for a defective part or an assembly error.
2. Standardise and use common parts and materials. Standardisation facilitates design activities, reduces inventory, and to standardise handling and assembly operations.
3. Mistake-proof product design and assembly. The assembly process should be unambiguous. Components should be designed so that they only can be assembled in one way and cannot be reversed. Notches, asymmetrical holes and stops can be used to mistake-proof the assembly process. Products should be designed to avoid adjustments.
4. Design for parts orientation and handling. The aim is to minimise effort and ambiguity in orienting and merging parts. Avoid parts that can become tangled, wedged or incorrectly oriented.

5. Minimise flexible parts and interconnections. Flexible or flimsy parts such as belts, gaskets, tubing, cables and wire harnesses are more difficult to handle and assemble and more susceptible to damage. Partition the product to minimise interconnections between modules and place related modules adjacent to each other to minimise the routing of interconnections.

6. Design for ease of assembly by utilising simple patterns of movement. Complex orientations and assembly movements in various directions should be minimised. Parts should include such features as chamfers and tapers. The product’s design should enable assembly to begin with a base component with a large relative mass and a low centre for gravity to which other parts are added.

7. Design for efficient joining and fastening. Threaded fasteners (screws, bolts, nuts and washers) are time-consuming to use in assembly. Where they must be used, standardise to minimise variety and use self-threading screws and captured washers.

8. Design modular products to facilitate assembly. A modular design should minimise the number of part and assembly variations while allowing for greater product variation during final assembly. Modules can be assembled in parallel to reduce the product’s overall production time and can be more easily tested before final assembly.

Synthesis

DFA is a method that helps in the design of assembly efficient products. Magrab sets out clear principles for achieving assembly efficiency. Several of his findings are important in regard to this thesis. One of his observations concerns a product’s ability to meet the demands of stability, or robustness, in the manufacturing process. This observation is extremely important as regards a product’s ability to provide a good basis for achieving high performance in the assembly process. The product’s simplicity and the straightforwardness of its configuration are also important as these qualities make it easier for people to understand the product. Such understanding in turn contributes to peoples’ ability to suggest improvements.
2.2.4 Modules and platforms

‘Mass customisation’ is a term used to describe a challenge that a large part of industry is facing. The challenge is to combine the economy of mass production with individually customised goods and services. Magrab (1997) insists that the primary means of achieving mass customisation is product modularity.

Product modularisation has been reported to show benefits in many areas. Smith and Reinertsen (1998) claim that the primary advantage of modularity is that it permits more concurrent development and greater flexibility in adjusting the scheduling of modules. Sanchez (1996) emphasises the benefits of modular organisation in product development work. He believes that modular architecture allows ‘decoupling’ of processes for developing new products, enabling these processes to become concurrent, autonomous and distributed.

In the automobile industry, modularisation and product platforms are closely related. Mufatto (1999) has studied the concept of a product platform in the automobile industry and states that in about 1994 almost all companies in the automobile industry were faced with the need to implement a platform strategy. According to Mufatto, a platform can be defined as a relatively large set of components that are physically connected as a sub-assembly and are common to different final models. A platform concept makes it possible to build many different cars with just a few building blocks.

The main reasons he cites for moving to platform development are cost reduction, productivity of product development, and reduction of development lead-time. From an organisational perspective, Mufatto sees a platform as a means of developing cross-functional teams within product development. Furthermore, he points to the benefits of modularisation in terms of simplification of assembly procedures.

Erixon et al. (1994) write about several issues related to modularisation. Von Yxkull (in Erixon et al., 1994) focuses on the assembly process in relation to modularisation of products. He writes that a modularised product emphasises successive development by decomposition of the assembly system into manageable units or module areas, ‘factories within the factory’. Such decomposition can isolate the effects of a change in one module to one module area in the assembly process. Furthermore, von Yxkull proposes that module
areas, or a number of module areas, can be suitable work areas for goal-oriented teamwork on the shop floor.

*Synthesis*

According to the literature, modularisation has many benefits. One of the most obvious is the ability to create many variants for a relatively low cost. Modules can also provide the basis for division of work in product development. Furthermore, modules can serve as the basis for division of the manufacturing process into ‘factories within the factory’.

**2.3 Summary**

The most important elements of the frame of reference presented in this chapter are as follows:

*As regards learning and competence development:*

- Work should be organised according to the demands of increased level of competence of everyone in the organisation.
- Competence development is dependent on individual attributes as well as on the prerequisites in the surrounding environment.
- Competence development requires a number of different skills.
- Utilisation of the tacit knowledge in an organisation requires opportunities for informal knowledge creation and exchange.
- An understanding of context is a basic prerequisite for competence development.
- Work should be organised in autonomous units that have sufficient knowledge and information about their context to become competent.

*As regards concurrent engineering:*

- Cross-functional integration early in the product development process is important in developing assembly efficient products.
- Methods promoting concurrent engineering can improve the exchange of information and cross-functional learning in cross-functional teamwork.
- Certain general principles can guide the design of assembly efficient products.
- Modularisation has the potential to enhance assembly efficiency.
- Modules can be the basis for the division of work both in product development work and in the assembly shop.

### 2.4 Research questions

The purpose of this thesis, as formulated in section 1.4, is ‘to explore the prerequisites for enhancing the development of assembly efficient products’. Furthermore, it was stated that ‘It focuses on organisational prerequisites, including organisational structure and working methods’ needed to promote learning and competence development in this specific area.

The literature surveyed in this chapter makes it possible to specify the basic research question as:

*How can competence in developing products designed for assembly efficiency be developed organisationally?*

This question can then be divided into the following components:

1. **How can competence in the development of assembly efficient products be developed?**
   
   1.1 *How can competence in the development of assembly efficient products be described?*
   
   1.2 *How can competence in the development of assembly efficient products be refined?*
   
   1.3 *How can competence in the development of assembly efficient products be transferred?*

2. **What are the organisational prerequisites for promoting competence development as regards the development of assembly efficient products?**

   2.1 *What organisational structure is needed to promote competence development as regards the development of assembly efficient products?*

   2.2 *What working methods are needed to promote competence development as regards the development of assembly efficient products?*
In order to understand how competence in regard to the development of assembly efficient products can be developed (question 1), the existing competence within the organisation must first be analysed and described (question 1.1). Kolb’s learning by experience model is used for this analysis. The next question is how the existing competence can be refined (question 1.2); that is, how can individuals learn to become competent. Competence development is here regarded as the process of moving towards the top of the spiral in figure 2.8. The third question is how individuals can learn about assembly efficiency from each other (question 1.3). The question concerns knowledge transfer, and thus Nonaka and Takeuchi’s model of knowledge transfer will be used in answering the question.

Question 2 is directly related to the normative aim of this thesis. It concerns both how to organisationally promote individual competence development towards the top of the spiral as described above, and how to promote transfer of knowledge between individuals. It is divided into two subquestions regarding a competence promoting organisational structure (2.1) and working methods that can promote competence development (2.2). Question 2.1 is related to the literature about competence-promoting organisations and how they are structured. Question 2.2 is about what working methods promote cross-functional exchange and learning.
3. RESEARCH METHOD

In section 1.6 the research for this thesis was described as typical of a qualitative mode of study. Leedy and Omrod (2001) make it clear that there is no magic formula, no cookbook, for conducting a qualitative study. Rather the process involves what can be described as an emerging design (Creswell, 1994). This chapter describes the emerging design of the research process for this thesis.

This chapter is divided into three subsections. The first sets out the starting point, the tentative theory and the working hypotheses. The second section describes the working method and gives general information about different studies. Section three contains some reflections on the appropriateness of the methodology used in this research.

3.1 The starting point

According to Creswell (1994) in qualitative approaches the research questions often evolve and change as the research progresses, influenced by the findings. This has been the case in this study.

The original idea for this study sprang from my licentiate thesis and developments at Volvo Car Corporation at that time. My licentiate research brought home the impact of product design on the assembly process. I realised that the design of the product was very important to achieving a good working situation in the final assembly shop. Moreover I saw the potential of utilising assembly workers’ knowledge in the development of new products.

At this time issues relating to cooperation between the final assembly shop and the product development team were very much in focus at Volvo Car Corporation. Manufacturing would soon begin for the first car on a new platform, the Volvo S80, which was seen as a major challenge for the organisation. The product differed greatly from previous products and was considered to be almost completely new. The manufacturing system had been rebuilt and the supplier structure had been changed. Close cooperation between the final assembly shop and the module teams responsible for product
development was seen as a necessity to handle the start-up of manufacturing of the new car.

The focus of my research was initially on cooperation between the assembly process in the final assembly shop and the product development organisation. It was assumed that it was a good idea to use product modules in the design of the organisational structure and that these would provide a basis for cooperation and cross-functional exchange.

The idea of a study focusing on the development of products designed for efficient assembly evolved in the autumn 2000. A tentative theory was formulated, in the form presented in figure 3.1. The role of a tentative theory is, according to Creswell (1994), to describe the main dimensions to be studied, the key factors, the variables and the presumed connections among them. Such a theory is not the same as a model to be tested (as in a quantitative study), but is a theory in development, which will be modified.

![Figure 3.1 A schematic representation of the tentative theory for this thesis](image)

A condition for the development of assembly efficient products is that knowledge and experience about the assembly process is drawn on and used in developing new products. Therefore an underlying assumption in this research is that cross-functional learning is needed for the development of assembly efficient products. Also basic to this research is the idea that cross-functional
learning can be facilitated by cross-functional teamwork, product modularisation and engineering methods and tools.

The model in figure 3.1 draws on different theoretical perspectives. Research about teamwork is traditionally the sciences of human factors and is also related to theories regarding concurrent engineering. Modularisation is an offshoot of research into future companies and competence-promoting organisations in combination with engineering research on modules. Research about methods and tools to support the engineering work comes from the field of engineering design.

The working hypothesis derived from this tentative theory was as follows:

1. Cross-functional teamwork can create a supportive environment for informal cross-functional exchange and learning.
2. Product modules can be used to create appropriate work entities for cross-functional teamwork.
3. Engineering methods and tools can improve the exchange of cross-functional learning.

3.2 Working method

The research for this thesis took the form of a process in which empirical studies were combined with academic supervision and discussions, Ph.D. courses, and literature studies. This process continued from the beginning of 1995 until the completion of this thesis in 2002. It is not possible to set out activity in detail, but some steps of major importance will be described.

The overall setting for the research in this thesis is two research projects involving KTH and Volvo Car Corporation. As a industrial doctor student, I was the full-time operating resource for both projects. Thus the industrial setting of this thesis has been provided by Volvo Car Corporation while the academic studies have been performed under the supervision of KTH.

The first project ended with the awarding of my licentiate thesis in October 1997.

Thereafter a new project was started, this time sponsored by Woxéncentrum at KTH, in cooperation with Volvo Car Corporation. This second project drew
on the findings of the licentiate thesis, but there was a shift in focus. Whereas the first project had concentrated on the final assembly shop, the second project focused on the cooperation between the final assembly shop and the product development departments. After a year’s work on the second project, I went on parental leave for 1½ years. I resumed work in the autumn of 2000, and have worked on the second project since that time. Some major steps in the research process are described below:

1. Licentiate work
2. Work with production teams
3. Modularisation study
4. Paper: ‘Systematic Development of Individual, Team and Organisational Learning’
5. Interviews on strategies
6. Case studies of the development of the cockpit and parcel shelf in the Volvo S80
10. Case study of a split of a module

The relation between these steps and the working hypotheses is roughly illustrated in figure 3.2.
1. **Licentiate work**

For the licentiate thesis I studied assembly work, the special problems of assembly work and the effects on assembly work of an organisational change program. In the course of this research I learned about assembly efficiency and the impact of product design in the assembly process. A brief description of the results of the licentiate work is found in chapter 5: ‘Licentiate Thesis – About Assembly Work’.

2. **Work with Production Teams**

On concluding my licentiate thesis, I was assigned to work on the development of production teams. This work was directly operative. This work gave me opportunities to study the cooperation between the final assembly shop and the product development process, including aspects of teamwork and modularisation. One conclusion drawn was that the Volvo vision of creating modules that could serve as work entities both in manufacturing and in product development had not been fully realised. The findings from this work are presented in chapter 7: ‘Communication Interface - Final Assembly and Product Development’.
3. *Modularisation study*

The modularisation study involved interviews that were conducted in cooperation with two Ph.D. students at KTH, Michael Blackenfelt and Roger Stake, who were doing research on technical issues of modularisation. My focus, however, was on how people from product development perceived the concept of modules and their attitude to the company’s modular strategy. I was searching for information that could lead to an understanding of why Volvo’s vision of modularisation had not been completely successful. One thing I learned from this study was that the product development department and those responsible for assembly differed in their perceptions of what a modular strategy meant. This study also illuminated the difficulty of implementing the manufacturing vision of dividing cars into modules. The results of this study are presented in chapter 6, ‘Modularisation’.


Learning and competence development is central to this thesis. This paper deals with the relationship between organisational learning, individual learning and team learning. The paper was produced in collaboration with Annika Werneman, a fellow KTH Ph.D. student who is doing related research on learning in an industrial environment. This paper was presented at the 3rd International Conference on Quality Management and Organisational Development in Aarhus, Denmark, in 2000, and is available in appendix C.

5. *Interviews on strategies*

These interviews built on the results obtained in study 3. The interviews were conducted directly after I returned from 18 months of parental leave. They thus served to bring me up to date on what had come of the module strategy, module teams and the visions and strategies for cooperation between those involved in product development and in final assembly. The interviews served to confirm the conclusions drawn from study number 3. However, they also gave me information about some new ideas and suggestions regarding a strategy for modularisation from a manufacturing perspective. The results of these interviews are reported in chapter 4, ‘Organisational Development’, and chapter 6, ‘Modularisation’.

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6. **Case studies of cockpit and parcel shelf**

The case studies of the cockpit and parcel shelf were undertaken subsequent to the decision to focus on assembly efficient products. The goal was to examine the development processes that had produced two assembly efficient products and to investigate what had led to these assembly efficient concepts. This study is presented in chapter 9, ‘Development of Two Assembly Efficient Products’.


This paper was written in collaboration with my supervisor, Ann Kjellberg, Associate Professor at KTH. It deals with theoretical principles relevant to this thesis. Specifically, it deals with the prerequisites for creating a learning environment in a company setting. This paper was presented at the 4th International Conference on Quality Management and Organisational Development in Linköping, Sweden, 2001. The paper is available in appendix D.


This paper was written in collaboration with Jonas Fagerström, a fellow KTH Ph.D. student who is doing research on methods for concurrent engineering. The paper develops theory about methods, how they are constituted and in what ways they can contribute to concurrent engineering. It was presented at the 16th International Conference on Production Research, ICPR–16, in Prague, Czech Republic, 2001. The paper is available in appendix E.


Marcus Larneby and Erik Backhans, both master’s students at Chalmers University of Technology, performed this work under my direction. Their task was to map the communication links between the final assembly flow and the different departments involved in product development and then to assess the effectiveness of different communication interfaces. This study is presented in chapter 7, ‘Communication Interface – Final Assembly and Product Development’.
10. Case study of splitting a module

This study was undertaken in collaboration with Magnus Persson, a Ph.D. student at Chalmers University of Technology, who is studying the demands on modularisation from different stakeholders in an organisation. The study involved a reverse investigation of the effects of modularisation in that we investigated the effects of a split of a module. This study is presented in chapter 8, ‘Assembly-Related Consequences of a Module Split’.

