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**Information Flow and Product Quality in Human Based
Assembly**

by
Gunnar Bäckstrand

A Doctoral Thesis

Submitted in partial fulfilment of the requirements

for the award of

Doctor of Philosophy

of Loughborough University

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ABSTRACT

Information is an important part of the manual assembly process. Information provides the user with the means to fulfil assembly tasks so that the right quality as well as high productivity are accomplished. This thesis addresses issues connected to information and information use in a modern manual assembly environment, and how these issues affect human operators, quality and productivity. The overall objectives of the research were to gain further knowledge on how attention affects the internal reject rate, to investigate these phenomena in industrial and laboratory environments and finally to propose a suitable evaluation method to be utilised at the design stage of an information system.

Studies were performed with the purpose of investigating how the assembly personnel were affected by the information and how it affected quality and productivity. The studies were performed in an assembly plant and in the laboratory. Quantitative data collection included 10 days and nights of production where the information impact on quality was investigated. Connected to this study was a qualitative survey performed among 171 persons from the assembly personnel. The laboratory study took place during three days, approximately eight hours each day. It involved 30 persons, all experienced assembly workers from the reference assembly plant. The focus of this study was how information affected the personnel and thereby the productivity.

The findings revealed that information affected the quality rates and productivity and that this can be linked to *how* the information is presented as well as *when* the information is presented. It was possible to link these findings to the outcome of a successful information search process, and to conclude that a use of an evaluation method or work process during the product lifecycle could have made it possible to avoid some of the problems connected to the information presentation. This is the basis for a proposed pragmatic evaluation method. The method was tested as a support system during the design of a prototype user interface to be used at the pilot plant.

The major contribution of this research is the connection between attention and quality as well as the connection between attention and productivity. Knowledge regarding the importance of presenting the information at the right time must also be regarded as an important and proven contribution.

Keywords: attention, information system, human factors, manual assembly, quality, productivity

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This journey started, although I did not know it back then, in 1996 with my preparation for university studies, and it will not stop with the completion of my PhD. I am curious what is coming next. My own expectations on my work has sometimes made me feel insufficient and now and then I have been 100% certain that I will fail to last all the way. Only with the help from my loved ones, my dear friends, supervisors and colleagues have I accomplished something that I will be proud of for the rest of my life, but again, without help and support it would not have happened.

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Many thanks to Dr. Dan Högberg at University of Skövde, who has spent so much time with me, my research and my thesis. He was the one that first inspired me to do a PhD, although it took some years before I actually started, and he has pushed me through the PhD process. He also became a dear friend of mine during this work. Many thanks as well to Professor Leo De Vin whom, has been a great support during my PhD, for example with my progress regarding the art of academic writing. I would like to thank the management at Volvo Powertrain Sweden as well as University of Skövde who gave me the opportunity to spend time doing a PhD. At Volvo Powertrain I would especially want to mention Kent Eriksson, Jonas Möller, the assembly personnel at the final assembly line, the management team in the assembly plant and colleagues. My relationship with Dana Dobrin started rather tensely, no one had informed her that a research project had started that would affect her department. However, our relationship has developed to a mentorship and friendship over the years. Our discussions have been

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This has been the most interesting task I have ever done, and I have learnt so much during this period. If someone asks if I would do it again, I would probably say yes without hesitating. However, right now, I will take a break from writing and sleep for a while.

Skövde, Autumn 2009.

Gunnar Bäckstrand

Email: gunnar.backstrand@volvo.com (Volvo Powertrain)

gunnarback@gmail.com (home)

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CHAPTER 1

INTRODUCTION

1.1 CONTEXT

In all manufacturing, it is vital that operators and assembly personnel have the right information, at the right time and at the right place (Wilson, 1997; Kasvi et al., 2000; D'Souza and Greenstein, 2003). This information is a key component within a production unit; without it, it is impossible to produce the required products (Sander and Brombacher, 2000). The information has different meanings depending on where it is presented, to whom it is presented, when it is presented and how it is presented. The information flow, “*Quality Information Flow*” (Forza, 1995), i.e. the stream of information from the production of the information to its consumption, is often very complex and often the information changes its form along the line. This complexity can directly influence the product quality and the production personnel in a positive (the information is a necessity for a successful task accomplishment) as well as in a negative way (Forza, 1995). If there is a problem in the one-to-one mapping between the information presented to the personnel and the information need there will eventually be a negative effect on quality (Losee, 1990; Wilson, 1997; Lou and Huang, 2003). The knowledge and skills that the assembly personnel possess will reduce the effect on quality of poorly mapped information. However, knowledge and skills cost money and time and the need for them can negatively affect flexibility. For example flexibility to respond quickly to changes in the work environment, flexibility to handle changes without new training, etc. may all be reduced. In addition, knowledge is vulnerable to changes in the working environment. That is, if there are changes to the product or the assembly process, the personnel have to acquire knowledge and skills on how to handle these changes, and the old knowledge and skills may not be useful in the same way as before. Therefore, the organisation itself must create an information flow that can support production personnel so that a product can be produced with a minimum of effort and with maximum quality.

The main issue with data and information is that they have to add value to the product itself (Hicks, 2007). This implies that, if data and/or information can increase productivity and decrease quality problems, it can have a positive effect on the product

value. This can be accomplished by creating an information flow (to and from the assembler) via, for example, the graphical user interface, that makes it easier for the personnel to fulfil a task, and thereby have a positive effect on productivity, and/or influence the quality in a positive way (Johnstone and Tate, 2004). One of the key issues in the development of information flow is to have knowledge regarding the context in which the information will be used (Fidel and Pejtersen, 2004). This issue puts demands on a work method that can provide knowledge to the people involved in the development of information systems. To be able to propose a work method or to develop one, it is important to understand the needs and demands that the user has on an information system (Wilson, 1997; Bäckstrand et al., 2006a). It is therefore important to consider human limitations as well as human strengths and to understand how humans interpret and use data and information in a specific context (Byström et al., 1995).

This research focuses on humans and their interaction with data and information in a production context where human behaviour, cognition and psychology are research topics that provide understanding of where the problems identified in the industrial settings might have their roots.

The company where the major part of the research was carried out is responsible for the development and production of engines, gearboxes and driven axles within the company group, and is the world's largest manufacturer of heavy-duty diesel engines (9-18 litres volume). It produces engines that have a cylinder volume of 5, 6, 9, 11, 12, 13 or 16 litres and the engines are used in trucks, excavators, articulated haulers, boats etc. Three main processes exist at the plant:

- Casting: Engine blocks and cylinder heads are produced from raw material in the foundry.
- Machining: Engine blocks, cylinder heads, crankshafts and camshafts produced in the previous step are machined to the right dimensions and tolerances.
- Assembly: The parts from the machine shop, together with outside purchased parts, are assembled in two steps:
 - Basic Assembly: All parts that are on the inside of the engine, for example pistons, connecting rods, crankshafts and camshafts are assembled at this stage in the process.

- Final Assembly: All parts that are on the outside of the engine, for example turbo, intake and exhaust manifolds, cable harness and oil pan are assembled at this stage in the process.

The research focus in this thesis is on the Final Assembly process, although some investigations have connections to the other processes. At the outset of this research, the plant management had identified a number of parameters that will affect production complexity in the future. The most important are:

- Increased product variant range. Increased amount of customer-driven variants.
- Higher production volumes.
- Shorter product lifecycles.
- Increased or maintained numbers of short-term employees provided by manpower supply companies.

These parameters add to production complexity and will affect issues related to information flow in all parts of the plant, but how? Today, the assembly personnel at the company have problems using the information in an effective way; the number of internal rejects is an indication that supports this statement (elaborated in Section 3.2). The expected increase in the workload of the assembly personnel, will affect their interaction with the information system. The question is how? Today the common opinion among managers and technicians is that the assembly personnel “have all the information they need” to successfully perform an assembly task. If this is the case, why do errors occur?

A general problem at the assembly plant is that the personnel make assembly errors by assembling the wrong parts or omitting parts in spite of the information available. This indicates that there is a connection between assembly information and quality. At the plant, assembly information regarding variants of a specific individual engine is a key component; if this information is not provided to the assembly personnel or found by them, it is almost impossible to assemble an engine according to the specification.

1.2 PROBLEM STATEMENT

Several researchers have identified the correlation between human factors issues and quality (Eklund, 1997; Axelsson, 2000; Drury, 2000; Paz Barroso and Wilson, 2000; Lin et al., 2001; Hong et al., 2007). At the company studied in this research an investigation regarding quality revealed that approximately 93% of the quality problem was connected to “Manpower”, with “Material”, “Method” and “Machine” accounting for the remaining 7% (Figure 1.1).

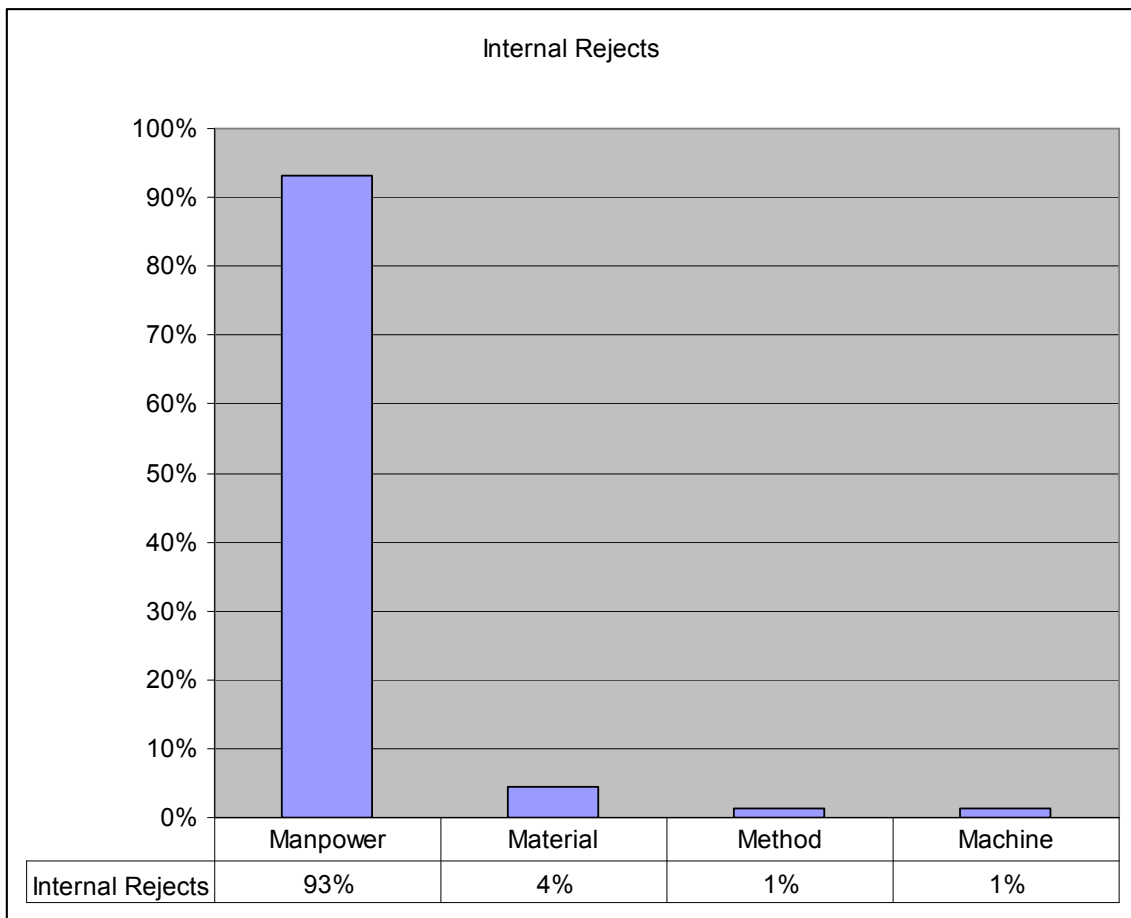


Figure 1.1: The relationship between the four main internal reject categories during a typical time period.

This shows rather clearly that human factors is a vital part of the quality work. One of the problems with the categories is that they are on an inadequate level-of-detail, i.e. just to categorise a problem as “Manpower” is not enough. A more detailed description is needed in order to aid the rectification of the quality problem. Hence, the “Manpower” category must be divided into more detailed sub-levels (domains), possibly structured

according to “Physical Ergonomics”, “Cognitive Ergonomics” and “Organisational Ergonomics” (IEA, 2009). The International Ergonomics Association (IEA) describes topics in the three domains as follows:

- Physical Ergonomics: Concerned with working postures, materials handling, repetitive movements, work related musculoskeletal disorders, workplace layout, safety and health.
- Cognitive Ergonomics: Concerned with mental workload, decision-making, skilled performance, human-computer interaction, human reliability, work stress and training.
- Organisational Ergonomics: Concerned with optimization of socio-technical systems, including their organisational structures, policies and processes.

To aid the quality improvement process in final assembly, it is considered advantageous to break down these three domains into even more detailed levels. If one looks at human factors (in general and cognitive ergonomics specifically) from a human errors perspective and relate it to the output quality, it is possible to use more detailed definitions of the problems connected to cognitive ergonomics. These definitions will be addressed later in the thesis (Section 2.4.7).

The number of internal rejects is a quality measure used to determine the level of the quality issues at the plant together with customer complaints. The focus in the thesis is on internal reject rates and why they occur. An internal reject can be defined as a quality issue found by the department responsibly for the problem and found before it reaches the customer. Depending on the product, these problems cause costs connected to the process of finding the problems (quality control etc.), reassembly of product and waste in the form of damaged product due to reassembly.

1.2.1 General description

The overall issue dealt with in this research is how humans in a production system influence quality and productivity when they use or do not use the information that is provided by the information systems. The main issues at a higher level are to understand:

1. Is it the information itself that possibly creates the problems? This concerns the quality of the information; is it possible to use the existing information in a way that leads to the assembly of a product with the right quality?
2. The user uses the information provided by the information system, but in addition to this is it possible that the user might be using other information sources that are not a part of the general information system?

It is of great importance to understand the role of the human in the assembly system. The different roles, i.e. the roles that humans in the context possess, will in different ways influence the production, the productivity and the quality. The main focus in the research is on the role “Assembly personnel” and how that role affects quality and productivity.

1.2.2 Specific description

If the assembly personnel have all the information they need, why do errors still occur? These errors sometimes lead to internal rejects. Even more seriously, sometimes errors are not recognised at the plant, which means that products not assembled according to specifications may be delivered. At the plant, the internal rejects are divided into different categories, such as leakages, wrong parts assembled, parts missing etc. A detailed description of these issues is given in Chapter 3. This research work focuses mainly on errors such as “wrong parts assembled” and “parts missing”. The error definition is presented in Section 2.2.5.

This leads to the formulation of a hypothetical model that views the different states of an information seeking process (Figure 1.2). This initial hypothetical model aims to visualise an information seeking process in an assembly context. The objective for an assembly worker going through this process, is to get information that can change the person’s knowledge, in this case knowledge of what and how to assemble. From a quality point of view, it is important that this process is effective in supporting the assembly worker in carrying out the predicted and proper action. Figure 1.2 will be elaborated on in Chapter 2.

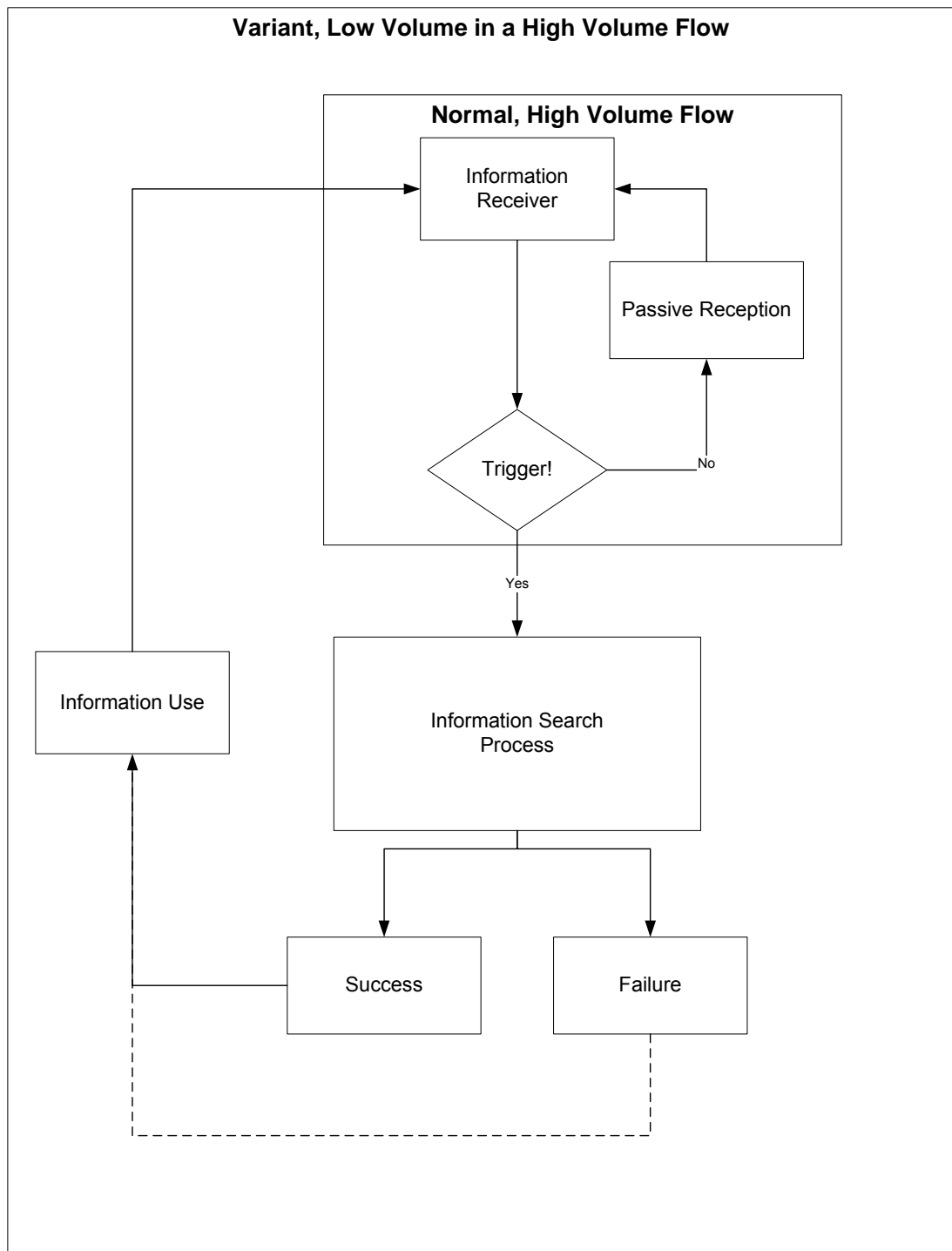


Figure 1.2: A hypothetical model of an information seeking process during different sorts of assembly tasks.

The model in Figure 1.2 is divided into two modes: “Normal, High Volume Flow” and “Variant, Low Volume in a High Volume Flow”.