Table 3.1 presents an overview of the empirical sources of data. This table shows when the different studies where performed, the methods used for data collection, the focus of each study, and in which chapter the results are presented. Further descriptions of the methodology used in each study can be found in the chapters where the results are presented.
<table>
<thead>
<tr>
<th>Study</th>
<th>Time period</th>
<th>Data sources</th>
<th>Focus</th>
<th>Results, see</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Licentiate thesis</td>
<td>Jan. 95–Oct. 97</td>
<td>Observation Documentation Interviews Presentations</td>
<td>Assembly work</td>
<td>Chapter 5</td>
</tr>
<tr>
<td>5. Strategies</td>
<td>Apr. 00–Jun. 00</td>
<td>5 Interviews</td>
<td>Module and cooperation strategies</td>
<td>Chapters 4 and 6</td>
</tr>
<tr>
<td>6. Cockpit and parcel shelf S80</td>
<td>Oct. 00–Nov. 01</td>
<td>11 Interviews Documentation</td>
<td>Development process</td>
<td>Chapter 9</td>
</tr>
<tr>
<td>10. A module split</td>
<td>Jul. 01–Mar. 02</td>
<td>16 Interviews Documents Presentations</td>
<td>Modularisation</td>
<td>Chapter 8</td>
</tr>
</tbody>
</table>

Table 3.1 Overview of empirical sources of data

3.3 Reflection on the methodology

The initial hypothesis and the methodology used in this thesis have already been described. The aim in this section is to reflect on the research procedure and the appropriateness of the methods used. The methods used for the licentiate study are not dealt with here since they were discussed at length in the licentiate thesis.
3.3.1 The choice of a case study design

As stated in section 1.6 this research has focused on understanding what is being observed. I have also stated that the purpose of this thesis has been to develop a model and that the research draws on conclusions from several different research areas. Thus one aim of this research has been to refine existing theory and to develop new theory presented in the form of a model.

The work in this dissertation can be described as a long-term case study. Case studies have been identified as an appropriate method for generating new theory by Yin (1994) and Eisenhart (in Huber et al., 1995). Alternatives to a case study design were never seriously considered. Rather, the fact that I was offered an opportunity to undertake a deep, long-term investigation of one company was seen as an obvious advantage. I have been given a unique opportunity to gain a deep understanding of the complex and context-related phenomenon of competence development in regard to the development of assembly efficient products.

Yin (1994) argues that the case study method is preferable when studying real life phenomena in complex settings. He also states that an explicit aim of case studies is to gain knowledge in order to understand how and why events occur. Dubois and Gadde (2002) argue that learning from a particular case conditioned by its environmental context should be considered a strength rather than a weakness. They believe that the interaction between a phenomenon and its context is actually best understood through in-depth case studies. Their view is supported by Eisenhart (in Huber et al., 1995) who writes that theory developed from case study research is likely to have important strengths such as novelty, testability and empirical validity, which arise from the intimate linkage with empirical investigation. Thus all of these authors (Yin, Eisenhardt, and Dubois & Gadde) support the use of a case study approach in the research for this dissertation.

3.3.2 The evolving methodology

The evolving nature of the research questions and the working hypothesis for this thesis were described at the start of this chapter and in section 1.6. The approach was described as qualitative (based on Creswell, 1994) and the research process followed was described as hermeneutic (based on Helenius, 1990, and Föllesdal et al., 2001). Consequently the empirical investigations follow an evolving pattern rather than some plan decided in advance.
Dubois and Gadde (2002) describe a special kind of case study that they refer to as ‘systematic combining’. Systematic combining is a process of continuous interplay between theory and empirical field studies. By constantly going ‘back and forth’ from one type of research activity to another and between empirical observation and theory, researchers are able to expand their understanding of both theory and empirical phenomena.

Analysis of the research procedure outlined in this chapter reveals a pattern of systematic combining in which empirical studies have been interwoven with theory development. This pattern is especially visible in the alternation between theory development and empirical investigation in the three conference papers (step 4, 7 and 8). Study of the pattern of empirical investigations in particular also reveals an evolving pattern. The first studies (2, 3 and 5) had a wide scope while the last three (studies 6, 9 and 10) were more focused and explicit. It was the last three studies that produced the explicit data that made it possible to finally create the model that is the product of this thesis (see chapter 10).

The work with production teams (study 2) gave extensive informal information about cooperation between the final assembly shop and the product development organisation. This information led to the more specific investigation of the modularisation process (study 3) and the interviews on strategies that followed (study 5). At that stage of the research process, the working hypothesis and the research questions crystallised in my thinking (see the tentative theory in section 3.1).

The next study (study 6) flowed out of the tentative theory. It investigated the development of two assembly efficient products, namely the cockpit and the parcel shelf for Volvo S80. These two products (or parts of the car) were selected for study on the basis of recommendations from experts within the organisation, as set out in chapter 9, ‘Development of Two Assembly Efficient Products’.

The study of the communication interface between those responsible for final assembly and the product development organisation (study 9) was undertaken in order to obtain extensive, explicit details about this communication interface. This study was of major importance in relation to the working hypothesis regarding modularisation. Without this study it would have been
impossible to draw any conclusions about the organisational effects of modularisation.

The study of a module split (study 10) contributed explicit data on the assembly-related effects of splitting a module. At Volvo Car Corporation modularisation takes place as a new car model is being developed. This makes it difficult to isolate the specific effects of modularisation, for technical changes are being made at the same time. The module split offered a unique opportunity to trace the assembly-related effects of modularisation, which is relevant to the initial hypothesis that modules offer a solution to the problem of achieving assembly efficient products.

3.3.3 Methods of data collection

The main methods of data collection for this thesis have been observation and interviews. These methods reflect the evolving nature of the research and the need to listen and observe in order to grasp critical events and issues if I was to understand the phenomenon of developing competence in assembly efficiency in its context.

Yin (1994) regards interviews as one of the most important sources of information in a case study. Bell (1987) states that the main advantage of interviews is that they are adaptable and flexible, allowing a researcher to formulate new questions during the interview in response to the answers given by the interviewee. The disadvantages of interviews are that they are subject to the problems of bias, poor recall, and poor or inaccurate articulation (Yin, 1994).

One way to overcome the problem of bias in interviews is to have more than one interviewer (Bell, 1987). Joint interviews were conducted in several of the empirical investigation reported here, including the modularisation study, the master’s thesis work and the study of the module split. The problem of poor recall was addressed by transcribing the notes from each interview as soon as possible after the interview. The problem of inaccurate articulation is, of course, hard to address, but this risk was somewhat reduced by my long-term acquaintance with the company and the phenomenon being studied. Misunderstandings due to differences in terminology or ways of speaking were thus probably less prominent than in other interview situations.
Interviews should, however, be combined with other sources of information according to Yin (1994). He suggests that information derived from interviews should be supplemented with documentation, archival records, direct observation, participant observation and physical artefacts.

Observation, both direct and participatory, has been a source of data in the research reported in this thesis. Direct observation has the advantage of covering events in real time in context (Yin, 1994). Participatory observation has the same advantages, and also brings further insights in that it enables the observer to perceive reality from the viewpoint of someone ‘inside’ the case study rather than external to it. ‘Many have argued that such a perspective is invaluable in producing an “accurate” portrayal of a case study phenomenon.’ (Yin, 1994, p. 88).

In this study, participatory observation was particularly prominent in the work with production teams. The fact that I have been an employee of the organisation during the years when these changes were taking place means that the method of data collection on organisational development in the company must also be regarded as participatory. This applies particularly to the organisational changes within the final assembly shop, which has been my ‘home organisation’ while I have been conducting this research.

The major disadvantage of participatory observation is the danger of bias (Yin, 1994). To minimise the effect of bias, the information gathered about production teams has merely been used as the starting point for further investigations in later studies. None of the findings from the work with production teams has been used without further investigation in a subsequent study.

Such documentation and archival records as were available have been examined. According to Yin (1994) the most important use of documents in case study research is to corroborate and augment evidence from other sources.

Key informants have been a further source of information. Yin (1994) states that key informants are often critical to the success of a case study. Such persons can provide important insights and suggest sources of corroborative evidence. Over the years, a number of persons have been key informants for this study. Some of these informants were involved for several years, and a few were involved throughout the licentiate and Ph.D. research. Even though
these informants are not explicitly identified in this thesis, the information they have provided has made a significant contribution to the research process.

Another source of information that is not explicitly mentioned in this thesis are the discussions, questions and comments that have flowed from presentations of the results of the studies. The value of such input should not be overlooked. It has contributed valuable corroborative information.

3.3.4 Methods of analysis

Data analysis lies at the heart of any attempt to construct theory from case studies. However, according to Eisenhart (in Huber et al., 1995) such analysis is both the most difficult and the least codified part of the process. One description of the nature of analysis in qualitative studies is offered by Creswell (1994), who writes that the researcher takes a voluminous amount of data and reduces it to certain patterns, categories, or themes and then interprets this information in terms of some schema.

In this thesis there are several levels of analysis, some of which are easy to identify but the majority of which are hard to pin down since the analysis is a learning process going on within my own mind. The following types of analysis were used in this study:
- interpretation of spontaneous observations
- interpretation of information leading to the choice of empirical investigations
- interpretation of interview results
- analysis within empirical studies
- analysis on the general level of the research questions and the resulting model (presented in chapter 10)

Some of these analyses deserve some extra attention, in particular the analyses of the last three empirical investigations (studies 6, 9 and 10), which contributed the explicit data that led to the final model.

Eisenhart (in Huber et al., 1995) writes that a key step in a case study research procedure is within-case analysis. One common method of conducting such within-case analysis is to conduct a cross-case search for patterns, looking at data from many divergent angles in order to reduce the risk of information-processing bias. A tactic for doing this is to select pairs of cases to identify similarities and differences between each pair.
The analysis of the last three empirical investigations (studies 6, 9 and 10) used this tactic. Study 6 compared the development process of two assembly efficient products, the cockpit and the parcel shelf for the Volvo S80. Study 9 compared two areas in the final assembly plant in order to study the interface between the final assembly flow and the product development organisation. Study 10, the study of the module split, compared the situation before and after a product change. Thus all three of these studies involve comparison of pairs of cases in order to identify similarities and differences, as suggested by Eisenhart (in Huber et al., 1995) as a method of reducing the risk of information-processing bias.
4. ORGANISATIONAL DEVELOPMENT

In this chapter I will describe some aspects of organisational development at Volvo Car Corporation that are of special importance to this thesis. In particular, I will focus on the KLE strategy, the OD program, frötallar, module teams and process-driven product development.

4.1 The KLE strategy

KLE is a Swedish acronym that stands for quality (kvalitet), delivery precision (leveransprecision) and economy (ekonomi). This acronym is also the name of a strategy aimed at achieving world-class performance in an assembly plant. Here I will outline the enormous changes that flowed from the introduction of this strategy in the final assembly shop in the plant at Torslanda in 1991.

The introduction of the KLE strategy was preceded by a number of changes. During the late 1980s, an effort was made to eliminate adjustment and inspection staff in the final assembly plant. Prior to this change, special adjustment personnel were stationed at the end of each section of the line. Their task was to check the assemblies produced on that section and to correct any defects. There were also a large number of inspectors. By the time the KLE strategy was introduced, most of these adjustment and inspection tasks had been eliminated and assemblers checked their own work.

Another early change was sprucing up the factory. It was cleaned and painted, and work teams were given responsibility for keeping their areas neat and tidy.

The stock in the assembly shop was also reduced, enabling a reduction in the size of the shelves along the assembly lines. This change created a brighter and more airy working environment for assemblers. Visibility in the factory increased, making it easier to see what was happening in the assembly flow.

In line with the KLE strategy, goal-oriented teams, known as KLE teams, were formed on the shop floor. The overall company goals were broken down by each KLE team into goals relevant to their part of the operation. Customer–supplier relations were established between the KLE teams in the flow (see
meaning that each part of the line was responsible for the output to their particular customer.

**Figure 4.1** Organisation of the KLE teams

The KLE teams were also assigned responsibilities that had formerly been the preserve of white-collar staff. The assemblers’ responsibilities and authority was thus increased.

### 4.2 The OD program

In 1995 an operational development (OD) program was started in the final assembly plant. This program was introduced as a new phase of the KLE strategy, focusing on involvement and understanding in order to reinforce the improvement work.

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**Work tasks of KLE team**
- Assembly
- Development of working methods
- Education of new employees
- Preventive maintenance
- Quality follow-up and drawing up of action plans

**Figure 4.1** Organisation of the KLE teams
A series of seminars were conducted in a top-down manner, starting with the top management in the plant and then spreading through the organisation level by level. Each seminar began with a discussion of strategic challenges. Customer and market demands, threats from competitors and possibilities for the future were identified. As a result of their strategic discussion, the plant management group formulated a strategic challenge and set measurable goals, which provided the topics for subsequent seminars.

Next, each work team discussed their specific contribution to the strategic challenge. Once this contribution had been clearly defined, the next step was to establish goals and ways of measuring progress towards those goals. Action plans were developed.

Follow-up on the OD seminars took the form of team meetings every second week. Initially, these meetings were also attended by specially trained coaches.

### 4.3 The role of frötallar (manufacturing liaisons)

In 1995 a new work role was established in the assembly plant as assemblers were chosen to participate in the verification of new products. It was hoped that this role would enable the transfer of experience and knowledge from the assembly line to the product development process. Those fulfilling this role would also be responsible for educating the assemblers on the line and transferring knowledge about the product to them.

The creation of the role of ‘Frötall’ was an attempt to make more systematic use of the assembly knowledge in the organisation. According to Fröjdh and Ljungqvist (2002) the exchange of information and experience between assemblers, designers and industrialisation engineers was stochastic before the introduction of frötallar.

### 4.4 Module teams and process driven product development

In 1994 a new way of organising the work on projects developing new car models evolved at Volvo Car Corporation. It was decided that the work should be organised in cross-functional module teams. Ideally, each module team should correspond to a module in the manufacturing process, and all the competencies needed for product development should be seated together in a cross-functional setting. Design engineers, industrialisation engineers,
purchasing engineers, purchasing economists, test engineers and the like should be located in close proximity to each other.

The organisation for developing a car was divided into 13 module team areas. Some of these areas did correspond to a module, such as a door, the engine or the cockpit, while others corresponded to other entities in the car. A module team consisted of between 50 and 200 people and comprised a number (3–8) of subteams. The work areas of each module team and the subteams are described in chapter 7, ‘Communication interface – final assembly and product development’.

The change to module teams at Volvo Car Corporation was accompanied by the introduction of the concept of process-driven product development. Before the development of the large platform of which the Volvo S80 was the first car, Volvo had developed new manufacturing systems every time they developed a new car model.

Process driven product development had two aims (Gustafsson & Lindblad, 2000). One was to develop cars that could be produced in a given manufacturing facility in order to minimise the need for new investment. The other was to develop the manufacturing system and the products in parallel. One way of accomplishing this goal was to break-up the car into modules that could be developed by cross-functional teams, with each design module corresponding to a separate module in the manufacturing process. It was thought that this approach could improve the communication and cooperation between product development and manufacturing.

4.5 Comments

Organisational changes like those described in relation to the KLE strategy were typical of the industry during the 1990s. Similar changes have been described by Kjellberg (1996b; Kjellberg & Kvarnström, 1996). A study tour of Germany in 1995 showed similar developments in German industry (described in Kjellberg et al. 1995). These programs of change were clearly inspired by the *kaizen* message referred to section 2.1.1.