- “Normal, High Volume Flow”: In this mode (Figure 1.2), the assembly task is controlled by an engine specification that is connected to a high volume product. Depending on engine type, for example 12 or 13 litre engine, the production of high volume products can be 100% of the production at a specific time.
- “Variant, Low Volume in a High Volume Flow”: In this mode (Figure 1.2), fewer engines are handled compared with the “Normal, High Volume Flow”. If 90% of the total amount of engines is related to the “Normal” flow, this mode handles (in this specific example) 10% of the total amount. This 10% contains a number of variants, from one to almost infinity, depending on engine type.

“Normal, High Volume Flow”. This mode contains three mental states (Figure 1.2):

- *Information Receiver* (Losee, 1997): This is the person that is exposed to the information flow, in this case one of the persons who assembles the engine.
- *Trigger*: A trigger is some kind of signal that creates an awareness of changes (Dix et al., 1998). In this case this relates to a change in the production flow, and thereby a change in the information need. Or interpreted differently, the identification of a knowledge gap regarding the next action to be performed (Wharton and Lewis, 1994).
- *Passive Reception*: The assembly personnel is more or less aware of the information flow but has no intention to act on data/information given (Wilson, 2000). If the assembly personnel for some reason miss or neglect the trigger, they will continue working in the “Normal, High Volume Flow” mode, and thereby increase the risk of an internal reject. While remaining in this mode, products will be produced according to the high volume specification.

“Variant, Low Volume in a High Volume Flow” (Figure 1.2):

At this stage in the thesis, this mode in the model is described on a rather general level. In Chapter 2, the model is further developed and used in the analysis phase as a support when describing current context and problem issues, as well as in the literature study. At this stage, the model basically illustrates that the outcome of an assembly task is dependent on a successful Information Search Process.

Assembly Flow

The assembly process for a specific workstation often starts with the arrival of an engine transported by a carrier (Figure 1.3). This arrival by itself is likely to trigger a data/information search process.



Figure 1.3: A carrier has arrived at a workstation. The computer screen on top of the carrier is part of the information system.

This process continues with the arrival and departure of a carrier/engine in seven-minute cycles. When a new engine arrives at the station, the assembly personnel are expected to start to gather information about what to assemble.

Initial observations have shown that the event “carrier arriving at the workstation” sometimes is not enough to trigger a change in state from passive to active reception. This can increase the risk that the assembly personnel miss changes in products and assembly tasks, i.e. continue working in the high volume area on low volume products (Figure 1.4). If this is the case, it is likely that an internal reject will be created, and the

assembly personnel continue working on the next engine that arrives at the workstation, and the “trigger”/assembly process starts over again.

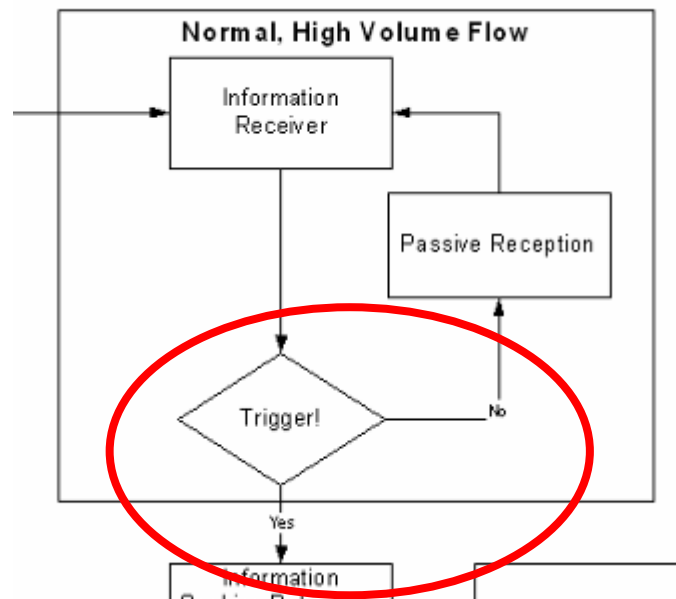


Figure 1.4: Trigger as one important error source.

If one assumes that the personnel observe the signal/trigger and thereby change from the high volume area to the low volume area (Figure 1.4), is the workers believed to change from passively receiving data/information to actively seeking data/information.

If the mental process is successful, the information is used in a correct and sufficient way and the outcomes from the assembly process are successful, and we are back in the “High Volume”-area and the information seeking process starts over again (Figure 1.2).

One major issue covered in this research is if, and if so why, the personnel do not use the information provided by the information system? Insufficient use of information combined with complexity is already today a contributor to the creation of internal rejects. It is notable that today’s production volumes would not be possible without the existing information system and that the work environment complexity is a result of the demand from the customers (Volvo Trucks etc).

From the description above is it possible to develop two research questions:

1. How can we use the information system’s potential without facing problems with insufficient use of information, or in the worst case no use of the information at all?

This includes how can we predict how an information user will interact with an information system.

2. How can we minimize the (negative) influence that identified parameters connected to the Information Flow and the Information Use have on the internal reject rate?

1.3 AIMS AND OBJECTIVES

This section describes the research aims and objectives and the initial hypotheses established for the research. It also describes the industrial and academic links for the research and gives an outline of the thesis.

The two research questions presented in the previous section and in the Problem Statement section create the basis for the aim of this research:

The aim of this research is to develop an evaluation working method that can support the design of Information Flow based on product and assembly process demands and to understand the underlying causes of the existing problems.

1.3.1 Hypotheses

As a starting point of this research, the following hypothesis was established:

High production volumes together with Information Overload create a workload that is the main cause for the relatively high number of internal rejects that are due to wrong parts assembled or parts missing.

This hypothesis had to be reformulated early in the research process due to results from a study conducted in the assembly environment (Bäckstrand et al., 2005a). The results from that study influenced the establishment of two new hypotheses that worked as the foundation for the subsequent research activities.

Hypothesis 1 - ‘Information seeking behaviour’

The degree to which Active Information Seeking behaviour is supported/triggered has a large influence on the number of internal rejects.

This hypothesis is based on the fact that in most of the cases, i.e. assembly tasks, the assembly personnel have enough information present in their working environment to be able to perform a correct task. Therefore, it is more likely that human behaviour in general, and Information Seeking Behaviour specifically, influence the internal reject rate and not the amount of information.

Hypothesis 2 – ‘Use of evaluation methods’

The use of an evaluation work method in the design phase of an information flow will affect the internal reject rate in a positive way.

This hypothesis is based on the assumption that the assembly personnel always strive for a performance outcome that lives up to the quality demands and targets. A common opinion among management and technicians is that the amount and the relevance of the data/information present in the assembly environment is enough to perform a correct task. This indicates that there is a deviation between the need and demand connected to a specific task to be performed by the assembler and the believed need/demand from the designers’ point-of-view.

1.3.2 Research objectives

The overall research objective is to study and substantiate the two hypotheses. The objective is divided into the following sub-objectives:

- To understand how the assembly personnel interact with the current information system.
- To gain knowledge of how different attention levels (i.e. active and passive) affect the rate of internal rejects.
 - To understand to some extent how different triggers affect the assembly process.
- To investigate and understand how information affects quality.
- To investigate and propose evaluation methods suitable for workplace design at different phases of the product lifecycle. The focus will be on information flow rather than graphical interface design aspects.

The research is divided into four stages:

Stage One (Thesis Chapter 2)

This stage investigates how the assembly personnel interact with the information present in their working environment.

Stage Two (Thesis Chapter 3)

This stage addresses the connection between different information providers and the internal reject rate. A study was conducted with the purpose of observing if a different information provider affected the internal reject rate. This study is detailed in Section 3.2.

Stage Three (Thesis Chapter 3)

In this stage a case study with the same purpose as in Stage Two was conducted. The main difference was that the case study took place in a controlled laboratory environment. This study is detailed in Section 3.3.

Stage Four (Thesis Chapter 4)

The focus in this stage was to study evaluation methods and their applicability and strengths in a design setting, with the overall objective that they will have positive influence on quality. Finally, a pragmatic work method is proposed including a description of information providers that could be identified by the work method.

1.4 INDUSTRIAL AND ACADEMIC LINKS AND COLLABORATION

From the start this research has been strongly connected to the industry and in this case to the industrial partner Volvo Powertrain Sweden, in Skövde, Sweden. The author has been an employee at Volvo Powertrain since 2004, and is a member of the Research and Development Department at the plant, as well as a member of the research group “User Centred Product Design”-UCPD at the University of Skövde. Volvo Powertrain Sweden develops and produces heavy diesel engines for customers within the AB Volvo-group such as Volvo Trucks, Volvo Penta and Volvo Construction Equipment. Other partners during the research were mainly the University of Skövde, supervision, Loughborough

University, affiliation and supervision, Volvo Trucks, Volvo Information Technology and Volvo Technology.

Most of the research work was conducted at the Volvo Powertrain assembly plant in Skövde and at the University of Skövde.

From April 2007 to June 2009 the author was a member of the EU-financed FP6 project MyCar (Flexible Assembly processes for the Car of the Third Millennium) together with participants from University of Skövde, Volvo Trucks, Chalmers University of Technology and Volvo Technology. The participants were: two PhD-students and three senior researchers from the University of Skövde, technicians from Volvo Trucks, one PhD-student and two senior researchers from Chalmers University of Technology and project leaders from Volvo Technology. The participation in the project has contributed to this research by showing that the problems existing at the Volvo Powertrain Skövde plant exist also at other companies. It also gave input to the knowledge regarding examples on how to present information in an assembly context.

The author was also involved in research and development projects as project leader, initiator or pre-study leader, in projects at Volvo Powertrain Skövde and in AB Volvo-group projects. These projects were all connected to information use and human involvement in production.

The work described in the thesis is entirely the work of the author (with the exception of Case study 2 where co-researchers were involved) and knowledge gained from leading and participating in the above projects.

1.5 OUTLINE OF THESIS

This thesis, as well as the research includes:

- Description of context: Evaluates and describes the context in which this research has been conducted.
- Problem statement: Evaluates and describes the problem area, for example how information can influence an assembly task. This includes the establishment of the research questions.
 - Aims and objectives: Hypotheses and research objectives.
- Sub-objectives, understand, and investigate: divided into 4 stages, see Section 1.3.2 for details.

- Case studies: Two major case studies were conducted.
- Evaluation working method: An evaluation work method is proposed.

Chapter 1 defines and describes the problem area and gives a general and specific presentation of the relevant issues. It presents the hypotheses that are central to the work. The chapter also describes the context in which the work was produced, as well as the conditions for the research, for example industrial and academic collaborations. The aim with the chapter is to create an understanding for the research context, but most of all to present the aims and objectives of the research.

Chapter 2 describes the physical flow as well as the information flow at the manufacturing plant studied. It also presents and describes some of the parameters that affect the complexity of the assembly process. A discussion about whether or not the problem is isolated to the specific context is presented. The discussion is based on the findings from six different assembly factories in two different countries. An investigation regarding some of the general problems connected to information use is presented. This investigation is based on findings from the literature study carried out and is connected to the problem experienced in the research context. The aim of Chapter 2 is to view some of the issues connected to information and quality from a specific as well as from a general point-of-view. The outcome from the knowledge gained in Chapter 2 is used in the studies presented in Chapter 3.

Chapter 3 presents the research methods that have been used during the research and presents arguments for why they have been used. The most important parts of Chapter 3 are the studies that have been performed.

Chapter 4 presents a work method and a proposition on when to use it and why. It also includes a discussion regarding the findings and how they can be applied in an assembly environment. This is done by presenting a prototype user interface which design is based on the proposed work method.

Chapter 5 includes general reflections and a discussion of this research and summarises some of the findings. It also presents and discusses the findings related to the two hypotheses presented in Section 1.3.1.

Chapter 6 presents the conclusions drawn from the research as well as the contributions made by this research. It also presents some of the work that can be performed in further work connected to this research.

CHAPTER 2

ANALYSIS

This chapter presents the current situation at the main research environment, Volvo Powertrain Skövde, and the challenges the company are facing, thereby detailing the conditions for the research carried out. The chapter also shares reflections and experiences gained from visiting other assembly plants and a discussion based on the findings within the research environment. It also establishes connections of those findings to existing research literature (literature survey).

2.1 INTRODUCTION

The analysis process is divided into three parallel flows (Figure 2.1).

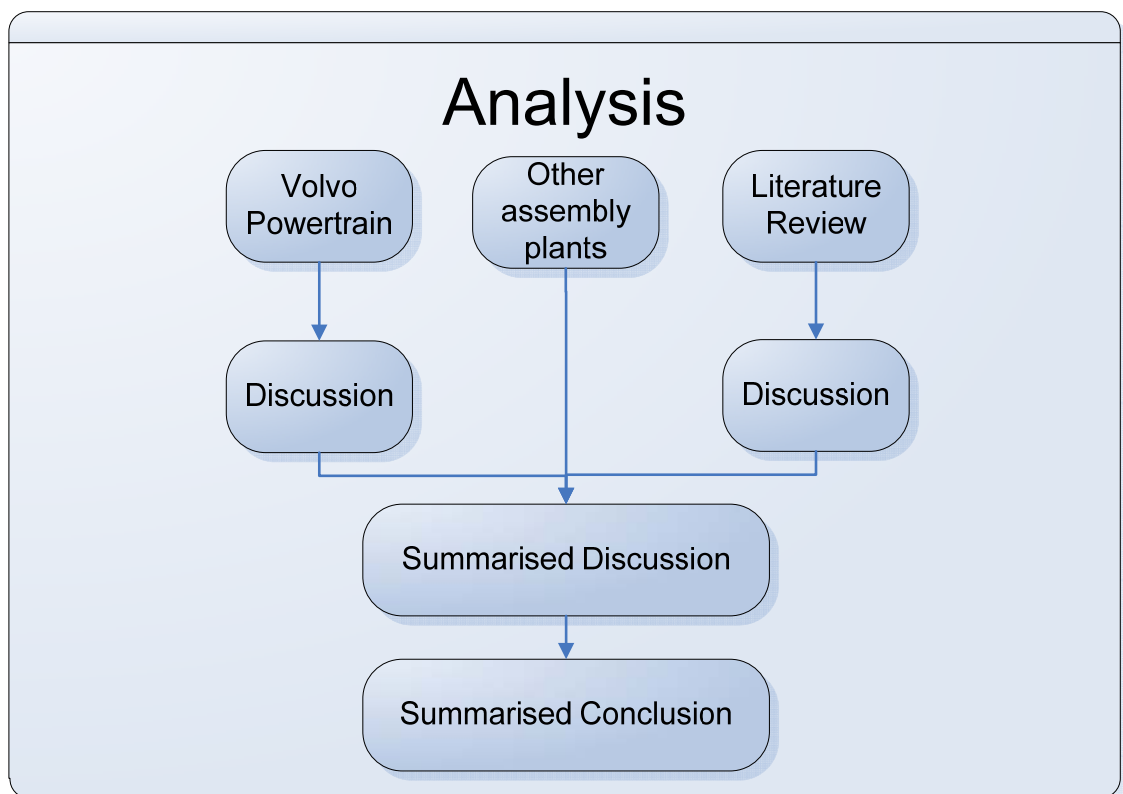


Figure 2.1: The parallel analysis flow of Chapter 2.

The parallel analysis flows are presented as individual parts and at the end of the chapter, the conclusions from the evaluation of the research context (Section 2.2) and the literature review (Section 2.4) are summarised in a discussion and an overall conclusion.

In the first part of the chapter, the research environment is described, with the focus on the physical flow as well as the information flow at the production plant. The second part of the chapter presents findings based on a literature survey.

In Chapter 1, a model was presented (Figure 2.2), which visualises a basic behavioural model of an information seeking process. This theoretical model will serve as a foundation for this chapter.

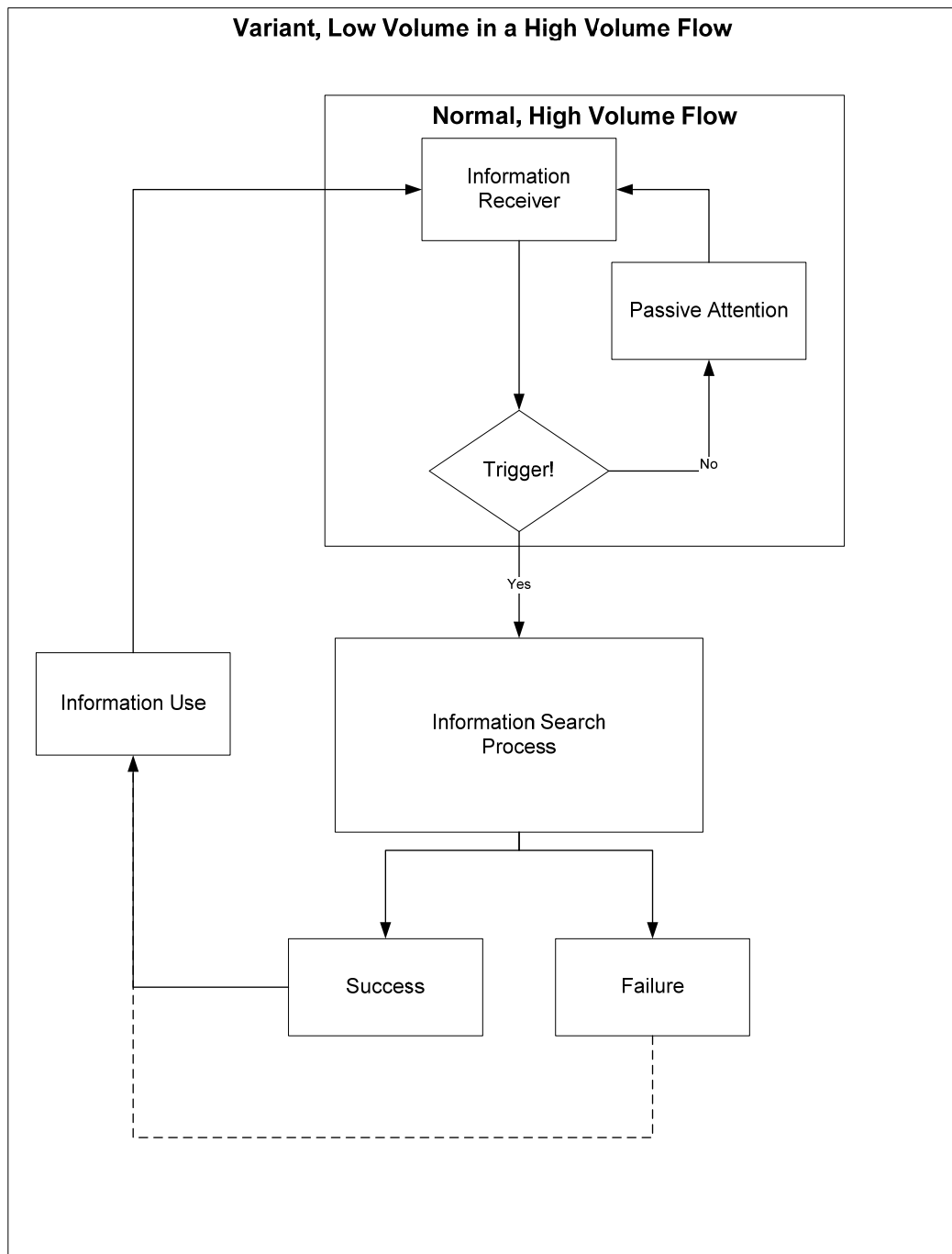


Figure 2.2: Information Seeking Model.