The OD program is what has been described in the literature as a successive goal decomposition program (Bergman and Klefsjö, 1991) and is related to a Japanese working method called *hoshin kanri* (Akao, 1991).
The aim of both the KLE strategy and the OD program was to increase the rate of improvement in the work in the final assembly plant. Further improvements were effected by the creation of module teams, by the introduction of the role of Frötallar, and by the introduction of product-driven product development.
5. THE LICENTIATE THESIS
– ABOUT ASSEMBLY WORK

My licentiate thesis, ‘Heading towards “A Learning Organisation”: A Study at the Torslanda Assembly Plant, Volvo Car Corporation’ (English translation of the title), laid the groundwork for this doctoral thesis. This chapter introduces the work done for my licentiate thesis and presents the results of that study.

5.1 Introduction

The research for the licentiate thesis focused on assembly work and how the work situation of assemblers had changed due to the implementation of the KLE strategy in 1991 (see section 4.1, ‘The KLE strategy’). The changes in the work situation included broader responsibilities, additional work tasks and work enrichment.

5.1.1 Purpose of licentiate thesis

The research set out to examine the specific problems associated with assembly work, identifying which problems had to be solved, analysing them and suggesting solutions.

5.1.2 Hypothesis and leading questions

The working hypothesis was ‘An organisational change such as KLE is fundamental to the creation of good assembly work in the automotive industry’.

The key questions were:
- What is important in assembly work?
- How can weaknesses be defined?
- What are the prerequisites for assemblers to perform their work tasks efficiently?
- What changes has the KLE strategy led to in assembly work?
- What problems are there today?
- How can these problems be solved?
5.1.3 Research method

The research project lasted from the beginning of 1995 to the autumn of 1997. Assembly work on four different parts of the assembly line was studied. These parts represented the different types of assembly work that were being done in the final assembly shop at that time. The overall research method involved a comparison of these different types of assembly work.

Data was gathered by working with the assemblers for some days on each of the chosen parts of the assembly line. During these days, direct observations were made and informal interviews were conducted with the assemblers. Data was also gathered from informal and formal interviews with other people in the organisation with experience and knowledge of assembly work.

A human factor framework developed by Kjellberg (1996a) was used to analyse the assemblers’ working situation. This framework focuses on work tasks in modern production systems.

5.2 Results

The results of the licentiate research were presented in two reports (Moestam, 1996, and Moestam, 1997) and then further reworked in the licentiate thesis (Moestam Ahlström, 1997). Two conference papers were also written and presented (Kjellberg and Moestam Ahlström, 1997, and Moestam Ahlström, 1998). A number of presentations were made both internally at Volvo Car Corporation and externally on a number of occasions.

This section will describe the most important contributions of the licentiate thesis. That is, the most important contributions as regards the subject of this doctoral thesis. For further descriptions of the data and its analysis see the conference papers in appendix A, ‘A Human Factors Framework for Analysis of an Assembly Work’, and appendix B, ‘Analysis of an Assembly Work’.

5.2.1 Characteristics of assembly work

Assembly work in large-volume automotive manufacturing is extremely monotonous and predetermined. Decisions are made in advance about exactly where, when and how the work will be done. The work is extremely
constrained, both at the moving assembly line and at the pre-assembly workstations.

It is important to stay alert all the time to ensure that the assembly is done correctly. However, the monotony of the work and its almost exclusive reliance on the most basic sensory motor skills mitigate against this, making it difficult to stay alert. When attention falters, mistakes are easily made. One way of reducing the risk of making mistakes is to ensure that the different suboperations are related to each other in some logical pattern that facilitates memorisation of the steps.

The ability to handle any deviations in the process is greatly restricted by the constraints of assembly work. Everything has to be done very quickly. When the number of variants in the assembly flow increases, the demands on the assemblers increase as well. They must then be able to handle a large number of products without any set-up time. This means that the assemblers need to know exactly what details they are responsible for and how these are to be assembled on each variant. They must also have a mental image of the problems associated with each variant and how these can be avoided.

5.2.2 Effects of the KLE strategy

The KLE strategy has enriched the work of assemblers with new work tasks including planning, control and the handling of faults and defects. This work enrichment enables assemblers to use capabilities other than the sensory motor ones needed for the actual assembly. More of their mental capacity is being put to use.

Assemblers’ ability to handle deviations in the assembly process has also been affected by the KLE strategy. Assemblers have been given access to more information, and their knowledge of the manufacturing system and the factors that affect it has increased. This, in turn, has meant that they are better equipped to understand why problems occur and how to handle them. Furthermore, the KLE strategy has led to systematic procedures for following up and eliminating deviations affecting the manufacturing process.

Freedom of action is very restricted in assembly work. Although it is possible to change tools and working methods, all changes must be standardised before they can be implemented. Methods also have to be in place to handle assemblers’ suggestions regarding changes to the product design. While the
possibility for change has always been present in the organisation to some extent, the focus on continuous improvement in the KLE strategy has encouraged initiative and resulted in more systematic methods of handling suggestions for improvements.

5.2.3 Organisational learning

Two types of learning have been identified in relation to assembly work, organisational learning and assembly learning. Organisational learning here refers to gaining an understanding of company processes and taking part in setting a vision, goals and strategies, as well as in defining customer demands. Assembly learning here refers to learning about a variety of assembly-related work tasks.

Assembly work in itself allows few opportunities for learning, and thus organisational learning is extremely important to create what can be regarded as a ‘good work’ (defined according to Kjellberg’s framework).

5.2.4 Effects of modularisation

Modularisation of the product with a view to creating ‘factories within the factory’ (see section 2.2.4) allows more opportunities for improving assembly work. Assembly work that has to be performed on, and especially inside, a car body very often requires poor work positions. Modules that can be assembled before being put into the car body are therefore preferable. Such modules also provide a better opportunity for assemblers to gain a holistic understanding of the specific modules that they are working on, enabling them to grasp the inner logic by which the different details are connected. This understanding, in turn, makes it easier to memorise the steps required during assembly and enhances the assemblers’ ability to contribute suggestions for improvements.
6. MODULARISATION

The aim of this chapter is to present an overview of modularisation at Volvo Car Corporation. Interviews were used to gather most of the data. The first set of interviews was conducted jointly with Roger Stake and Michael Blackenfelt, Ph.D. students at KTH.

The introduction sets out the background to this study, its purpose and the methods used. The results are then presented and analysed.

6.1 Introduction

When Volvo Car Corporation started to develop a large platform, it introduced a modular strategy. This was the first time in the history of the company that different car models had been developed with a common module base, or platform.

Before this, each car model had been developed in sedan and estate models (for example the Volvo 850 sedan and estate variant). These variants had some of the elements of a platform in that there was considerable commonality between the models (they shared the same components). But essentially these were variants on the same product, marketed to the same group of customers. By contrast, the products on the large platform, the S80, V70, and S60, were designed and marketed as different products targeted at different groups of customers.

6.1.2 Purpose

The purpose of the study presented here was to examine Volvo’s modular strategy in order to find out how existing modules had evolved and to grasp future ambitions.

6.1.3 Method

The first part of this study was undertaken jointly with Ph.D. students Roger Stake and Michael Blackenfelt, who were studying modularisation in Swedish
industry. Their research resulted in a conference paper (Stake and Blackenfelt, 1998) and two doctoral theses (Stake, 2000, and Blackenfelt, 2001).

I suggested that Volvo Car Corporation should be included in their study and requested permission to participate in the interviews they were conducting. My reason for doing this was to gain a wider understanding of modularisation. We interviewed four persons who had been involved in the modularisation of the large platform. Each semi-structured interview lasted for about 2 hours. The interviews were followed by joint discussion and analysis of the results of the interviews.

The questions that were the focus of my concern were:
- How was modularisation done?
- To what extent were manufacturing considerations involved in the modularisation process?
- What modules are there?
- Is it possible to modularise a whole car?
- Do manufacturing and product development have different understandings of the concept of modules?
- Are the module team entities also modules?
- Are the subteam entities also modules?

The interviews with Stake and Blackenfelt gave rise to further questions that I explored in a further 5 interviews with people working with manufacturing strategies. These interviews lasted between 1 and 2 hours each and focused on the following questions:

- Can a car be modularised completely as initially envisaged with corresponding modules in product development and manufacturing?
- What is being done from the manufacturing side of the company to realise the initial idea?

6.2 Results

In this section the findings of the study are presented in five subsections. The first gives a short description of the background to the introduction of the platform concept. The second outlines the basic thinking regarding modularisation of a car. Subsection three provides further details about the process of modularisation, and the results of this work are then presented in
subsection four. Subsection five describes an interesting project focusing on what modularisation might look in the future.

6.2.1 The platform concept

At the end of 1993, a dramatic split from a partnership with Renault meant that Volvo Car Corporation had to develop its own programme for development of new models. During 1994 a new strategy was formulated, involving the development of a number of different car models on a common platform. The aim was to broaden the product portfolio beyond traditional family cars to include the pre-family and post-family customer segments. The management also wanted to increase the rate of new model introductions.

To be able to afford these changes, it would be necessary to have a high degree of system and component commonality between different models. It was also considered important that all the cars on the platform should be able to be manufactured in the same manufacturing flow. Accordingly a strategy of modularising the car was adopted.

6.2.2 The modules

The theoretical model of modularisation adopted at Volvo Car Corporation has three levels. First, the car is divided into a number of large modules, level 1 modules. These large modules correspond to the work areas of the module teams. The level 1 modules consist of a number of smaller modules, level 2 modules, which correspond to the work areas of subteams within the module teams. The level 2 modules in turn consist of level 3 modules. Product variety is achieved by changes or variations in the level 3 modules.

The product platform defines what is common to the different products on the platform. It includes such things as definitions of geometric module interfaces and technical principle in the design of the modules.

6.2.3 The process of modularisation

The first step in identifying modules was a rough geometric division of the car. The principle was that it should be possible to change the length of the car by increasing the length in the middle of the car, thereby avoiding changes in the design-intensive parts such as the engine compartment and behind the back
seat. The width of the car could also easily be adjusted to fit different engines (the engine is placed across the car in the cars on this platform).

Relation diagrams were used to position the different cars on the platform in relation to the market. These diagrams showed the relation between price and car length, price and cylinder volume, and price and engine.

MFD (Erixon, 1998) is one method that was used to identify modules. Much effort was put into decisions concerning the balance of uniqueness and commonality. It was important to locate uniqueness in the modules that needed to be unique to differentiate the products in the eyes of the customer and to have commonality in the modules that were not visible to the customer.

Fairly early in the platform planning work, strategic manufacturing issues came into focus. The management of the final assembly shop at Torslanda had a vision for the future assembly process. Their basic idea was that a car should consist of a number of large modules, which would be assembled in parallel flows to the main assembly line. Robots would then attach the finished modules to the car body in the main flow. Basic to this concept was the idea that suppliers could have both development and manufacturing responsibility for complete modules.

These ideas were very influential in the modularisation process. In the end, the modules that were identified represented a compromise between the ideas from manufacturing and those that were product-design oriented. An issue of decisive importance from the product-design view was the relation with suppliers. It was considered desirable that the supplier of a unit should have only one partner, one development team, to work with.

6.2.4 Results of modularisation

The platform planning and modularisation work has produced results in at least three areas: the product platform, module team organisation, and pre-assembly modules.

In only a few cases does the area for which a module team is responsible correspond to a module, as modules are understood in this thesis (that is, as a pre-assembled component). More often, a module team is merely assigned a clearly defined geometric section of the car, such as the exterior or the interior.
The correspondence between the module teams and assembly flow is further investigated in chapter 7.

As far as pre-assembly modules are concerned, there are some modules that have basically always been modules. Examples of these are the seats, the doors, the rear axle and the engine. In the development of the large platform some completely new modules were developed (new for Volvo Car Corporation, at least). These modules are the inner roof, cockpit, parcel shelf and front inner.

The inner roof is a pre-assembly that consists of the ceiling, insulation, lamps, courtesy handles and sun visors. The pre-assembled unit is lifted into the car with a lifting device and screws are automatically tightened. Only a few screws need to be fastened manually.

The cockpit is a pre-assembly of which the main components are the dashboard (with glove compartment and tunnel bracket), heater, steering column, cable harness, passenger airbag and various panels. The cockpit unit is assembled by a robot, which then lifts the module into the car and fastens it to the car body.

The parcel shelf is a pre-assembly of which the main components are the shelf with textile carpeting, speaker grills and a sun curtain. The parcel shelf is lifted into the car body by two assemblers working together and fastened with just a few manual operations.

The front inner is a pre-assembly of which the main components are a steel cross member, headlights with wipers, a signal horn and a hood lock. The front inner is lifted onto the car body with a lifting device and then manually fastened to the car body.

6.2.5 The Beyond Project

The Beyond Project focused on the future manufacturing of cars. The goal was to anticipate the demands customers would make in the future and to recognise what these demands would require of the manufacturing system at Volvo Car Corporation.

An anticipated scenario for customers’ expectations was outlined. The scenario showed that the number of car models would have to increase from
the existing six (at the time of the study) to about fifty models available simultaneously. The lead time for development of a new product would need to be reduced to 12 months. The expected life cycle of a product was estimated to be 2 years. It should be possible to produce a product in volumes ranging from a series of 100 cars to 50,000 cars.

This scenario gave rise to ideas involving a total transformation of how a car is built, the key concept in which was having a ‘low entry ticket’, meaning that a new product must be developed and produced as cheaply and as fast as possible.

As thinking about how to realise these ideas evolved, the ‘Beyond Concept’ was born. In this concept a car is built on a frame of extruded aluminium profiles, with the car body made of a coloured composite material. Such a design could be produced using a completely different production system from the one currently in use.

The interviewees believed that the existing way of building a car imposes constraints that make it impossible to achieve the desired flexibility. The biggest problem is the steel car body. The process of pressing the steel sheets is complex and any change to an existing design is time-consuming. If the frame were made of extruded aluminium, the design of a product could be changed far more freely. Furthermore, the aluminium frame would allow much greater modularisation of the car than the existing steel car body.

In the Beyond Concept, modules could be completed with interior and exterior details before being fastened to the aluminium frame. This would result in a radical reduction of the lead time in assembly and in the manufacturing process as a whole. It would also make it possible for a customer to exchange (upgrade) single modules in the car.

6.3 Analysis

It is clear that there was a desire to create modules in line with the concept of factories within a factory. In this vision, each module in the assembly system should correspond to a design team in the product development organisation. However, this vision was not realised. Compromises were made. The actual structure of the communication interface between the assembly flow and the product development organisation is further investigated in chapter 7.
Modules are discussed in somewhat different ways in the final assembly shop and in the product development organisation. From an assembly point of view, modules are product entities that can be pre-assembled before being attached to the car body in the main assembly flow. In the product development organisation, the module interface and the degree of commonality are considered the most important feature of modules.

The Beyond Concept is interesting as an idea of how to realise the vision of factories within a factory. Mufatto (1999) has described the difficulties of modularisation given the existing car concept, based on a pressed steel car body. He also believes that a radical change in the car concept is a prerequisite for more complete modularisation.
7. COMMUNICATION INTERFACE
- FINAL ASSEMBLY AND
PRODUCT DEVELOPMENT

The results in this chapter are based on two different work efforts. The first part of the material stems from my operational work of creating ‘production teams’ during 1998. The second part of the material consists of a master thesis work performed by 2 master students during 2001 (Backhans and Larneby, 2001). My role in that master thesis work was that I initiated the study and was supervising the work. In this chapter the results from the work with the production teams are presented as the background for the master thesis work.

7.1 Introduction

This section start with a background description of the production teams and what results interesting for further study that work gave. Then follows a description of the research purpose of the master thesis work and methods used.