Wilson (1999) describes a model (Figure 2.3), based on characteristics presented by Ellis (1989; 1993), that views the overall steps of information seeking. The purpose of this combined model is to describe the different steps in an information search process, to describe the influencing factors that can affect the outcome and to describe the factors that start the process as well as the outcomes of the process.

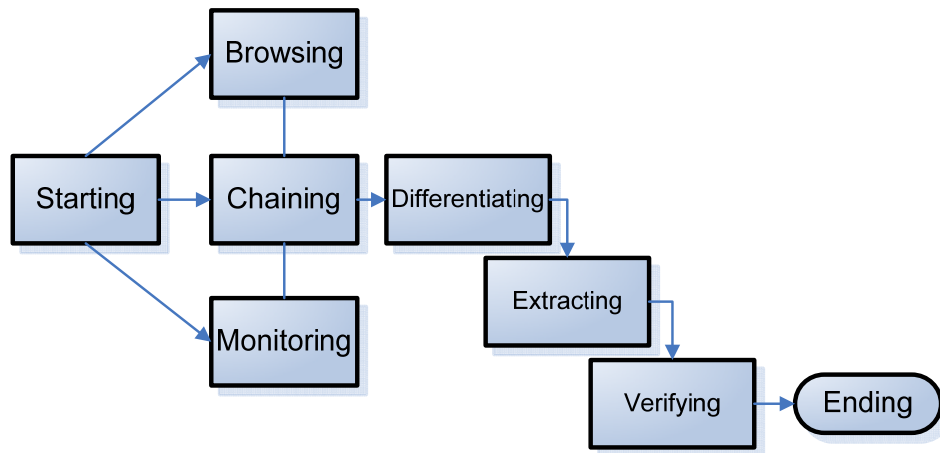


Figure 2.3: Information Search Process by Wilson (1999).

Wilson’s model is too general and too rough for identifying the causes of assembly errors at the assembly plant. The model is however useful as a foundation for contextual investigations regarding the connection between information and internal reject rate.

If one compares Wilson’s model with the information search process presented in Chapter 1, one can identify three phases (Figure 2.4) that will be discussed in more detail below.

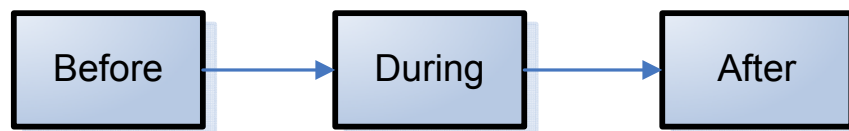


Figure 2.4: The three major phases in an information search process.

The model that Wilson presents, based on Ellis, does not deal with issues that can explain the connection between information and internal reject rate since the model is focused on the process and not how the Information Seeking Process itself affects the output quality. To be able to understand the impact of information a more detailed model of the information search process is needed. It must describe Before, During and After the process as well as factors influencing the process. These four matters are elaborated in the following sections.

“Before”

What triggers an information search process? Are there specific goals that trigger a need? Are there signs in the assembly environment that trigger the attention, and is the reaction to that attention the start of an information search process?

In all the tasks that are performed at an assembly plant, as well as elsewhere, an overall goal must be accomplished (Vicente, 2006; Mursu et al., 2007). This is not specific to the assembly plant, and there is a strong connection between goals and actions in the decision making process (Thagard and Millgram, 1997). This overall goal can be divided into problems that must be solved and goals to be achieved, and thereby it is possible to divide the overall goal into subgoals, i.e. a goal hierarchy, achievable by, in this case, the assembly personnel (LaBerge, 1995; Thagard and Millgram, 1997). This striving to achieve a goal can be a trigger to start an information search process but there must exist other events (stimuli) in the environment that capture our attention and thereby trigger a search process. According to Badre and Wagner it is a combination of the two (goals and cues/stimuli) in our environment that makes us search for and focus on relevant information (Badre and Wagner, 2007).

“During“

How do human abilities, such as use of memory, attention (active, passive, shared, divided etc.), awareness etc. influence the outcome of an assembly task? Is decoding of information related to the processing, and is data a part of the decoding process?

An information search process can be affected by disturbances from other information sources (“distractors”) in the environment that can affect our attention (Geyer et al., 2008; Narasimhan et al., 2009; Schubö, 2009). The goal of attention, to pay attention (knowing where and when) (Coull and Nobre, 1998), is to, according to LaBerge (1995), support the human in three ways: accuracy, speed, and maintenance of mental processing. However, it also supports the remembering of events in a better way and increases the awareness of occurring events (Pashler and Johnston, 1998). This is done by focusing the neural resources for recognition on a specific area in the context (Olshausen et al., 1993). The interesting parts here are attention and awareness. Is it possible that attention and awareness are two major components during a search process?

“After”

Is there a connection between the internal reject rate and the outcome and results from the information search process? Are the process and human errors connected in a way that influences the number of internal rejects?

It is problematic to divide the action of an information search process from the main process, i.e. to assemble. It is likely that the two exist in parallel. According to Sireteanu and Rettenbach (1994) it is possible for initial serial tasks to become parallel due to a training effect. It is therefore likely that a skilled assembly worker can assemble and search for information at the same time. However, if an assembly task is to be successful, a correct information search process must precede the assembly task, otherwise the outcome of that assembly process could be just pure luck since it is based on presumptions. It is likely that this process is continued during the entire assembly task, and that it starts over and over again. It starts with an observation and ends with an act, but continues once again with an observation.

“Influencing factors”

Human limitations, human demands (psychological and physiological) in the assembly environment can affect the performance of an assembly task in terms of quality and productivity.

“Human errors can only be defined with reference to human intentions or expectations” (Pennathur and Mital, 2003). The expectation of the outcome of an assembly task, or any task at all, must be that the product produced within the assembly process should possess the right quality (Vicente, 2006). There is more than one stakeholder when it comes to defining what is the right quality (Sörqvist, 1998). For the time being, the definition of the right quality is a product that is not an internal reject, i.e. it is assembled according to specifications. The intention of an information search process is to create knowledge that makes it possible for the personnel to perform an action, or at least gain knowledge, that leads to the fulfilment of the expectations (Tang and Solomon, 1998; Vicente, 2006).

It is possible, from the previous discussion, to identify some issues that can have an effect on the information search process and thereby the internal reject rate. These issues are:

- Attention¹: How does attention relate to the outcome of an assembly process?
 - Is a goal and/or stimulus a predecessor to an information search process? If yes, in what way?
- Awareness²: Can awareness of an action influence the outcome of an assembly process?
- Human errors: Without doubt, an internal reject can be a product of a human error. However, there are different types of human errors. Thus, the result may be the same (an internal reject) but the cause may vary.
- Information and data: What role does the information itself play? Is it possible that there are differences in data and information and that the two influence the search process in a negative way?

In Section 2.2, the industrial related research context and its needs are presented. The existing problems are addressed and form a foundation for the literature survey. In later sections the process presented in Figure 2.2 will be further developed as a result of the knowledge gained from the literature survey. This detailed process is utilised and evaluated during the case studies (Chapter 3).

¹ Attention: “the action of turning one’s mind to (somebody/something) or noticing (somebody/something)” Hornby, A. S. (1997). Oxford Advanced Learner’s Dictionary of Current English. In Crowther, J. (ed.). Oxford: Oxford University Press.

² Aware: “having knowledge of (somebody/something)” Ibid.

2.2 VOLVO POWERTRAIN

The production lines at Volvo Powertrain Skövde are divided into parallel flows, the *physical flow* and the *information flow*. The number of parts and amount of information attached to a specific product (engine in this case) increases during the refinement of the product. The information provided to the assembly personnel varies and is connected to specific stations and specific tasks. In the following section a brief description is presented with the aim of illustrating the environment and the need for information that the assembly process creates.

2.2.1 Physical flow

The majority of the engines are assembled in a high volume main flow, (Figure 2.5 and 2.6. A larger view can be found in Appendix A). In this main flow a high volume product is assembled, but there are elements of low volume products assembled in the same product flow. High volume products are engine types that are produced in high numbers. A low volume product is an engine assembled with less frequency. These definitions are subjective and can be seen as being defined based on the assembly line characteristics and the products assembled in that specific assembly line. The assembly is divided into two major parts: *basic assembly* and *final assembly*.

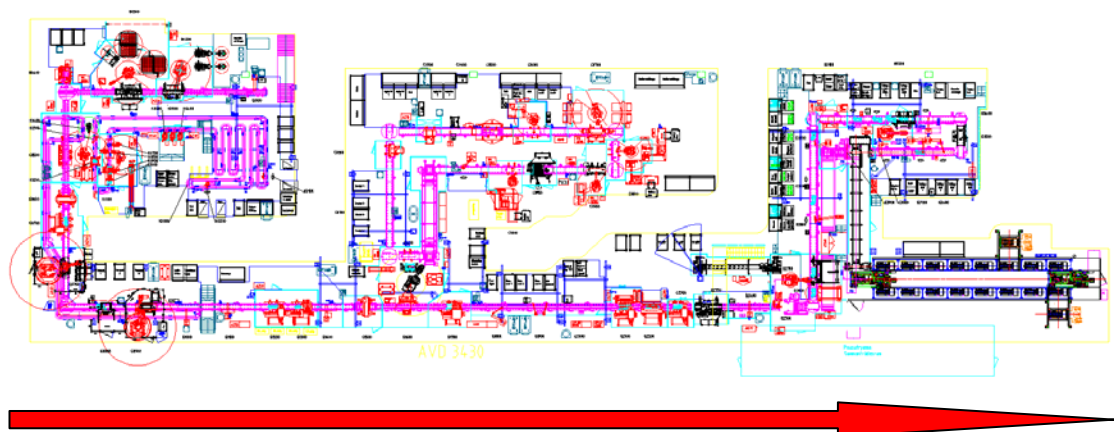


Figure 2.5: Engine line, basic assembly.

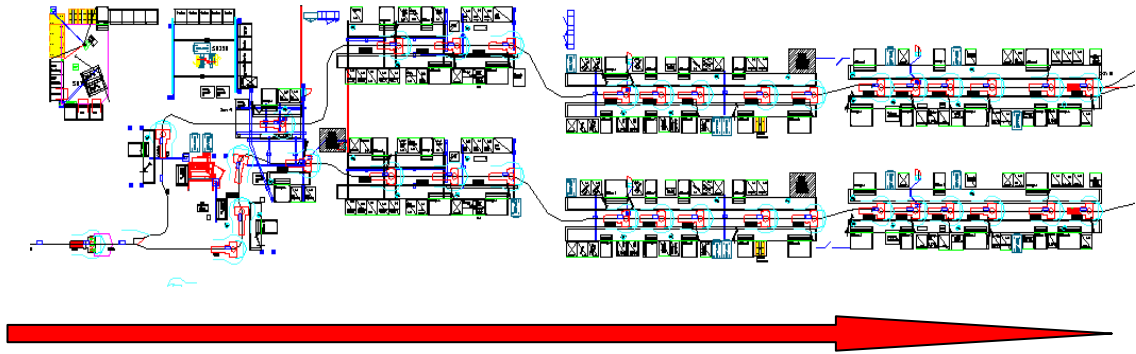


Figure 2.6: Engine line, final assembly.

In basic assembly, there are elements of manual assembly but the major part of the assembly is automated.

At this stage of the assembly process the variations of the product are few due to economical and production complexity reasons. At the beginning of the assembly line only one engine block variant is used. At the first station an engine block is allocated by a customer order. This is done by identification of the block and a registration for the specific order. At the same time an order is sent to a pre-assembly station for pistons, connecting rods and to the cylinder head assembly line. The variety of pistons and rods are limited as well as the cylinder heads, but they still add complexity to the product. The product is finalised in this first phase and stored in a short-term storage. At this point the product is rather complex but the information connected to the individual engine is limited.

In final assembly most of the work is manual. This calls for differences in the information flow. Compared with basic assembly, in the final assembly much of the information is there as a support for the personnel, i.e. the information is visual on a computer screen or on an instruction sheet (Figure 2.7 and 2.8).



Figure 2.7: Example of one of the products, part of the information system (the computer screen on top of the carrier) and the carrier.



Figure 2.8: Example of a final assembly line.

The assembly line is divided into approximately twenty-three assembly stations (the layout is dynamic over time, so the total number of assembly stations can vary).

The work process for the assembly personnel starts typically with a carrier arriving at an assembly station (Figure 2.9).

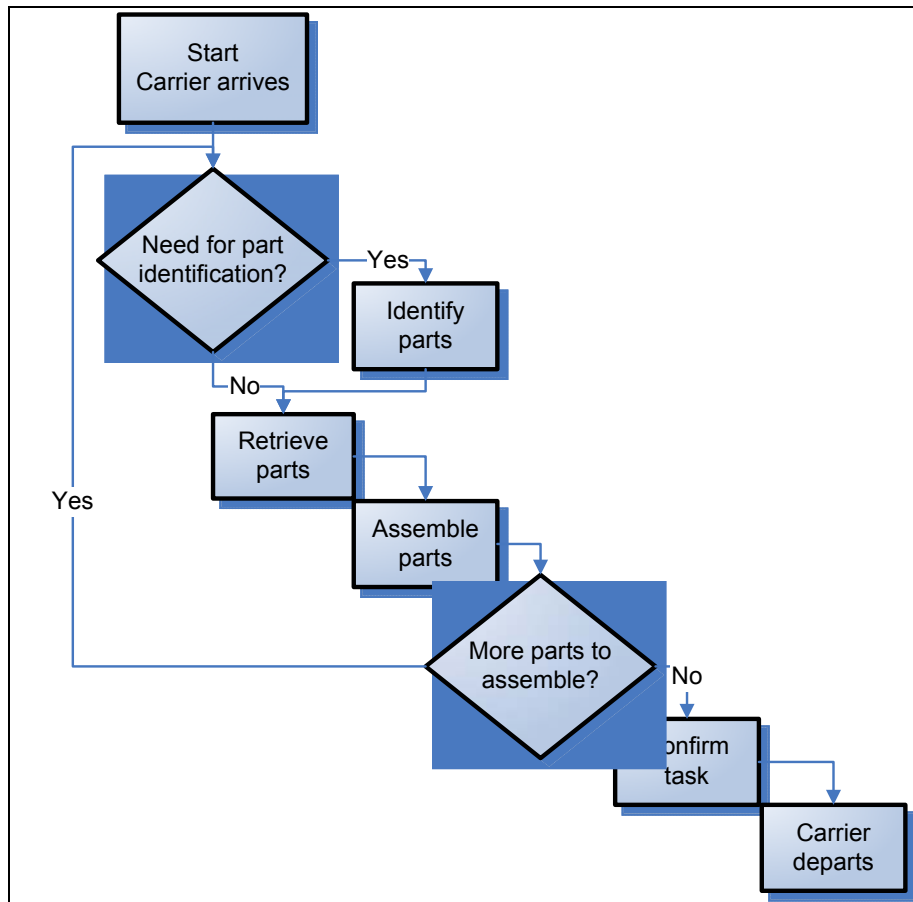


Figure 2.9: Assembly work process.

This process starts over approximately every seven minutes, i.e. every seventh minute a new carrier arrives at an assembly station and the assembly process starts over again.

At the beginning of the final assembly line the engine is mounted on a carrier by an automated process. At the same time the data gathered during the basic assembly stage is uploaded to the mainframe, and information regarding the engine is downloaded to the carrier so that the information needed can be presented on the computer screen attached to the carrier. During the carrier's movement in the assembly line the information is updated at each station.

2.2.2 Information flow

The presence of low volume products within the same assembly line demands a dynamic interface and a dynamic flow concerning information transfer for individual engines. The character of this information can for example be parts to assemble on the specific engine, but it can also be information regarding how to assemble the engine.

The amount of information, connected to a specific individual engine, increases during the process of value adding activities. At the beginning of the assembly process, basic assembly, the variants are kept to low and the major reason for this are commonality demands that previous machining processes put on product design from an economical perspective.

The effect of this is the low variant range in the beginning of the assembly process that leads, according to the production technicians at the assembly plant, to the following two major effects:

- Flexibility: By keeping the variants to a few at the beginning of the assembly process a more flexible production process can be created. The parts that create a variant should hence be assembled as late as possible during the process.
- Simplicity: By keeping the variants to low, the production process can be more simplified.

Accordingly, as the product complexity increases at the later stages of the assembly process, the need for more information increases.

The user interfaces in basic assembly are rather simplified. A large amount of the information in basic assembly is not visual for the personnel. The main part of the data and information that exists or is created in basic assembly is connected to the automated process, i.e. robots etc. This information is rather similar to that used in final assembly but is not visualised in the same way. Obviously, the information is used for example by maintenance personnel, but they are not considered in this research. Typical information in basic assembly is mainly:

- Robot programs: Robot trajectories are information used by the robots. What trajectory to be used is controlled by the product variant. After the system has identified the variant, the robot decides what program is to be used for that particular engine individual.

- Control instructions: Control instructions are used by the personnel as a support in, for example the quality work.
- Assembly instructions: What to assemble. Information for the assembly personnel. This is the information used by the personnel to identify the variant and to identify what part to assemble on the individual engine.
- Data from process: This data is not visual to the personnel, but can be viewed on demand. Typical information is process data, for example cycle time, process status, error codes, etc.
- Product data: Data created during the basic assembly process. The data is stored in an escort memory³ during the process. The data is read from the escort memory early in the final assembly process and is sent to a mainframe. This data is connected to a specific individual engine and follows the engine during the whole assembly process.

In the final assembly area the data and information have a different character. In basic assembly the focus is to provide the automated process with the data and information needed, whereas in final assembly the focus is on the assembly workers and their needs. The data/information is mostly viewed via the computer screens, in some cases attached to the carriers, and in other cases situated within the workstation. Instructions on how to assemble the parts on the engine are distributed in paper form and each station has its specific instructions. These instructions only exist in the assembly context in paper form.

³ An escort memory is a data storage device attached to a product. It is possible to read and store data from and to the device. This creates the possibility to store data connected to a product during the manufacturing process. This data can then be uploaded to a database and be used for example when traceability is needed.

Header	Qty.	Instruction text	OP1	OP2	OP3
21020476 SERVOPUMP	1				
977030 O-RING	1				
946671 FLÄNSSKRUV M8*30	3				
Kolla flankspel på servohjulet		Enl. instr. 430arif8			
21023285 HUS.BR.FILTER	1			X 8	
946671 FLÄNSSKRUV M8*30	3				
20866609 BR.RÖR, MAIN FILTER-CYL.H	1	Bakom insug			
949747 KLAMMA	3	Till br.rör			

Figure 2.10: Example showing the information provided via the IT-system.