7.1.1 Background – the production teams

In the winter 1997/1998 Volvo Car Corporation Torslanda were closing up to manufacturing start of the Volvo S80, the first car on the new platform. This was seen as a huge challenge to the organisation in the final assembly shop and the management realised a need to start some form of ‘module teams’ in the final assembly shop, correlating to the module teams in product development, to cope with introduction of the S80.

Production (including product development) of the S80 has within Volvo Car Corporation been described as a revolution in the industrial system. The development of the car had been performed in a new product development organisation, the module-team organisation. Suppliers had been involved in the development work to an extent that not had been practised before.

For the final assembly shop the manufacturing start of the S80 meant quite considerable changes. The assembly system was reorganised and rebuilt. From an assembly system consisting of two parallel assembly lines, one producing the old Volvo S70 and V70, and the other producing the Volvo 940 and Volvo
960, two one single assembly line that would produce the S80 and later on also the other products on the platform.

The technical solutions in the design of the S80 were a large step of change from previous models. In the assembly shop this meant that almost all assembly operations were altered. Moreover, suppliers had taken over some assembly work with the result that large subassemblies were delivered to the assembly shop to an extent that was a large change compared to previous concepts.

The initial idea of module teams in the final assembly shop came from the vision of modules that were work entities in product development work as well as in the assembly organisation (see section 4.4 and 6.2.3). That is, the idea that one module was assembled by a work-team in the assembly shop. One module team in assembly would then be a cross-functional team representing all types of competencies needed for assembly of the car. The cooperation with product development would be improved by having this clear interface between one module team in assembly and one module team in product development.

In the work of forming the module teams in the final assembly shop it soon became clear that it was not possible to have teams based on modules in the assembly shop in general. Rather, there were some modules that could be suitable work entities for a team, but the larger parts of the car were not modularised. A majority of the assembly flow had connections to several of the module teams in the product development organisation.

Due to the problem of finding suitable modules in the assembly flow the teams were instead formed around each assembly department. These teams got the name ‘production teams’.

In the work with the production teams an investigation was made of the interface between organisation of the assembly work in the final assembly shop and the module teams. This examination clearly revealed the fact the vision of ‘production modules’ had not been fully realised. Instead the picture (see figure 7.1) showed quite a complicated structure of product related couplings between the module team organisation and the assembly flow (and organisation).
In the upper part of the picture the module-teams are found. In the lower part of the picture is the assembly flow. Each circle in the lower part of the picture is a department in the assembly organisation. The lines between the module teams and the assembly departments show the product-related couplings.

**Figure 7.1** Product related couplings between the module teams and the final assembly organisation.

Another interesting issue from the work with the production teams was a general pattern of where in the assembly plant the implementation of production teams worked well and where there were difficulties. It showed out that it was easier both to form the teams and get them going in the part of assembly that had relatively simple product related coupling with the module teams compared to the parts of assembly that had complex connections with many module teams involved.

The results from work with the production-teams led to a need of further investigation. A question that did arise was how the picture 7.1 was looking on sub-team level in the module-team organisation. This question was important as it is on the sub team level the product development working teams really exist. The module teams are organisational units with a cluster of sub teams and the sub teams are the teams that have a tight cooperation on a daily basis.
As described in section 6.2.2 the general idea is that the sub-teams should correspond to level-2 modules.

7.1.2 Purpose

The research purpose of the master thesis work was to make an investigation of the product related couplings between the assembly flow and the product development organisation on sub-team level.

The second research purpose was to investigate how the communication between final assembly and product development was affected by complexity versus simplicity in the interface between the assembly flow and the sub-teams in the module teams.

7.1.3 Method

The first task was to find the sub-teams. This also meant an updating of the picture of the module-team organisation and also of the organisation of the assembly. When this master thesis work was performed some organisational changes had been made that meant some changes of the picture in figure 7.1.

The second task was to find the communication effects of complex versus simple interface between assembly and product development. This analysis was made by comparison between one area in the assembly organisation with a fairly simple interface, to product development, and one area with a complex interface.

Totally 108 interviews were made. For the first task the interviews were rather short and some of them were made by phone. For the second task the interviews were longer and questionnaires were used in the interviews.

7.2 Organisational Descriptions

This section starts with a description of the organisation in the final assembly shop. Then follows a description of the organisation at product development. Last in the section is a description of some important work roles of relevance for this study.
7.2.1 Organisation final assembly shop

The organisation in the final assembly shop at Volvo Car Corporation is divided into six workshops (see figure 7.2). Every workshop is divided into 4-6 assembly departments, which consist of 1-3 KLE-teams. Each KLE-team consists of about 20 assemblers.

![Diagram of six workshops in the final assembly shop](image)

*Figure 7.2 The six workshops in the final assembly shop*

The assembly departments and the assembly flow is viewed in figure 7.3. The main flow is the straight line from department 1:00 to ML. The departments DU, Front Inner, Loop A, Loop B, Pallet Line, PUR Pre-assembly, Door Right and Door Left make pre-assemblies in flows parallel to the main assembly line.

![Diagram of the assembly flow](image)

*Figure 7.3 The departments in the assembly flow*

7.2.2 Organisation Product Development

The organisation of product development is shown in figure 7.4.
The employees in each platform are organised in module teams. The module teams are unique for each platform and for the large platform, focused in this thesis, there are nine of them. They are Electronics, Cockpit, Transmission, Engine, MP, New Interior, Exterior C, Door and Painted Body and the size of them is about 50-150 people.

7.2.3 Important engineering work roles

At Volvo Car Corporation there are some engineering roles that can be seen as a links between product development and the assembly flow. It is here relevant to speak of four engineering roles that all can bee described as types manufacturing engineering. To be able to separate them the nomenclature used at Volvo Car Corporation is here chosen to describe them. These engineers are ‘pre production engineers’, ‘quality drivers’, ‘industrialisation engineers’ (beredare, in Swedish) and ‘assembly process engineers’. The industrialisation engineer belongs to the product development organisation while the other
three are organised at the department of Manufacturing Engineering in the final assembly shop.

The quality drivers are working with problems appearing in the assembly process. They make the first analysis of the problem and then contact the people it may concern.

Main task for the pre production engineers is to guarantee high quality when introducing changes of the product or the process at the assembly line, both for running updates and new product projects. The work tasks of the pre production engineers include for example, serial building & test assemblies, support of the KLE teams, analyses of quality problems and acting as representatives for the final assembly in meetings in the module teams (and in the sub teams).

The pre production engineer and quality drivers are organised in four different groups to be able to solve the problems at the line and guarantee high quality at introductions as good as possible. These four groups are, MP/Chassis, Electronics, Interior and Exterior and belong to the department Manufacturing Engineering, which is located close to the assembly line and whose assignments is to support the assemblers at the assembly line. In each of these four groups there are 4-6 pre production engineers and 2 quality drivers, who are physically located together, to facilitate cooperation. The joint work distribution is different between these four groups, for example in MP/Chassis and Electronics some pre production engineers only work with projects and some only with the running production. In Exterior and Interior every pre production engineer work with both running production and projects. There is also some variation in how the quality drivers work in each group.

The industrialisation engineers can be described as the manufacturing engineers in the product development organisation. They work in the module teams and are there the specialists on the manufacturing (including assembly) process. One important work task of the industrialisation engineer is to govern that the product can be manufactured efficiently. This work includes making work descriptions and calculations of assembly time and cost.

The main task of the assembly process engineers is to control the quality of the assembly process and to increase productivity in cooperation with the KLE-teams.
7.3 Results

This section brings results of the study, i.e. the connections between the module teams (and their sub teams) in the product development organisation and the departments in the final assembly shop. It also includes a comparison between two extremities, regarding the amount of connections to product development, in the final assembly.

7.3.1 The module teams

Figure 7.5 shows the connections from each module team to the departments in the assembly flow. At the top of the figure the module teams are illustrated. At the bottom of the figure the assembly flow in the final assembly shop are illustrated. The boxes at the bottom represent the departments in the final assembly shop and the unfilled boxes mark the pre-assembly departments. Finally the lines between the module teams and the final assembly shop illustrate the product-related connections.

Figure 7.5 The connections between the module teams and the final assembly shop.
7.3.2 Connections at the sub team level

The results of the investigation at the sub team level shows that the pattern of connections between the module teams and the assembly departments is complicated also at the sub team level. The results from two module teams are displayed in the following description. The results for the other 7 module teams are found in appendix F.

Figure 7.6 shows the results for module team MP (Marriage Point is the part of the assembly process where the chassis and the car body are joined, ‘married’). As shown in the figure most of the connections with the final assembly shop are made at the departments Loop A, Loop B and Pallet Line. This is where the chassis of the car is built, which can explain the amount of connections.

In module team MP there are about 130 people and they are organised in eight different sub teams. For each of these sub-teams there is one industrialisation engineer who is responsible for the necessary contacts with the final assembly shop. An exception is the sub-team Wheel Suspension, where there are two
industrialisation engineers, one responsible for front wheel suspension and the other one for rear wheel suspension.

Figure 7.7 shows the results of the investigation concerning the module team New Interior. New Interior has connections to several departments in the final assembly shop. This large amount of connections are due to the fact that New Interior manage several and small components.

In this module team about 70 people are working and they are organised in four different sub-teams which are Headlining & Panel & IC, Luggage & Carpets, Seats and finally Surface Materials. There are two industrialisation engineers working in the module team and they work with two sub-teams each.

**7.3.3 Comparison between two extremities**

Two departments have been chosen for further examination. These departments are Front Inner and 1:02. Front Inner represents a department with few connections to the product development and department 1:02 represent a department with a large number of connections. Interviews,
consisting of a questionnaire and a more subjective part, with relevant professions as industrialisation engineers, design engineers, pre production engineers, quality drivers, production leaders and assemblers, were made.

Communication pattern

Figure 7.8 shows the results concerning Front Inner in the form of a communication pattern.

There are three professions dominating the connection between product development and Front Inner. These are the industrialisation engineer, the pre production engineer and the production leader. In the final assembly shop the assemblers communicates with their production leader. The production leader gets overall quality impressions from the quality specialist in the KLE-team and she also gets daily information from the workshop manager who is responsible for all departments belonging to the workshop MP Area. For issues concerning product development the production leader mostly contacts the pre production engineer and sometimes also the quality driver. They bring
the information to the industrialisation engineer and analyse it together with him. In the same way the industrialisation engineer, for issues concerning the final assembly shop, contacts the pre production engineer and they together contact the production leader and the assemblers. Sometimes the production leader and the industrialisation engineer contact each other directly.

For Front Inner the production leader only has one contact person among the pre production engineers. This engineer works with products concerning three different departments in the final assembly shop which means he needs to communicate with a couple of production leaders but also with a couple of industrialisation engineers. The work concerning Front Inner however means contact with only one production leader and only one industrialisation engineer. This industrialisation engineer in its turn totally has contact with two different pre production engineers but for Front Inner only one. As the products concerning Front Inner foremost are bought from suppliers the design engineer (from Volvo Car Corporation) has not been present very often at meetings in the final assembly shop.

The communicative situation for department 1:02 is illustrated in figure 7.9. For department 1:02 the same professions are involved in the communication as for Front Inner. There is one production leader and one quality specialist from the KLE-team and a large number of assemblers. There are also pre production engineers and quality drivers and industrialisation engineers at product development.
The production leader in this department, in the same way as for Front Inner, has contact with a quality specialist (from the KLE-team) and a workshop manager and, for issues concerning product development, he communicates foremost with three pre production engineers. Another profession in the communication is the quality driver and especially the quality specialist in the KLE-team often uses this contact. As a matter of fact the quality specialist only has one contact to the Manufacturing Engineering department and it is the quality driver.

The pre production engineer concerned has connections to several departments in the final assembly shop and also to several module teams at product development. This means their work in the 1:02 is only a small amount of their total workload. For 1:02 there are three different pre production engineers to communicate with and two different industrialisation engineers or design engineers each, some of them representing different module teams. The quality driver has contact with an industrialisation engineer representing even one more module team.
Furthermore, the industrialisation engineers at product development have an extensive communication network and it is not unusual they have connections to three or four pre production engineers. But for the work concerning 1:02 they often communicate with one pre production engineer each.

A comparison between Front Inner and 1:02 reveals considerable difference in the communicative situations for the two. The most obvious difference is the amount of persons involved in the communication network. For Front Inner there are about five persons involved, while there are about 15 persons involved in communication concerning 1:02.

*Quality of communication*

Considering Front Inner the people involved generally think that the communication situation is easy and good working. Considering 1:02 the opinions goes apart. Some think the communication works well while others think the communication is insufficient.

At Front Inner a sub-module is pre-assembled which, when ready, is sent to the assembly flow, while at 1:02 is a department at the moving assembly line. There are about 30 assemblers at Front Inner divided into two shifts. At 1:02 there are about 110 assemblers, also them divided into two shifts. These differences may affect the communication situation, which are interesting keeping in mind when reading the following description which focus on what the employees think of the communication between the final assembly shop and the product development organisation.

Below answers from some interesting questions from the subjective part of the interviews are presented in two tables (see tables 7.1 and 7.2). These tables shows some answers from the production leader and pre production engineers. The questions these tables refers to are:

1. Are you updated with desirable information or do you have to search for this information?
2. Do you know the professions of your contact persons or do you just know their name?
3. How often are the industrialisation engineers represented at the production team-meetings?
4. Is the information topical?
5. Is the information available?
6. Is the information consistent?
7. Do you want to change anything, considering the communication situation?

<table>
<thead>
<tr>
<th>Front Inner</th>
<th>1:02</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. She is updated</td>
<td>He has to search</td>
</tr>
<tr>
<td>2. She knows the professions</td>
<td>He just knows the name</td>
</tr>
<tr>
<td>3. Not so often</td>
<td>Almost never</td>
</tr>
<tr>
<td>4. Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>5. Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>6. Yes</td>
<td>No</td>
</tr>
<tr>
<td>7. No, it works well</td>
<td>Yes, industrialisation engineers should be present at meetings concerning the final assembly shop</td>
</tr>
</tbody>
</table>

Table 7.1 The answers from the production leaders

As mentioned before there are three pre production engineers involved in the communication concerning the department 1:02. They answered relatively likewise and the answers are listed below.

<table>
<thead>
<tr>
<th>Front Inner</th>
<th>1:02</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. He is updated</td>
<td>They are updated, even with too much information</td>
</tr>
<tr>
<td>2. He knows the professions</td>
<td>They know the professions</td>
</tr>
<tr>
<td>3. Often enough</td>
<td>Vary</td>
</tr>
<tr>
<td>4. Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>5. Yes</td>
<td>Yes, but have to search</td>
</tr>
<tr>
<td>6. Vary</td>
<td>Vary</td>
</tr>
<tr>
<td>7. Yes, more presence from the industrialisation engineer at the production team meetings is desirable</td>
<td>No, it works well</td>
</tr>
</tbody>
</table>

Table 7.2 The answers from the pre production engineers

There are some obvious similarities and differences easy to observe by studying these answers from the interviews. The production leaders at Front Inner does not feel she has to search for the needed information, while the production leader at 1:02 think he has to. An explanation is that the production leader at 1:02 communicates with three pre production engineers while the
production leader at Front Inner only work towards one. Furthermore the production leader at Front Inner only needs to contact one industrialisation engineer, while the production leaders at 1:02 needs to contact about six industrialisation engineers.