The main information provider is the IT-system, i.e. the computer screens (Figure 2.10).

The information provided via the IT-system has three main purposes:

- Support the personnel in the decision making process regarding *what* to assemble in a specific assembly station and on what engine. That is, what specific part does an engine require.
- Support the personnel regarding the assembly process. *How* an individual engine should be assembled.
- Support the personnel regarding *when*, in what order, they should assembly the parts.

The information provided to support the decision regarding *what* to assemble focuses mainly on providing part numbers and part names (Figure 2.10). The information on the computer screen is updated as the engine arrives at the workstation. The part numbers are presented to the personnel with the purpose of aiding them in the decision making process regarding what to assemble. The part number is used on the material shelf as well (Figure 2.10) so that the personnel can find the right parts. The information provided by the information system does not support the assembler in finding the part. This is part of

the workstation training and the personnel need to learn by heart where to find the part and the part number is there to help them verify that they have found and picked the right part.



Figure 2.11: Example from a material shelf front. The part number is present on both the box containing the part and on the material shelf front itself.

The information on *how* to assemble the parts is also provided, in some sense, at the same time as the part number is presented (Figure 2.10). The system provides information to the personnel on what order the parts should be assembled and in what order the tasks, for example tightening of bolts, should be performed. Not all the steps in the processes are presented and some process information is provided via paper-based instructions located near the personnel. An example of information not presented is the orientation of hose clips as this is something that the personnel need to learn. They can also use the paper-based instructions during the assembly process to refresh their memory.

2.2.3 Parameters affecting assembly complexity

Some parameters have been identified that influence the production complexity. For some parameters it is possible to see distinct trends that support this. The data shown as trends in Figure 2.12 and Figure 2.13 was gathered at the specific plant. This is common production and human resource data that the plant management use in their daily work.

In Figure 2.12 the increased trend for two important parameters are plotted. The number of engines produced and the number of design change notes (DCN)⁴ are parameters that can directly affect the assembly personnel and their workload. The number of DCN per year creates a much more complex work environment by its nature. The trend for the two parameters has developed in the last ten years and the management predict that this trend will continue into the future.

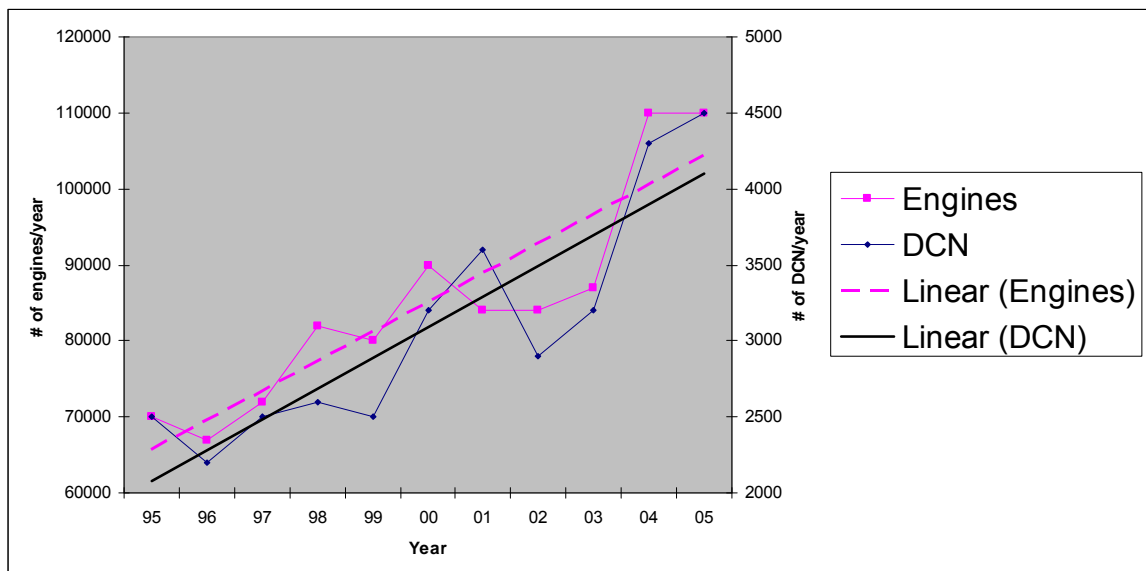


Figure 2.12: Trend regarding number of engines and design change notes per year.

⁴ A design change note (DCN) is a change in the engine setup, e.g. a new or a changed part that will produce a new part number or a new part. These changes can sometimes create a need for a new presentation of the assembly parts in a specific assembly station. These changes can more or less affect the assembler, in some cases the changes are so small that the assembler is not affected in any way, and sometimes the change can cause a rebuild of parts of the assembly line.

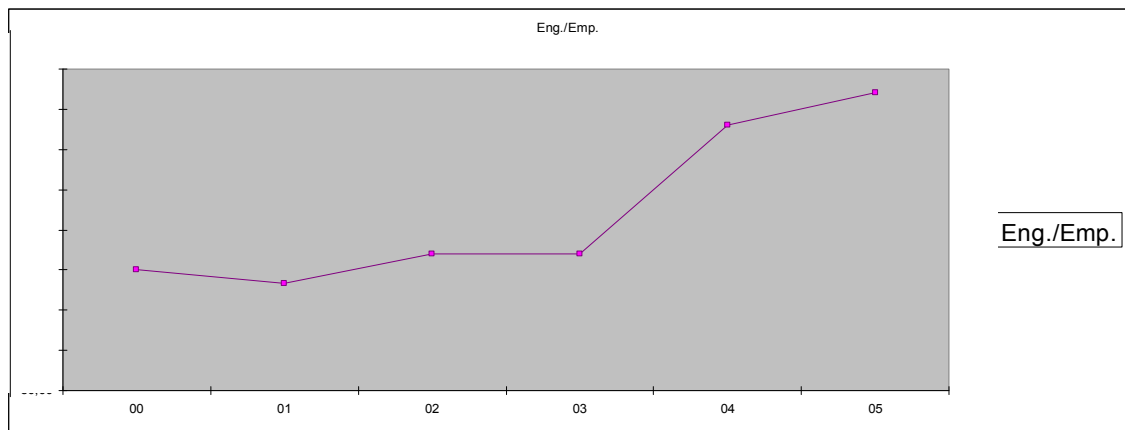


Figure 2.13: Trend regarding engines produced per employee per year (Values on the vertical axis are absent due to company confidentiality).

Figure 2.13 shows how productivity has increased for the five years 2000 to 2005. The trend in productivity is calculated by the management to continue or increase in the future. Different means, for example new technology, will make this possible but it will also create a higher demand on the production systems and thereby on the information systems as well as on people.

In an initial study performed at the company some parameters were investigated and analysed (Bäckstrand et al., 2005a). Three of them were:

- Volume.
- Time and event.
- New employees.

“Time and event” and their influence on information use and quality will be elaborated further in Chapter 3.

2.2.4 Information use

An advanced information system, combined with more traditional information providers such as paper instructions etc., is a powerful tool when it comes to providing data and information to the end user and is sometimes a necessity in a complex assembly environment (Reed, 2001; Greenough and Tjahjono, 2007). It should rapidly provide the user with correct information/data so that the user has the support he or she needs to fulfil a specific task with the right quality (Dencker et al., 1999; Greenough et al., 2001). As it is, the information use is not optimised in the specific plant. The indicator of this is the number of internal rejects caused by “wrong part assembled” and “part missing”, see Section 1.2. These two quality categories are believed to be influenced by how the assembly personnel interact with the different parts of the information system.

2.2.5 Quality definitions

A fundamental part of the quality work is mapping of quality problems. This can be done in different ways but there are some stages that have to be part of the quality process. They are (Sörqvist, 1998):

- Preparations.
- Planning.
- Execution.
- Follow-up.

These four steps represent a standard way of working with quality. The interesting part for this work is not the process itself; instead it is the different types of quality problems and their definitions. These definitions are a necessary part of the quality work and create a possibility to trace the quality problem back to its origin. Once the origin is found, the work of finding the root cause can start.

There are approximately 75 different types of quality faults defined related to final assembly at the specific company. Three of them are of particular interest and they are:

- Component missing (fault code: 141).
- Wrong component assembled (fault code: 142).
- Extra component assembled (fault code: 144).

These three faults are believed by the author to be connected to an assembly error that is related to a situation where the assembler does not perceive and use the information presented via the information system in the way expected. They also together are the third highest cause of internal rejects at the plant. This will be further elaborated in Section 2.4.3 and 2.4.7.

2.2.6 Discussion

The work environment at the plant is rather complex, similar to many other assembly plants. The interesting part here is the combination of product complexity, changes in the work environment and the internal reject rate. This combination creates a demand on the information in the work context and this demand is of relevance within this work. The conclusion from the analysis of the work environment is that the information flow to and from the assembly personnel is complex and it is affected by continuous changes due to process and product changes.

2.3 OTHER PLANTS

Early in the research project eight factory visits took place. These visits were very interesting and an important part of the research, although it was not possible to conduct any in-depth investigations, for example regarding the internal reject rate. When one compares different manufacturers a reflection is that handling of information in an assembly environment is a general problem. During two of the visits there were clear events where errors (internal rejects) had occurred due to wrong part assembled. This indicated that the problems investigated at the reference plant were not isolated events. A conclusion from the visits was that the quality risk connected to the handling of information was present in all factories, as well as the problem of an inefficient use of information.

In at least in two of the plants an interesting event was observed. To be able to handle the parts to assemble the personnel had created new information on their own.