Production team meeting with the assemblers, pre production engineers, production leaders and industrialisation engineer is supposed to take place continually. In department 1:02 this meeting does not exist, which can explain the lack of information from the product development organisation that the production leader feel. At Front Inner this special meeting has been going on for a while, but the presence of industrialisation engineer has been inadequate. To counteract this trend the pre production engineer were appointed to be responsible for this meeting. The aim was to move the meeting mentally closer to the industrialisation engineer, so the industrialisation engineer would participate to a greater extent and both the pre production engineer and the production leader think that it nowadays work better.

The difference in the amount of people involved in the communication is also a conceivable explanation to the different answers to question two. The production leader at Front Inner are aware of the professions of her contacts persons, while the production leader at 1:02, who needs to contact much more persons, often does not know the professions of his contact persons. Another issue that illuminates the differences between the two selected departments is the answers to the following question:

How difficult is it to get in touch with the right persons?

The production leader at Front Inner answered she often gets in touch with the right person without searching too much, while the production leader at 1:02 means that he never or rarely gets in touch with the desired person at the first call. He is often directed to another person several times before he gets the information desired.

One way to measure the quality of the communication is to study the topicality, the availability and the consistency (Larsson, 2001). Irrespective of profession almost every interviewee thinks the internal communication is topical and available but the answers goes apart concerning the consistency of information. The production leader at Front Inner thinks the information is consistent, while the production leader at 1:02 does not agree. Probably the amount of people involved is the explanation also to this difference.
Meetings represent a big part of the communication between different professions. The general result of the questions from the interviews concerning meetings is that meeting is a good medium to exchange useful information. As for an example almost every interviewee answered they prefer personal contact when exchanging information.

According to Larsson (2001) internal meetings can be divided into formal and informal meetings. Formal meetings are for example meetings that feature regular in the weekly activities, while informal meetings are for example spontaneous group meetings. Studying the thoughts from the questionnaires about this kind of meetings, an obvious difference between the two departments, Front Inner and 1:02, can be discern. The production leader, quality specialist (from the KLE-team), pre production engineer and quality driver participate at more formal meeting at Front Inner than at 1:02. Still the amount of the informal meetings is about the same. The result from the subjective part of the interviews shows that the pre production engineer and quality driver working with components concerning 1:02, totally in their work have more meetings than the pre production engineer and quality driver at Front Inner, since they have connections to several departments in the assembly flow. Therefore a certain priority when selecting interesting meetings to participate in is made. This is one of the explanations why they participate in less formal meetings at 1:02 than at Front Inner.

7.4 Analysis

The communication between the product development organisation and the final assembly shop is very important for the organisation’s results, and as shown there are many connections between most of the module teams and the final assembly departments. The communication network is for the major part rather complex. Some areas with few connections are discovered, but they are rare.

The communication is affected by a couple of factors, as for example social and technical factors (Larsson, 2001). It also emphasises the importance of using a common language. It is obvious, according to the answers of the interviews, there is a difference in the language between the final assembly organisation and the product development organisation. Especially the pre production engineers experience this difference since they have much contact
with the industrialisation engineers as well as the production leader and the assemblers. One of the pre production engineers interviewed says an industrialisation engineer and an assembler sometimes have different terms for the same product or process. This is of course less successful considered the importance of the communication between the product development organisation and the final assembly shop.

One of the questions asked to the interviewees discussed which communication channel they preferred and which one they foremost used. It was also asked if any of the communication channels had increased/decreased during their time at Volvo Car Corporation. The answers to these questions did not show any difference neither in a comparison between Front Inner and 1:02 nor in a comparison between different professions. Almost everyone answered that personal contact is preferable to phone and e-mail, but often there is not enough time to use this, why using phone still is most common.

Smith and Reinertsen (1998) claim that the probability of two persons communicating increases with the nearness. This is confirmed by the interviews as the employees located together say they have good relations. As for example the industrialisation engineer and the design engineers for Front Inner are located close to each other and they have daily contact. This behavior is the same for the pre production engineers and the quality drivers at Manufacturing Engineering as well as for the production leaders and the quality specialists (from the KLE-teams) in the final assembly shop. It is of course desirable to achieve nearness among all the employees, irrespective of profession, but the size of the company and the amount of employees complicates the situation.

An obvious result of this study is that the less amount of connections at Front Inner makes the communication easier there than at 1:02. This is supported by both the objective and the subjective part of the interviews. The probably reason to this is that there are less persons involved in the communication at Front Inner. Larsson (2001) states that fewer people facilitate communication and that the quality of communication decreases with the number of involved persons. This means the departments in the assembly flow, which have few connections, and therefore probably even few persons involved most likely have an easier communication situation in general than departments with several connections.
8. ASSEMBLY-RELATED CONSEQUENCES OF A MODULE SPLIT

This chapter contains a description of a case study. This study was made together with PhD-student Magnus Persson at Chalmers University of Technology. The data from this study could not be explicitly shown in this thesis due to confidential matters.

8.1 Introduction

The object of this study is a change of a part of a car that formerly was a complete module. This module was formerly assembled as a complete module at a pre-assembly station before it was assembled to the car body. For cost saving reasons some components were separated from the main module. The separated components were instead assembled into the car body after the main module had been attached to the car body.

8.1.1 Purpose

The purpose of this study was to study the assembly related effects of the split of the module, described above.

8.1.2 Choice of case

This case meant a chance to study the differences between the pre-assembly of a ‘complete’ module and assembly of the same parts (almost) when the module was split and assembled directly into the car body in the main assembly flow.

8.1.3 Method

Data for this study has been collected by the use of interviews and examination of internal written documentation. Interviews have been made with people involved in, or effected by, the change. The interviewees represent the professions design engineer, industrialisation engineer, pre production engineer, production leader and ergonomist (further educated physiotherapist).
The guiding questions during the interviews have been:

- What did the change consist of?
- What were the reasons to make the change?
- What information was input in the decision process?
- How did the product change effect the assembly work?
- What quality problems were there before the change?
- What other problems were there before the change?
- What quality problems have been observed after the change?
- What other problems have been observed after the change?
- What might be the causes of the increase of quality problems?
- How does the estimated effect of the change relate to the actual result?

Documentation that has been used in this study includes data from the internal system for registration of quality deviations, investigation report of change suggestion, assembly instructions, and data from the reports that continuously are being made by the ergonomists in the plant.

The studies for this case description can basically be divided into two phases. The first part of the work was made by Magnus Persson. This first part of the study resulted in an internal (Volvo Car Corporation) presentation. Included in this presentation were the result on quality and ergonomics at the time being. In this first phase of the study 6 persons were interviewed.

In the summer 2001 Magnus Persson and I realised that we both could have great use of a deeper investigation and analysis of this case. This led to a decision to make a co-operative work effort with more interviews and further examination of existing documents. This work was performed during the summer and autumn 2001. A collection of up-dated information from the quality system was made and the assembly-related consequences were further explored. There were 10 persons interviewed in this second phase, two of those were also interviewed in the first phase of the study. The result was reported in an internal report (confidential Volvo Car Corporation report Moestam Ahlström & Persson, 2002) and has been presented at four occasions at Volvo Car Corporation.
8.2 Results

This section presents the results of the study in eight subsections. First the object of the study is described, followed by a description of the assembly work before and after the change. Section three contains a brief description of the work process that led to the decision to execute the change of this product. The following five subsections contains data comparing the situation before and after the change considering quality, assembly time and lead-time, fragmentation of work content, physical work strain and cost.

8.2.1 The object of study

The object for this study is a module that here will be called module A. This module consists of a main part and a number of components that are assembled to this. These assemblies were before made at a pre-assembly station next to the line. After the module was completed the functionality was tested. Then the module was assembled to the car body at the moving assembly line.

Due to a rationalisation project the design of module A was changed. The change of the module meant that some components were separated from the main module in such a way that these components no more could be assembled at the pre-assembly station. Instead, these components had to be assembled after module A was attached to the car body. Consequently these components had to be assembled on the moving assembly line.

The design change also meant that the possibility to test the functionality of module A at the pre-assembly station was eliminated. Instead, the functionality was tested at the end of the line when the car was finished.

8.2.2 The assembly work

Before the design change the assemblies at the pre-assembly station were arranged so that the assemblers had good accessibility and visibility to perform these work tasks. After the change the assembly work have become problematic. It has shown to be difficult to perform these work tasks at the moving assembly line since the car body puts constraints regarding the possibility to arrange the work in a manner that allows a good working position. The result has become that the assembler has an uncomfortable
working position were it is difficult to reach and to see when performing these assemblies.

8.2.3 The change process

During a period there were a number of rationalisation projects going on at Volvo Car Corporation. They mainly aimed at decreasing the purchasing and assembly cost. One of these rationalisations was about decreasing the purchasing cost for the some components belonging to module A. By changing the design of these components there could be a large decrease of the purchasing cost. An investigation about this rationalisation was done. This investigation resulted in a report, here called the rationalisation-report. In this report it was said that this change should result in a considerable cost saving.

This cost saving was for a design change that affected two modules, here called module A and module B. Most of the possible cost saving are related to the changes of module B. Information about that was available from the rationalisation-report. According to results from the interviews made in this case study it would have been possible to change module B without changing module A. However, that option was not considered in the rationalisation-report.

A cross-functional development team (a subteam), made the original design of module A. The purpose with the cross-functional development was to have a module that was based on requirements from all the company’s main functions (design, manufacturing, purchasing and service) not only on design requirements. The investigation that resulted in the design was though not made by a cross-functional team. Instead, that investigation was initiated and performed by the design department.

One important fact to mention is that the test of module A’s functionality that was made earlier at the pre-assembly station was removed before the change. The reason for this was that there were almost no quality problems of module A. Therefore, a cost saving was made by taking away the functionality test at the pre-assembly station.

A decision to make the change was taken, and the change was implemented. In the following of this section the result of the change will be presented, according to quality, assembly time and lead-time, fragmentation, ergonomics, and cost respectively.
8.2.4 Quality

Before the change the quality of the module was very good, as can be seen in figure 8.1. After the change it is no longer that easy to detect quality problems before the module is assembled to the rest of the car. Five types of quality problems have been measured before and after the change. In figure 8.1 there are three stacks for each type of quality problems, the first one shows the number before the change, the second one the number right after the change (0-6 months) and the last one the number after a year (12 months-).

![Figure 8.1 Change of quality output due to the change](image)

8.2.5 Assembly time and lead-time

As described in section 8.2.2 the change has led to that considerable part of the assembly work related to module A had to be moved from the pre-assembly station to the main flow. Since pre-assembly means the same as parallel assembly flows the change means that the lead-time in the assembly process has increased.
The change has also resulted in some new work tasks that do not add value to the customer. These work tasks is due to unexpected quality problems. Extra work has been added to prevent these quality problems to occur. This extra work is made in the main assembly flow and consequently means an increase of the lead-time in the assembly flow.

According to calculations of assembly time the total assembly time have increased. Calculations of lead-time shows that the assembly time at the moving assembly line, in the main flow, has increased. This also means that the lead-time has increased.

8.2.6 Fragmentation of work content

Before the change, the assembly of module A was located to one workstation, the pre-assembly station. After the change, these assemblies have been split and are today made at different parts of the assembly line located in different parts of the plant.

In the old concept, before the change, the assemblers had a long work cycle in which they completed the whole module. Furthermore, the assembly of the module was concentrated to two closely located departments, the pre-assembly station and the department at the moving assembly line where the module was assembled to the car.

The change has resulted in a split of responsibility for the assembly of module A. It has also reduced the assemblers’ possibility to get a holistic understanding of the work tasks.

8.2.7 Physical work strain

According to interviews with production leaders and an ergonomist there were no problems with the assembly work of module A before the design change. Good visibility and accessibility made the work of these assemblies non-problematic. The assembly of the components that after the change is assembled at the moving assembly line were included in a long work sequence where one assembler made all the assemblies of the module at a work station next to the line. The assembly of the components that were affected by the change were only a minor part of the work in one work cycle. In the ergonomics report an evaluation of physical workload is made on the whole work cycle, that is, not for these components in specific.
In the ergonomics evaluation of the work cycle, including these components, is graded as work strain 2, according to the classification system used by the ergonomists in the assembly shop (on a scale ranging from 1 to 3). The most physically strained body parts are the shoulders.

The grade 2 in this system of classification means that the physical work strain is high to a degree that it is ‘probably not bad’. In the classification system it is stated that such work can be handled by ‘ordinary healthy men or women’ (without getting injuries – our comment). Further, it says that this level of work strain is a ‘realistic goal for car production’.

After the change the ergonomic situation became worse. In the ergonomics report for the actual assemblies at the moving assembly line it is stated that this assembly is very poor from an ergonomic point of view. The level of work strain is graded to 3. The most physically strained body parts are the back and the neck.

The grade 3 in this system means that the physical work strain is high to a degree that it is ‘bad, injurious’. Further it is stated in the classification system that such work can be handled: ‘probably by young men, short period of time’ (without getting injuries – our comment). The general statement of such work tasks is that they ‘have to be improved’.

8.2.8 Cost

In the confidential report the result of actual cost saving from the change is presented. The total cost consists of assembly, quality, purchasing and ergonomics cost. The results from those calculations show that the actual cost saving was not as large as expected.

8.3 Analysis

In this chapter the results of the study is analysed. First is an analysis of the change of the output quality. The second subsection is an analysis of the change in the work situation for the assemblers. Then follows an analysis of the change of cost.
8.3.1 Quality

The cost related to poor quality after the change is not big in relation to the savings of purchasing cost. In the report written before the change there was an estimate of possible quality problems that would be the consequence of the change. However, none of the five types of quality problems described in figure 8.1 were foreseen.

The people involved in the change were aware of the increased risk of more quality problems, but the decision to make the change was taken anyway. Their thought was that the quality of module A would be a little worse, but that it could be fixed already in the plant to a rather low cost.

Right after the change the number of quality problems increased quite considerable. But, after some months it decreased a little and than stabilised on a rather constant level. However, this level was higher then it was before the change. Quality problem type 5 did not exist before the change, but after the change there were a lot of cars with this defect. After the running-in period that quality problem is no longer existing, however the explanation to that is the extra work mentioned in section 8.2.5, meaning that the assembly cost has increased.

8.3.2 Work Situation

Irrespective of the cost for the quality problems, the increase of quality problems is striking. What might be the cause of this distinct deterioration? An examination of the results presented shows that the greater part of the quality problems are related to assembly of the components that have been separated from module A. The result from the interviews points at the change of assembly method to be the source of the problems. As described earlier the new assembly method means that the assemblers have to make the assemblies in an uncomfortable working position where it is hard to reach and to see to do the assemblies.

The main part of the quality problems of type 1 and 2 are, according to our findings, related to that these assemblies have not been made. The assemblers have forgotten to do them. These problems are probably due to the split of the assembly work in combination with the poor ergonomic situation. In the old concept the assemblers got a clear overview of all assemblies at module A.
This meant that there was almost no risk that some assembly would be missed or forgotten.

In the new concept the assemblers almost only have to rely on memorisation of the work. It is not possible to get an overview of the assemblies. In a repetitive assembly work with the short work cycles, as there are on the moving assembly line, it is a well known fact that the attention to the task do fail from time to time (see for example Moestam Ahlström, 1997). That is in the nature of the work. Therefore, it is most unfortunate when the assembly has to rely on memory solely.

Furthermore, the split of the assembly of module A between different departments means that these work tasks are fragmented. Fragmentation of work tasks is negative considering the assemblers’ possibility to understand the function of the parts that they assemble (Ellegård et al., 1992). This makes it even more difficult to remember to do all assemblies. Furthermore the split of responsibility is detrimental to the communication between product development departments and the shop floor departments (Backhans and Larneby, 2001).

8.3.3 Cost

The actual cost saving did not become as large as expected. The main explanation to this difference is that some costs have increased unexpectedly. There was a large saving in purchasing cost. However, the assembly cost increased, some assembly operations have been necessary to add. This was not foreseen before the change was made. The ergonomics cost has also increased, after the change it has become more difficult for the assemblers to make the assemblies than it was before. Hence, injuries and sick leaves have increased. Finally, the quality has become worse than it was before the change.

8.4 Conclusions

In the study of the change of module A both positive and negative effects have been identified and analysed. In this chapter the conclusions are presented according to the following six parameters, which have been found to be relevant to use to measure the effects of the change:
- Quality
- Cost
- Assembly time
- Lead-time
- Physical work strain
- Fragmentation of work tasks

Then follows a combination of the parameters. The chapter is ended with some general conclusions that have been possible to make from the study made.

The following figures illustrate the relations between the situation before the change, the estimated effects of the change and the actual result of the change. These figures do not show exact measures. Rather, the aim of the figures is to visualise and give a holistic view of the results from this study.

Figure 8.2 illustrates the general principle that is used in the following figures related to each parameter. The level of each parameter is expressed on a scale ranging from low to high. Low means that it is not considered being a problem. High means that it is, without doubt, a problem. The levels of the parameter are pointed out by dots before the change, the estimated level due to the change and the actual result after the change.

![Illustration of principle for the following figures](image)

The level of each parameter is relative and the aim is to show the degree of improvement or deterioration caused by the change. The judgements of the different parameters are also relative to each other considering seriousness of problem or importance of positive aspects. These judgements are based on the results from the interviews.
8.4.1 Quality

Figure 8.3 illustrates the level of quality problems before the change, the estimated effects of the change and the result of the change. Before the change the quality level regarding the module A were not considered to be a problem. The level of quality problems before the change can therefore be considered to have been low. In the estimations of the effects of the change the number of quality problems were not expected to increase. The actual quality result after the change is much poorer than what was expected in the rationalisation-report and is today definitely a problem.

![Level of quality problems](image)

*Figure 8.3 Change of quality problems*

8.4.2 Assembly time

Figure 8.4 illustrates the level of assembly time related to the assembly of the components of module A that were changed. The figure shows the assembly time before the change, the estimated effects of the change and the result of the change. The assembly time were not expected to change due to the change of the design. The actual result shows that the assembly time has increased mostly due to work tasks that have been added because of quality problems.

![Level of assembly time](image)

*Figure 8.4 Change of assembly time*

8.4.3 Lead-time

Figure 8.5 illustrates the level of lead-time related to the assembly of the components of module A that were changed. The figure shows the lead-time before the change, the estimated effects of the change and the result of the change. In the estimations before the change it was expected that the lead-time would increase due to the fact that work was shifted from a pre-assembly, a
parallel system to the main flow, to the main flow at the moving assembly line. This fact must have been known, even though it was not explicitly discussed in the rationalisation-report. The actual result was an even longer increase of lead-time due to the extra work mentioned above.

![Figure 8.5 Change of lead-time](image)

8.4.4 Fragmentation of work content

Figure 8.6 illustrates the level of fragmentation related to the assembly of the components of module A that were changed. The figure shows the fragmentation before the change, the estimated effects of the change and the result of the change. Before the change the assembly of these components was a part of the completion of a whole module. The work was not fragmented. In the rationalisation-report fragmentation of assembly work is not at all mentioned. That the change was going to mean fragmentation of work tasks must, nevertheless, have been known. In reality the fragmentation of work tasks became very pronounced because of the split of the assembly between different departments.

![Figure 8.6 Change of level of fragmentation](image)

8.4.5 Physical work strain

Figure 8.7 illustrates the level of physical work strain related to the assembly of the components of module A that were changed. The figure shows the physical work strain before the change, the estimated effects of the change and the result of the change. Before the change the assembly at the pre-assembly were considered to be non-problematic. It can therefore be considered to mean a rather low level of physical work strain. Results from the interviews show that it was known that the product change would mean a deterioration of
physical work strain. The results after the change show that the effect of the change became \textit{as bad as estimated}.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{physical_strain.png}
\caption{Change of physical work strain}
\end{figure}

\subsection*{8.4.6 Cost}

Figure 8.8 illustrates the level of total costs related to the assembly of the components of module A that were changed. The figure shows the cost before the change, the estimated effects of the change and the result of the change. Before the change the purchasing cost for these components can be considered to have been \textit{high}. The estimations in the rationalisation-report pointed at big a saving, meaning \textit{low} costs. The actual result is \textit{not as positive as expected}, due to unexpected costs for quality problems, ergonomic issues and increased assembly time.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{cost.png}
\caption{Change of cost}
\end{figure}

\subsection*{8.4.7 Combination of parameters}

In figure 8.9 the levels of each parameter are combined. The figure shows that before the change the only problem was the cost. The levels of the other parameters were quite reasonable.
Figure 8.9 Combination of the parameters

The estimates of the change showed a considerable potential of savings due to decrease of purchasing cost. The cost related to quality would increase somewhat, but not considerably in relation to the savings. The assembly time was not estimated to increase and the increase of lead-time was not considered to become a problem. The working situation in the assembly shop would become worse due to a higher level of physical strain and fragmentation of
work tasks. But, neither the physical work strain nor the fragmentation was regarded to be sources of more quality problems or increased costs.

The actual result of the change deviate from the estimations on most of the parameters. First of all, the quality problems have increased much over the expected level. The savings due to reduced purchasing prize have not resulted in the calculated total cost reduction. The assembly time has increased due to the extra work that has been added. The lead-time has increased somewhat more than expected. The deterioration of physical work strain and fragmentation of work tasks became almost as expected. However, the increase of quality problems due to the deterioration of physical work strain and increased fragmentation of work tasks became much worse than expected. In fact, in the rationalisation-report the risk of increased level of quality problems due to human factor related issues were not estimated to cause any new quality problems.

8.4.8 General conclusions

This study shows that poor ergonomic conditions means increased risks for quality problems. It also shows that fragmentation of work task, meaning split of responsibility and wholeness, risks causing quality problems.

Furthermore, we can learn about the effects of modularisation in the manufacturing system. Modularisation that leads to large entities, modules, that can be pre-assembled parallel to the main flow is positive in a number of aspects, such as:

- The lead-time in the assembly flow decreases due to the decrease of assemblies in the main assembly flow
- The possibility to arrange the assembly work in a way that lower the physical work strain, compared to assembly direct at the car body, increases
- The possibility for the assemblers to understand the functionality of the parts they assemble increases

8.5 Important comments on the case

This chapter have presented a case where a product change (split of a module) resulted in negative results on a number of parameters, including physical
work strain and fragmentation of work contents. In relation to this case it is however important to understand that the general development at Volvo Car Corporation is towards increased modularisation of the product, which means improved working conditions both regarding physical work strain and holistic work contents. This case is thus an exception from the general development.
9. DEVELOPMENT OF TWO ASSEMBLY EFFICIENT PRODUCTS

This chapter reports on two case studies. An introduction to both cases is followed by a description of each case, first the parcel shelf and then the cockpit module. The cases are then analysed.

9.1 Introduction

The Volvo S80 was the first model produced by Volvo Car Corporation after the module team concept had been introduced. There is widespread agreement within the organisation that this model represented a major step towards a more assembly efficient product. Consequently I decided to focus this case study on the development of the Volvo S80. As it is impossible to study the development of every detail of the car, it was decided to focus on specific parts. Following discussion with various people in the organisation and with the supervisors of this research project, the parcel shelf and the cockpit module were chosen for study.

In order to appreciate the progress towards assembly efficiency, the parcel shelf and cockpit module in the S80 were compared to the corresponding parts in the Volvo 940.

9.1.1 Purpose

Products where assembly efficiency has been achieved were studied in order to determine what led to these solutions.

9.1.2 Scope and delimitation

The main focus of this study was on the process whereby the parcel shelf and the cockpit module in the Volvo S80 were developed. The assembly efficiency of the products is roughly compared to that of corresponding parts in the Volvo 940. No attempt has been made to quantify all aspects of assembly efficiency. Rather, it has been assumed, based on the expert opinion of manufacturing and industrialisation engineers within Volvo Car Corporation, that the new parcel shelf and the cockpit module are more assembly efficient.
Practical considerations are the main reason for the absence of quantifiable comparisons. For example, while it would have been interesting to compare the assembly-related quality of the output of the Volvo 940 and the Volvo S80, any results would have been skewed by the fact that the quality requirements are generally higher for the Volvo S80. The S80 is a more exclusive car than the Volvo 940 ever was, and customer requirements for quality have increased considerably since the time when the Volvo 940 was produced.

Furthermore, the Volvo S80 has higher performance in general and incorporates more sophisticated technology, making it difficult to compare with the Volvo 940 as regards both the quality of output and the assembly time. It was therefore decided not to attempt a quantified comparison of the actual quality of output, assembly time or assembly cost of the products.

Differences in assembly methods are discussed, but the focus is on differences at the level of principle rather than on comparison of details.

9.1.3 Working method

The primary method of data collection was semi-structured interviews with the people involved in developing the parcel shelf and the cockpit. The assembly instructions for both the cockpit and the parcel shelf of the Volvo S80 and for the corresponding parts in the Volvo 940 were also studied.

Attempts were made to find documents that could support the data obtained from the interviews. However, it turned out that protocols and notes that could possibly have described the work process were no longer available. People had discarded these as they had moved on to new work tasks, considering that this type of documentation was no longer important.

I also attempted to examine computer-based models of the products at different stages in order to identify critical events in the development process. However, changes in the design proved difficult to trace because in both cases the ideas at the start of the development process were refined but never really altered. As the interviews proceeded, I realised that examining the models was a waste of time as it would not bring me closer to answering the key questions in this study.
These key questions were:
- Who or what was the driving force to develop an assembly efficient concept?
- How did the concept evolve?
- Were there any obstacles to the realisation of the concept, and if so how were these handled?
- Which people worked on the development team and what were their roles?
- How was cooperation within the team organised?
- Was there a systematic working procedure?
- Was a specific methodology used and, if so, to what extent?

The questions I asked in the interviews included:
- What was your task in the development project?
- During which period were you involved in the project?
- What is your professional background?
- Who else were involved in the project and what were their roles?
- How did you cooperate with the other team members?
- Were you in the same vicinity as the rest of the team or not?
- How frequent did you communicate with the other team members?
- Did you feel that the team shared a common view of their task?
- Were there any controversies in the team?
- Who or what was the driving force to develop an assembly efficient concept?
- In what way is the product assembly efficient?
- What methods and tools were used?
- Did you use DFA?
- How did the product concept evolve?
- Who participated in the pre-study?
- Were there any obstacles to the realisation of the initial concept?

The study of the development of the parcel shelf involved interviews with five persons for about 1 to 1½ hours each. Three of those interviewed were the core development team responsible for the development of the parcel shelf for the S80, consisting of one industrialisation engineer, one design engineer and one engineer representing the supplier. The other two interviewees were the industrialisation engineers responsible for the parcel shelf in the S80 at the time of the study and an industrialisation engineering manager whose responsibilities included the parcel shelf.
Four persons were interviewed about the development of the cockpit module. One of these was the industrialisation engineer responsible for the whole cockpit unit. That interview lasted for 2½ hours. The other three persons involved in developing the cockpit were interviewed for about 1 to 1½ hours each. These were the industrialisation engineer for the cross member and the dashboard, the design engineer for the dashboard and one manufacturing engineer from the assembly shop who was responsible for the transformation of the assembly system for the cockpit unit. I also participated in a work group on the transformation of the assembly process of the cockpit module for about six months in the autumn of 1997. This work group gave me extensive information about the cockpit unit and the related assembly process. Furthermore, I interviewed two manufacturing engineers about the assembly process of cockpit-related parts of the Volvo 940.

9.2 Case study: parcel shelf

The case study of the parcel shelf begins with a comparison of the parcel shelf of the Volvo S80 and that of the Volvo 940. The process by which the parcel shelf for the S80 was developed is then presented. Finally, I examine how assembly efficiency was achieved.

9.2.1 Comparison of parcel shelf designs

All interviewees considered the parcel shelf for the Volvo S80 to be better and more assembly efficient than the parcel shelf for the Volvo 940. The Volvo 940 shelf consisted of three main parts: the shelf, insulation and a cover strip. A number of screws and other fasteners were required to assemble these three parts to the car body. Most of the assembly operations had to be performed sitting inside the car body in uncomfortable working positions.

The parcel shelf of the S80 is a unit that requires only a few operations to attach to the car body. Screws and other time-consuming fasteners have been eliminated and assemblers only have to secure three clips. Two assemblers working in parallel, one on the right side of the car and one on the left, perform the assembly operation. Very few operations have to be carried out inside the car body, which makes the assembly of the parcel shelf for the S80 far easier for the assemblers.
As regards the quality of output, the interviewees considered that the parcel shelf of the S80 has the potential to give high quality output than the parcel shelf of the 940 because there were fewer loose details. However, it has not been possible to verify this belief (see explanation in section 9.1.3).

9.2.2 Development of parcel shelf for the Volvo S80

From the outset, the aim was to develop a new technical solution for the parcel shelf, not to refine an old one. The question that was put to the development team was ‘What would an ideal parcel shelf look like?’ rather than ‘What improvements can we make to the existing concept?’

The inputs to the design were as follows:
- a model from styling
- technical specifications on sound absorption
- properties related to customer demand regarding product function and aesthetics
- a requirement that the unit be as complete as possible before assembly into the car body (Volvo Car Corporation wanted this in order to maximise the outsourcing and the supplier was interested in maximising their assignment.)
- a requirement that the parcel shelf be manufactured by a supplier and delivered to the assembly line packaged in the same sequence as it was to be built on the final assembly line
- a requirement that the parcel shelf be assembled into the car body manually (that is, without any lifting device)

The development team consisted of a design engineer (D), a representative of the supplier (S) and an industrialisation engineer (I2). D and S were involved in the pre-study together with another industrialisation engineer (I1), who had a wider area of responsibility that included the parcel shelf. Engineer I1 was involved in the entire parcel shelf development project but was not a member of the core team.

In the pre-study, engineer I1 envisaged minimising assembly work inside the car body by making the parcel shelf a complete module that could be assembled into the car body with as little effort as possible. This idea was accepted by the other persons involved in the pre-study who then set to work to realise it.
During the project phase, the initial concept was refined. Even though some problems occurred, the concept was never threatened. Much effort was put into finding solutions that integrated as many details as possible, minimising the number of screws and clips.

The core development team worked closely together. They communicated with each other daily and also had frequent formal meetings. Besides the core team, other people were involved in parts of the realisation process. A design engineer from the main supplier organisation in Germany was at Volvo Car Corporation every second week. The supplier also hired consultants to work mainly on making drawings and models of the product. There were between two and four consultants, depending on the workload.

9.2.3 Assembly efficiency

All three industrialisation engineers interviewed said that there was an emphasis on products being adapted for assembly in the development of the S80. A reduction in the man-hours per car in the assembly process was an explicit target. The interviewees believed that this target spurred them on to ensure the assembly efficiency of the product.

Some general guidelines that the interviewees recall were the use of a module strategy (outsourcing and integration of details), the elimination of screws (too time-consuming), designs that incorporated guiding devices (to ensure correct assembly), and the use of a reference system for all parts (to secure product geometry in manufacturing).

Engineer I2 described the guidelines that he worked with as follows:
1. No screws should be used.
2. The reference system should be integrated in the parcel shelf design.
3. As much integration as possible, subject to the constraint that the parcel shelf would have to be installed through the back door and without the use of a lifting device.
4. Distinct fasteners with guiding devices should be used.

Engineer I2 believed that the key to the successful design of the parcel shelf was that engineer I1 had a very good initial idea of what the parcel shelf should ideally look like. A strength of this idea was that it was ‘realisable’ (capable of being realised within the framework of the project). Engineer I1 had worked as a manufacturing engineer in the final assembly shop with the
parcel shelf within his working area. He stated that ideas drawn from that time in the assembly shop in combination with DFA shaped his thoughts about the parcel shelf concept.

The parcel shelf design was subjected to DFA analysis, but none of the interviewees said that this resulted in any changes to the design. DFA analyses were, however, seen as valuable when used to analyse the parcel shelf design of some competitors. Some new approaches to details of the design emerged from these analyses.

Industrialisation engineer (I2) says that the module team concept was a strength in the realisation of the parcel shelf. He believed that all members of the team expressed their opinions, reached an agreement, and then worked strongly for the agreed solution.

Both I1 and I2 have a high regard for the design engineer, saying that he listened carefully to the opinions of the industrialisation engineers and was always very easy to work with. Engineer S says that the assembly efficiency of the product they developed was due to I2s skill as an industrialisation engineer.

Engineer I2 also had experience of working both as an assembler and as a manufacturing specialist in his KLE team. He regarded his background as a very important asset when it came to knowledge about how to achieve assembly efficiency in the development of the parcel shelf.

9.3 Case study: cockpit

The case study of the cockpit module begins with a comparison of the cockpit module for the Volvo S80 and the corresponding parts of the Volvo 940. The process by which the cockpit module for the S80 was developed is then presented. Finally, I examine how assembly efficiency was achieved.

9.3.1 Comparison of cockpit design concepts

The main parts in the cockpit module are the dashboard (with glove compartment and tunnel bracket), steel cross member, heater, steering column, cable harness, radio equipment, passenger airbag, and a number of different panels. In the Volvo S80 all these parts are assembled at a pre-assembly
station as a separate module. An adjustable carriage with a special fixture is used for the pre-assembly work. After completion of the module it is transported to the main assembly line and assembled into the car by a robot.

In the Volvo 940 there was no cockpit module. Some pre-assemblies were done on the dashboard, but most of the cockpit-related assemblies were performed in the main assembly flow. Consequently most of these tasks were performed inside the car body.

First the cable harness, then air pipes and then the heater were assembled into the car body. Before the dashboard was assembled, the steering column was also assembled into the car body. The passenger airbag, the glove compartment, the tunnel bracket and the different panels were assembled after the dashboard had been installed in the car body.

The manufacturing engineers interviewed stated that some of these assemblies had been very troublesome, especially the assembly of the heater and the cable harness. Uncomfortable working positions inside the car body and poor illumination in combination with tricky assembly operations had made the work difficult.

9.3.2 Development of the cockpit for the Volvo S80

The initial idea of a cockpit module sprang from the cooperation between Volvo Car Corporation and Renault during the early 1990s. The intention at that time was that Volvo Car Corporation and Renault should develop new cars with common concepts.

Renault did have a cockpit module, which was referred to in English as the ‘driving unit’ (mentioned here because the cockpit unit is frequently called the driving unit within Volvo Car Corporation, especially in the final assembly shop). As Renault had about thirty factories with identical manufacturing processes and Volvo Car Corporation at the time had four factories with differentiated manufacturing processes, the decision was to use Renault’s manufacturing process as a basis for developing new processes.

By the time cooperation with Renault was cancelled in 1993, the idea of having a cockpit module had taken root in the organisation at Volvo Car Corporation. The idea did, however, meet some opposition. To realise a cockpit module it was necessary to have a cross member on which the module
could be built. This cross member would give the module enough stability to allow it to be handled separately, outside the car body. The cross member can be seen as an unnecessary part since it has no other function than to support the cockpit module.

From a safety aspect, however, the cross member was considered to be of the utmost importance. The windshield on the Volvo S80 is much more domed than on older car models. Consequently the member below the windshield in the Volvo S80 has a more bent form than in older models, which reduces the protection it offers in the event of a side collision. The additional safety offered by the cross member was one factor in favour of a cockpit module concept. Another argument for choosing the module concept was the associated improvement in assembly ergonomics.

Realisation of the concept was difficult. One obstacle was the problem of finding a system solution that would solved all the interface-related problems, including the interface of the cockpit module to the car body, the interface of the cockpit module to the robot, the interface of the cockpit module to the assembly fixture, the interface of the cockpit module to the transportation fixture and the interface of the cockpit module to the fixture from which the robot lifts it. It took almost a year to find a solution, with the help of benchmarking with other car manufacturers and RobCAD simulations.

There were some conflicts with the styling department, which wanted to change the interface between the tunnel console (where the gearshift and the handbrake are placed) and the cockpit module. RobCAD simulations were used to investigate whether this styling change would be feasible within the module concept. The simulations showed that if the styling change were made, the cockpit module would be too large to fit through the door opening. The plans to change the styling concept were dismissed.

A team consisting mainly of design engineers and industrialisation engineers developed the cockpit module. The core development team consisted of six to ten people, changing over time. The team were located together in an open office area, where the desks of the design and industrialisation engineers were adjacent to each other. The development team worked as an integrated unit through the whole development project. The core team were supplemented with purchasing engineers and people with other specific competencies who were called in from time to time.
The team leader was an industrialisation engineer devoted to the idea of having a cockpit module. He had been involved in the development of the cockpit module from the time when Renault was involved. He had started his career as an assembler on the assembly line and had worked in the assembly shop for four years before he started working as an industrialisation engineer.

9.3.3 Assembly efficiency

The interviewees say that efficiency was the main focus in the process of developing the cockpit module assembly. The explicit target of man-hours per car was a driving force in the product development.

There were general guidelines concerning assembly efficiency in the Volvo S80 project that were followed in developing the cockpit module. The central concepts, as recalled by the team leader, were:

- standardisation of details such as fasteners
- guiding devices, to ensure that each detail was assembled correctly
- integration of details (related to DFA)
- reference system, to secure the product geometry in manufacturing

The interviewees stated that the module team concept focused on manufacturing issues and agreed that the teamwork was very good in the development work. There was a common conception of the task and everyone’s opinion carried equally weight. The industrialisation engineers stated that the design engineers were prepared to listen to their views about the assembly process.

The design engineer interviewed believed that the industrialisation engineer, the ‘frötallar’ and the process project person had a lot of ideas on how to design details so that the cockpit would be easy to assemble correctly. The design engineer also believed that the industrialisation engineer’s experience with final assembly was very valuable in the realisation of an assembly efficient concept.

9.4 Analysis

In both of the case studied, the interviews paint a picture of a development process characterised by teamwork. There was a spirit of cooperation and a
shared conception of the task and the goal of the development work. There were no real conflicts; rather, the work process was characterised by respect for the different competencies within the team. The industrialisation engineer’s experience in the assembly shop was valued as an important resource in the development processes.

The focus on reducing the man-hours per car in conjunction with the message about the importance of considering manufacturing aspects in the S80 development project gave official sanction to the striving for assembly efficiency. The general guidelines on how to achieve assembly efficiency strengthened this message and gave input on how to actually realise these goals.

In both cases the development teams were encouraged to think of a totally new design for the product, rather than using old product concepts as the starting point. It was thus possible for the development team to think about an optimal design instead of just refinements. This approach was a key factor in the large-scale improvement in assembly efficiency that was achieved in the design of the parcel shelf and the cockpit module in the Volvo S80.
This chapter starts with a summary of the empirical results, which is followed by an analysis of the results in relation to the frame of reference set out in chapter 2. The model that was produced as a result of this thesis is then presented.

10.1 Summary of empirical results

*From chapter 5: Licentiate thesis – About Assembly Work*

The organisation of assembly work should be based on the assembly of meaningful entities. In other words, the different operations involved in assembly should be connected to each other in a logical pattern, as opposed to fragmented work where the different work operations have no logical connection to each other. Assembly work based on a logical sequence reduces the risk of making mistakes as it facilitates memorisation of work. Assembly based on logical entities, such as modules, also facilitates understanding of the work context and thus makes it easier to identify possible improvements.

Assembly directly on the car body, especially inside the body, often calls for poor working positions that impose high physical work strain. It is far easier to achieve good working positions with lower work strain when working with pre-assembly units. Thus modularisation of a product also offers the benefit of reducing the physical strain of assembly work.

*From chapter 6: Modularisation*

In developing the large platform that includes the Volvo S80, there was a desire to have a design in which a substantial part of the car would consist of modules that could be pre-assembled before being finally assembled on the pressed car body. However the empirical investigation showed that despite efforts to achieve this the vision was not fully realised. It seems that it is not possible to fully modularise a car given the existing principles of car design. The Beyond Project identified new possibilities for automobile design. In principle, modularisation should be possible with a design using a frame
composed of extruded aluminium profiles to which modules that are complete in terms of both interior and exterior details could be attached.

*From chapter 7: Communication Interface – Final Assembly and Product Development*

The results of the study presented in chapter 7 show that the interface between the assembly flow and the product development organisation is in general rather complex, both at the module team level and at the level of subteams. The results also indicate that there is far better communication in those parts of the organisation where the interface between final assembly and product development is fairly simple.

*From chapter 8: Assembly-Related Consequences of a Module Split*

The results of the study presented in chapter 8 show that modularisation can lead to higher assembly efficiency. Splitting a module resulted in increased work strain and fragmentation of tasks. Consequently the quality of output decreased and thus the assembly time increased. The lead time, that is the assembly time in the main flow, also increased.

*From chapter 9: Development of Two Assembly Efficient Products*

Some common characteristics were found in the development of the two products studied. The development work was done by cross-functional teams with shared conceptions of the task and the goal. There was a focus on assembly efficiency within the organisation, emphasised by explicit guidelines on how to achieve a good design. These guidelines set out the general principles for assembly efficiency. The teams were encouraged to think of an optimal design rather than to refine old concepts. The contribution of assembly knowledge from people with experience of assembly work was found to be of decisive importance in realising assembly efficiency.

### 10.2 Analysis of empirical results

This analysis is divided into three subsections. Following a general analysis of the prerequisites for developing assembly efficient products, the results are analysed in terms of the two sets of research questions introduced in section 2.4.
10.2.1 Analysis of prerequisites

The empirical results yielded some technical principles that contributed to the assembly efficiency of the products. Generally speaking, the principles for assembly efficiency described by Magrab (see section 2.2.3) were borne out by the empirical results. Many of these principles were incorporated in the general guidelines governing the design of the Volvo S80.

The question then is what prerequisites contributed to the competence required to realise assembly efficient product design. The categorisation of prerequisites presented in chapter 1 is repeated in figure 10.1. It is clear that technical knowledge about how to design assembly efficient products existed within the organisation (1). At the organisational level (2), it is possible to identify a number of prerequisites that provided opportunities to develop competence in the design of assembly efficiency products. The most obvious of these is the focus on issues relating to assembly in the product development process. On the individual level (3) there was obviously willingness and commitment to the goal of developing assembly efficient products.

Figure 10.1 Prerequisites for competence development
10.2.2 Analysis of competence development

The analysis in this subsection is directly related to research question 1:

How can competence in the development of assembly efficient products be developed?

This question was divided into three subquestions. This analysis will follow those three subquestions, starting with the first:

1.1 How can competence in the development of assembly efficient products be described?

In the cases described in this thesis, the assembly knowledge required for the development of assembly efficient products is associated with three groups: assemblers, manufacturing engineers and industrialisation engineers.

Manufacturing engineers fulfilled the work roles in the final assembly organisation that were described in chapter 7 as the pre-production engineer, the quality driver and the assembly process engineer. All three of these work roles fell under the department of manufacturing engineering in the final assembly organisation. They are grouped together here because the precise division of work tasks changed a number of times in the course of this thesis.

The assembler has direct knowledge of assembly. The manufacturing engineer is knowledgeable about how to achieve efficiency in the final assembly process. The industrialisation engineer is knowledgeable about how to design assembly efficient products and the product development process in general. The differing fields of expertise of these different professions are presented visually in figure 10.2.
The differences in their work tasks mean that these professions generally have different learning profiles. Assemblers acquire knowledge through their hands, that is, through concrete experience or tacit knowledge. In terms of Kolb’s learning by experience cycle (discussed in section 2.1.2) the strength in the assemblers’ learning profile is concentrated in the upper part of the circle (see figure 10.3). Industrialisation engineers have almost the opposite learning profile, as they are trained to grasp by comprehension rather than by apprehension. The learning profile of manufacturing engineers is more uniform and is not concentrated in either part of the learning cycle.
1.2 How can competence in the development of assembly efficient products be refined?

Intention, in this case a focus on assembly efficiency within the organisation, can lead to increased awareness. This deployment of attention has the potential to lead to increased learning about assembly efficiency since deployment of attention is the basis for reflective observation (see figure 10.4). Reflective observation leads to the forming of abstract concepts. These abstract concepts lead to new mental models that result in further observation of concrete experiences. Intention can thus lead to competence development.
For assemblers, intention can lead to observation of the efficiency of the work tasks they perform daily. The more experience assemblers have of different assembly operations, the more they can compare the different assemblies and note which are more troublesome than others. These observations may lead to ideas on how to change the troublesome ones.

As with the assemblers, intention can lead manufacturing engineers to observe product-related assembly efficiency and to become more active and innovative in contributing ideas for improvements. They can generalise from a larger part of the assembly process than assemblers. They are also in a better position to communicate with the industrialisation engineers and other persons in the product development process.

Intention also effects the learning of industrialisation engineers. However, consideration of assembly efficiency during product development is part of their ordinary work. Thus the effect of intention is not as pronounced as it is
with assemblers and manufacturing engineers. However, intention may increase their determination to strive for assembly efficient solutions.

The technical principles that were laid down to guide the development of assembly efficiency played a significant role in refining the competence of the industrialisation engineers. These principles gave the design engineers abstract concepts that affected their mental models and thereby had an effect on their development of competence.

The benchmarking studies also contributed to refining the competence of industrialisation engineers. Those studies enabled them to analyse (partly with the help of the DFA method) the design solutions of competitors to see how they had realised assembly efficient solutions. These benchmarking studies thus contributed concrete experiences relating to the design of assembly efficient solutions.

1.3 How can competence in the development of assembly efficient products be transferred?

As can be seen from the above analysis, assemblers, manufacturing engineers and industrialisation engineers have complementary competence on how to achieve assembly efficient products. It is thus important that there be knowledge exchange between these professions. Furthermore, the knowledge must also be transferred to the other members of the product development team so that assembly efficiency is integrated in the product development process.

It is important to bear in mind that tacit knowledge cannot be expressed without losing some of its richness (as pointed out in section 2.1.2). Therefore, it is important to have forums for informal knowledge exchange or ‘socialisation’, to use the terminology of Nonaka & Takeuchi (1995). Close cooperation between assemblers, manufacturing engineers and industrialisation engineers increases the chances that tacit assembly knowledge will be used.

The empirical studies produced striking results with regard to close collaboration within development teams. These cross-functional teams had the regular communication and cross-functional relationships to support early and frequent exchanges of preliminary constraints, ideas, and objectives that were described as important by Clark and Fujimoto (1991). They worked according
to the total integration principle (Kjellberg, 1992) and were united by a commitment to a common goal.

In the empirical studies also data highlighted the importance of management’s commitment to developing assembly efficient products. That commitment sanctioned the work to achieve assembly efficiency and strengthened the position of industrialisation engineers. Their position was further strengthened by the inclusion of frötallar and manufacturing engineers from the assembly shop in the product development process as they were a source of detailed input about the assembly process.

10.2.3 Analysis of organisational prerequisites

The analysis in this subsection is directly related to research question 2:

*What are the organisational prerequisites for promoting competence development as regards the development of assembly efficient products?*

This question was divided into the following subquestions.

2.1 *What organisational structure is needed to promote competence development as regards the development of assembly efficient products?*

2.2 *What working methods are needed to promote competence development as regards the development of assembly efficient products?*

The organisational change process whereby the module teams were established focused on cooperation with the assembly plant in the product development process. There was a clear desire to improve the communication between organisational units, and this desire was formalised in the creation of the cross-functional setting in the module teams and subteams. The goal of this close cooperation was to integrate the knowledge from downstream activities in upstream development work, as described by Clark & Fujimoto (see section 2.2.1). The creation of modules facilitated this cross-functional communication and cooperation.

The desire to develop assembly efficient products was strengthened by the message about process-driven product development (see description in section 4.4). Furthermore, challenging goals were set as regards man-hours per car. These goals came with guidelines on how to achieve assembly efficiency.
There were thus visions, goals and strategies related to development of assembly efficiency, and these were known.

The empirical investigation showed that modules are one way of achieving assembly efficiency. Modules can be meaningful units on which to base the organisation of assembly work. Where modules can be realised, they also provide a basis for division of work in product development. A module then facilitates communication and cross-functional learning between final assembly and product development because the interface becomes smoother.

The organisational structure of a module-based organisation facilitates an understanding of context within the organisation. The modules can form the basis for cross-functional teams that can be the autonomous units with the freedom of action that is desired in a competence-promoting organisation (as described in section 2.1.3).

To sum up, the following four organisational prerequisites were present in the organisation:

1. Increased cooperation between product development and final assembly
2. Total integration of assembly competence in product development work
3. A clear intention to increase efficiency in final assembly
4. Modularisation of the product

**10.3 A model of how to promote competence development**

This section is divided into two subsections. First the model is presented and then the value of modules is explicitly stated.

**10.3.1 The model**

The purpose of this thesis has been to explore the prerequisites for enhancing the development of assembly efficient products in order to develop a model of how to promote learning and competence development in this specific area. The model that is a result of this research process is presented in figure 10.5.
Figure 10.5 Model of prerequisites for enhancing competence in developing assembly efficient products
The ‘what’ and ‘how’ pattern in this model is inspired by Suh’s (1990) theory of axiomatic design. ‘What’ refers to ‘what do we want to achieve?’ ‘How’ refers to ‘how can that be done?’

If competence in the development of assembly efficient products is to be developed, the prerequisites for promoting such competence must be provided (1). It is vital that members of the organisation be able to understand the context in which they work (1.1), that there be cross-functional exchanges between different functions in the organisation (1.2), and that there are clear intentions in the organisation (1.3).

A transparent organisational structure is a prerequisite if members of the organisation are to understand how the organisation is constituted (1.1). A transparent organisational structure should be based on autonomous units in which it is possible to achieve holistic understanding (1.1.1). Such an autonomous unit can be based on a module. These autonomous units should be connected in a transparent pattern that makes it possible to understand how they are connected and how company processes function (1.1.2). A process-oriented organisation is one way to achieve this.

Cross-functional exchange and the associated learning is necessary to develop competence in developing assembly efficient products (1.2). To facilitate such exchange it is beneficial to provide forums where people with different competences in relation to assembly efficiency can meet. There need to be forums where competence in assembly efficiency is totally integrated in the development work (1.2.1). One such forum is a cross-functional development team working towards a common goal. To be able to utilise the rich resources of assembly-related knowledge in the assembly organisation there is a need for close cooperation between the product development teams and members of the assembly organisation (1.2.2).

In order to achieve competence in the development of assembly efficient products, an organisation must have a clear intention to do this (1.3). The goal must be clear to all organisational members. Making the goal clear requires the provision of full information, beyond that required for a specific task. The vision (1.3.1), the goal (1.3.2) and the strategy (1.3.3) must be known in the organisation. One way of spreading the vision within the organisation is through seminars with open discussion and space for reflection, as was done in the operational development programme at Volvo Car Corporation (see description in section 4.2). Goals should also be explicitly stated as
measurable targets. A strategy to reach the goal is also vital to strengthen the message, for example, a strategy can be expressed in the form of basic technical guidelines.

10.3.2 The value of modules

This research has investigated the hypothesis that modules can contribute to developing competence in the development of assembly efficient products. The model outlined above sets out the organisational prerequisites for developing such competence, and it is clear that modularisation of the product is one way to meet these prerequisites.

A transparent organisational structure can be realised through modules that represent autonomous units in product development that are interconnected to corresponding parts of the assembly organisation (1.1.1). This approach also yields the process-orientated organisation required by the model (1.1.2). Modules make ideal work areas for cross-functional teams where assembly efficiency is an issue that are totally integrated in the development process (1.2.1). The simple interface between the module-based product development team and the corresponding part of the assembly process facilitates close cooperation between these two organisational units (1.2.2). Frequent communication between these units is an important prerequisite for utilisation of the rich tacit knowledge in the assembly shop. Furthermore, an organisational unit based on a module form a suitable unit that can focus on its contribution to the overall vision (1.3.1). Those who are on the module team can have explicit goals to work towards (1.3.2) and they can implement the organisation’s strategies in their work (1.3.3).
11. DISCUSSION, CONCLUSIONS 
AND FURTHER RESEARCH

It is now time to discuss the implications of the research results reported in this thesis. Some discussion of the relationship between the results and the model presented in the previous chapter is followed by more discussion of the findings in regard to modularisation. Recommendations for organisations and for future research are made. Finally, there is a discussion of the academic contribution of this research and some reflection on the quality of the research results.

11.1 Organisational prerequisites for development of assembly efficient products

In this thesis, the utilisation, refinement and development of existing competence was taken as the point of departure for achieving sustainable development of assembly efficient products. It was also assumed that having the organisational prerequisites in place would enhance willingness to work towards assembly efficient concepts. Such willingness would motivate a search for technical ways to design of assembly efficient products. The findings of this thesis support the view that organisational prerequisites are basic to being able to develop assembly efficient products.

In the previous chapter the results of the study were summarised in a model of the organisational prerequisites for success in developing competence in this particular field. The key issues highlighted in the model were a transparent organisational structure, a clear intention on the part of the organisation, and an organisational structure that promotes cross-functional exchange.

*Transparent organisational structure*

A fundamental element in developing competence is acquiring an understanding of the context (see section 2.1.3). A transparent organisational structure is vital to achieving such understanding.

The empirical investigation presented in chapter 7 shows that a simple communication interface between the assembly organisation and the product
development organisation is extremely important for high quality communication. It also shows that a simple interface means that fewer people are involved in the communication and that this promotes cooperation.

Comparison of these results with the findings of Nonaka and Takeuchi (1995) makes it possible to draw further conclusions about the effects of a simple communication interface. Nonaka and Takeuchi found that socialisation is important if an organisation is to make use of its rich supply of tacit knowledge. Close cooperation makes socialisation possible. A simple communication interface between the final assembly organisation and the product development organisation promotes the exchange of tacit knowledge and is thus a way of using the rich assembly-related knowledge of members of the assembly organisation in the development of assembly efficient products.

The literature on competence promoting organisations (presented in section 2.1.3) indicates that simplifying the interface between different organisational entities is a way to create the desired understanding of context. In this thesis, the way to create this understanding is described in terms of transparency. Solutions are needed that makes the organisation and its processes transparent.

**Cross-functional exchange**

In the introduction to this thesis it was explained that cross-functional exchange and learning are necessary for the development of assembly products. This thesis argues that cross-functional organisational settings are required to facilitate this cross-functional learning.

The empirical results of the case studies presented in chapter 9 show that the cross-functional exchange between the industrialisation engineers, manufacturing engineers, frötallar and design engineers was of the utmost importance in the realisation of the assembly efficient concepts. This close cooperation meant a frequent exchange of facts, opinions and thoughts between the representatives of the different professions involved. Nonaka and Takeuchi’s thinking on socialisation (discussed in the previous section) gives a theoretical explanation of why the closeness in this cross-functional collaboration is so important. The reason is that it is the closeness that creates opportunities for the exchange of tacit knowledge. Thus the creation of cross-functional settings is important for developing competence in the development of assembly efficient products as it facilitates the cooperation across
functional borders that is needed to fully use the assembly knowledge resident within members of the organisation.

Clear intention

To make full use of people’s ability to contribute to company progress, it is vital that they understand the direction and ambitions of the company. This is another aspect of the understanding of context that is necessary for competence development. This thesis proposes that clear signalling of intention is vital to developing competence in the development of assembly efficient products. The striving for assembly efficiency must be acknowledged and authorised if it is to be a priority. Only such authorisation can change the mindset of members of the organisation members and make it possible to draw on their full potential for developing competence.

The results from the empirical investigation presented in chapter 9 show that the intention to develop assembly efficient products was made very clear. The application of Kolb’s (1984) model clarifies the connection between intention and competence development. Intention directs the attention and can thus lead to reflective observation, which is basic to the learning by experience process and important for the development of competence.

11.2 The effect of modularisation

A working hypothesis underlying this research has been the belief that modularisation contributes to the development of competence in the development of assembly efficient products. The results support this view both as regards the direct positive effects of modularisation on the assembly system and as regards its contribution to an organisational structure that promotes the development of competence in assembly efficiency.

The results obtained from the research leading to my licentiate thesis (chapter 5) suggest that assembly work should be based on the assembly of meaningful entities, preferably modules. Assembly of modules (pre-assemblies) has the potential to lead to better working positions since it minimises assembly operations inside the car body. Modules also give assemblers an opportunity to obtain a holistic understanding enabling them to grasp the inner logic by which the details are connected. This understanding facilitates memorisation of work tasks as well as the assemblers’ ability to contribute to improvements.
The positive effects of modularisation in the assembly process are supported by the empirical findings presented in chapter 8. Modularisation was shown to decrease physical work strain, improve holistic work content and the quality of output, and decrease assembly time and lead-time. The results from these studies thus show direct positive effects of modularisation in the assembly process.

The results presented in chapter 7 show that when modularisation is used to create corresponding organisational entities in the product development organisation and in the assembly organisation, the communication interface is simplified. As argued in section 11.2, simplification of the interface is vital for the cross-functional exchange that is basic to developing competence in the development of assembly efficient products. Modularisation of the product is thus a way to create the desired transparent organisational structure that is vital to a competence-promoting organisation.

11.3 Further recommendations and future research

Modularisation

The results presented in chapter 6 make it clear that it is difficult to modularise automobiles given the current principles of automobile design. The pressed car body seems to work against modularisation. However, if automobile design were based on a frame, it might be possible to develop a modularised automobile. A commitment to such a development at Volvo Car Corporation would require extensive work and unconventional, innovative thinking. Such a decision must therefore be seen as an issue of long-term strategic planning.

This area could be the subject of future academic research. One option would be to analyse the technical principles that constrain modularisation today and to identify the principles that would underlie solutions to these problems. The work done in the Beyond Project (see 6.2.5) offers scope for interesting analysis.

Transparency

Sustainable development of assembly efficiency requires a clear understanding of the prerequisites for competence development. This thesis
had identified transparency within the organisation as a vital issue since understanding of context is basic to competence development. If members of an organisation are to be able to understand how the organisation is working, the organisation must be transparent. It is likely that there are several ways in which this transparency could be created. The number of possible solutions to the problem may be limited only by our imagination.

To achieve the desired transparency within an organisation means asking questions such as the following:

- How can we increase the transparency of the structure of the organisation?
- How can transparency be achieved in this work/process?
- How can we make challenges clearly visible?

The message of this thesis on the issue of transparency is – Make the organisation transparent! By increasing transparency, employees can be enabled to understand, take part in and actively contribute to improving company processes. Although I feel confident in making this general recommendation, I am well aware that my results are based on study of only one company. I would therefore recommend that when applying these findings to other organisations, the particular circumstances within each organisation should be taken into account. The issue of the generalisation of results is further discussed in section 11.5.

11.4 Further discussion of academic contribution

Most of the research related to concurrent engineering focuses on the development of tools, and design methods. This is not surprising since most of this research is related to engineering disciplines that traditionally have little involvement with human factors. But, concurrent engineering is about people and how they cooperate, exchange ideas and thoughts, define goals, and take decisions. So, however important engineering methods and tools are, they are not enough. To understand how to promote cross-functional cooperation and competence development, it is important to understand the prerequisites for competence development. This thesis is thus a contribution to the consideration of vitally important human factors.

Studies of assembly efficiency have focused on the development of methods. This is exemplified by Egan’s (1997) finding that in 1997 there were twelve
commercially available methods for design for assembly (including the DFA method of Boothroyd et al., 2002). While there is no reason to doubt that these design for assembly methods contain valuable information about how to develop assembly efficient design solutions, such knowledge is not enough. The technical knowledge supplies the basis for developing assembly efficient products, but this thesis makes it clear that realisation of assembly efficient products also requires that organisational prerequisites and willingness are present. To achieve sustainable development of assembly efficiency, there must be a focus on competence development and the prerequisites for competence development. This thesis contributes knowledge about the organisational prerequisites for competence development based on case study research.

In the introduction to this thesis is was stated that earlier research has shown positive effects of modularisation in terms of its being a suitable base for division of work in the product development process (Smith & Reinertsen, 1998; Sanchez, 1996; Mufatto, 1999). The effects of modularisation on manufacturing systems have been reported by Erixon et al. (1994). This thesis has contributed knowledge about organisational effects in the relation between an assembly shop and the product development department. Furthermore, it has contributed to our knowledge about the effect of modularisation in an assembly shop.

This thesis contributes to research on competence-promoting organisations by offering a concrete case study focusing on the development of assembly efficient products. This focus has made it possible to explicitly identify the requirements for a competence-promoting organisation. It has thus contributed knowledge derived from an in-depth analysis of data from a specific case.

11.5 Reflection on the quality of results

There are no generally accepted guidelines for assessing qualitative research. This point was made in relation to qualitative approaches in general by Creswell (1994) and applied specifically to case study approaches by Eisenhart (in Huber et al., 1995). She believes that the problem is that in case study research ‘good’ theory emerges at the end, not the beginning, of the study. This implies that the results cannot be tested within the framework of the study.
Yin (1994) has proposed that the question of the generalisability of case study research should be handled in terms of analytical generalisation as opposed to the statistical generalisation that is common in quantitative approaches. This proposal is supported by Dubois and Gadde (2002) who argue that case study research relies on analytical inference. Further, they argue that logical coherence is the foundation for analytical generalisation and is therefore an important criterion for quality in case research.

Eisenhart (in Huber et al., 1995) emphasises the importance of providing sufficient information about the research process to make it possible to judge the adequacy of the research procedure and its outcomes. Bell writes (1987) that in a case study approach it is more important to provide sufficient detail for a reader to be able to relate to than to generalise from the research.

In this thesis, an attempt has been made to provide as rich a description of the data, the methodological procedure and the frame of reference as is possible without obscuring the essence of the research. The intention has been to show how the research has evolved and to reveal the logic of this process. When it comes to generalising from these results, it is up to the reader to ‘relate’ to the study (as described by Bell above) and to judge the applicability of the findings.
12. REFERENCES