Case 1:

The task was to examine what type (thickness) of shims a specific assembly required, and to assemble the same. The assembler used a template made of steel to measure the thickness needed. The process was divided into:

1. Use the template to measure the thickness needed.
2. Find the shims on the shelves in material storage.
3. Assembly the shims.

The results from the template measurement were presented to the assembler in the form of parts of millimetres, i.e. 0.05; 0.10; 0.15 etc. This information then had to be transformed to a part number. This required an instruction sheet. After a while, the assemblers will of course use their knowledge regarding what measurement connects to a specific part number. The interesting aspect in this case is that instead of using the instructions the personnel had created new information providers. The solution was that the personnel made their own information by providing marker pen markings on the plastic containers that contained the shims. By doing this they would not need to use the part numbers provided by the instruction sheets. This can be seen as a sign of creativity, but the problem is that by creating their own information flow the official information system was not used and thereby a quality risk was created. It is difficult to trace possible quality problems when the personnel use an unofficial information provider.

Case 2:

Assembly of air tanks. This case has similarities with the above. As in the previous example the personnel felt a need to create new information and information providers. The assembly process in this case was:

1. Gather information of the final product.
 - a. Find assembly number.
 - b. From assembly number, find part numbers included in the assembly.
2. Gather parts to assembly.
3. Deliver final assembly to next station.

Before they could gather the part, the assemblers created new information in the form of hand printed tape strips that they put on the product. In the next step of the assembly process some of the assemblers had created their own information in book form. In that book they wrote information and instructions that could not be found in the work environment.

From a quality point of view this behaviour is a quality risk. From an economical point of view it is a waste. From a flexibility point of view this behaviour creates an inflexibility due to the fact that it is difficult to move or introduce a person to the assembly area. From a productivity point of view it can reduce productivity because it can affect the time it takes for a person to reach full productivity.

The problems are not always obvious to the management, but can be rather easily spotted when one studies the environment with a focus on information handling. A problem that all the plants have in common is that the information is presented in a way that does not support humans. That is, it is very difficult to understand what to do and what to assemble based on the information presented.

2.4 LITERATURE REVIEW

In this thesis, the focus is on the graphical interface which is one of four main information providers that present or transfer information to the assembly personnel. The information is presented to (or transferred to) the personnel via:

- A graphical interface, a computer monitor: When a carrier arrives at a workstation, the computer monitor is updated with information regarding what part should be assembled at the specific station.
- Paper instructions: Paper instructions are accessible in connection to the workstation. An example of instructions could be the assembly order for different parts.
- Direct communication between colleagues and managers.
- The context, for example parts already assembled on an engine.

The graphical interface and the information present informs the personnel about, among other things, what to assemble, but how does the information affect the persons that are supposed to use it? Earlier in this chapter, an information search process model was presented (Figure 2.2). As previously discussed, these three major components are not enough to describe or to understand the information search process. The main “ingredient” should be the information itself and its definition. It is possible within related literature to find several definitions regarding what is meant by *information*. One relevant issue is the distinction between *data* and *information*, and the importance of such. Is it possible that information presented on a computer screen is data and not information, and if so, does it matter? This is elaborated in Section 2.4.2.

The literature review presents and discusses components within an information search process. The main purpose is to try to find existing theories that can explain the problems connected to the information flow and the internal reject rate.

2.4.1 Background

As mentioned earlier, a common opinion among managers and technicians is that the assembly personnel have all the information needed in their work context. One can always argue if this is a fact or not. On the other hand, if this statement is true there

should not be any errors made because of a lack of information. Still, errors occur that seem to be an effect of a lack of information. How is this possible?

The literature investigation started from a standpoint that states:

- All information needed is available in the work context.
- The personnel always strive to assemble the product in a correct way.
- The personnel have the skills needed to assemble the product in a correct way.

The first part of the standpoint had to be investigated within the final assembly area to confirm that this was indeed the case. The investigation performed by the researcher showed that yes, all information existed. The investigation also revealed that there were some questions regarding how this information was handled by the assembly personnel. By handled, the researcher means that if a process exists that defines and explains how a human makes decisions leading to an execution of an action then the process should explain how the decision-making process is supported by the information presented to and used by the assembly personnel. To be able to make decisions based on information a basic criterion is to understand. To be able to draw any conclusions from information one has to understand the meaning. This made it relevant to investigate what is *information*. Is it possible that what is information for one process, e.g. assembly, quality control etc., is not for another, and if so, if it is not information what is it?

An interesting research field identified is Information Literacy. The term literacy can be defined according to Oxford Advanced Learner's Dictionary (1995) as the “ability to read and write” and information literacy can be described according to Julien and Barker (2009) as “*the set of skills required to identify information sources, access information, evaluate it, and use it effectively, efficiently, and ethically*”. Information Literacy originating from the library profession in general and bibliography in particular, and it has produced conceptual models for information seeking and retrieval (Marcum, 2002). One common standpoint for these models, for example (Kuhlthau et al., 2008), is that they are based on:

- A subjective opinion (by the one that searches for information) that a gap in knowledge can be filled by information.
- That a person actively searches for information; that a need exists.

Carol Kuhlthau presents an Information Search Process (for example (Kuhlthau et al., 2008)) that she applies to students and their search for information connected to specific student assignments. This search process can be applied to this work as well. It is divided into five stages, briefly presented here:

- Initiation: At this stage an assignment is announced.
- Selection: A topic is selected by the student.
- Exploration: Explore information to learn about the topic.
- Formulation: At this stage the student forms a focus, for example a hypothesis or an angle.
- Collection: In stage five the student collects information on their focus.
- Preparation: This stage prepares the students to write.

The process includes parts that are of interest, but it can not be directly connected to the output quality from an assembly process. It includes all the components necessary, although on a very high level, for a successful search but it only handles the “During” stage of the model presented in Figure 2.4.

The quality definition presented in Section 2.2.5 for one of the internal rejects, “Wrong components assembled”, indicates that the personnel have:

1. Not observed the information presented.
2. Misinterpreted the information.
3. Used the wrong information sources.
4. Intentionally neglected the message.

“Not observed the information presented” should be an effect of a non-started information search process or at least a search process that relies on information provided from an external source, and not an internal memory source. And a non-observation of external information should increase the risk that one assembles the wrong part.

This reasoning indicates that before one can start an information search process, one has to be aware of the fact that the need for information exists and that this information is crucial for the output quality of an assembled product. If one fails to observe the information presented, the other problems (2-4 listed previously) will not occur, so the

focus at this stage is to understand what starts or does not start the information search process.

This conclusion highlights that there must be something missing in the process described by Kuhlthau, at least from a general perspective. The purpose, at this stage, is not to evaluate if the Kuhlthau process is correct or relevant in this context, it describes very well how students work. The purpose is to describe the reasoning, conclusions and assumptions that have been made as a preparation phase for the literature review. A reflection after studying information search processes was that it seemed that these processes all relied on the idea that a user actively searches for information, for example a student searching for information for an assignment, a person trying to use an ATM (automated teller machine) etc. Based on this argument, it seems that this way of using information is not applicable in the research environment. The reason for this is that although the information is sometimes hard to understand, it is present in the work context. The conclusion is that there must be something that starts an information search process and if this is not present the affect is that no information is “consumed” and this can lead to an internal reject that had the effect that parts are missing on the product, or that the wrong parts were assembled. It seems that there are some keywords at this stage that have to be understood better:

- Active information searching and the opposite, passive information search.
- Attention. Can attention affect how a person perceive, observe, use etc. information? And can this be connected to a quality output?

It seems that being active when one searches for information can be a key issue, but how does one get active, and is it possible to be active all the time? Is it possible that an assembly worker searches for information during an eight hour shift, and if so, are there any drawbacks? The first step in the literature review is to investigate if there is a difference in actively and passively searching for information (a remark is that the conclusion was that if active search for information existed, then passive search should exist at least to some extent) and if there is a difference in how the two affect the information search process. This investigation leads to a review of Information Behaviour which discusses passive attention, passive and active search, and ongoing search. Based on this review, some interesting suggestions were made:

- Passive attention can be seen as an activity where information acquisition may take place without intentionally seeking it, such as watching television, listening to the radio or driving a car.
- Passive searches are “those occasions when one type of search (or other behaviour) results in the acquisition of information that happens to be relevant to the individual” (Wilson, 1997). The conclusion from this remark is that in passive mode one does not search for information, but that the acquisition of relevant or interesting information is a happening, and that it is not from the beginning of an active activity.
- Active search is when an individual searches for information that is important or relevant to them.
- Ongoing search is when an active search is established and one has a basic framework regarding knowledge, ideas etc. but where occasional continuing search is carried out to update or expand one’s framework. An example could be getting more knowledge regarding a consumer product were one planning a purchase and searching the internet for more information regarding that specific product.

These points suggest that there are active and passive ways to attend to information. This might be rather obvious to the majority, but nevertheless it is important that it is known and defined. The interesting part here is that active and passive indicate that something must start an information search process, some kind of *trigger*. This trigger might change the search and attention from passive to active mode and thereby start the information search process. If this trigger starts a search process what happens when it is absent?

When the literature survey started, there were some keywords identified that were the output of the investigations that, one could call a pre-literature study, that started with the information search process defined by Kuhlthau (2008). This definition was later abandoned for the definition provided by Wilson (1997). This together with the question of how it was possible to make errors, internal rejects, despite the fact that all information existed in the work context was the foundation for the literature survey.

The keywords for the literature study were:

- Information and data.
- Active and passive information seeking.
- Active and passive attention.

- Triggers.
- Quality, the effect on.

2.4.2 Defining data and information

Data

The sentence below is a hexadecimal version of ASCII (American Standard Code for Information Interchange) code.

*“68656C6C6F20776F726C64”*⁵

This code is a representation of data and has to be transformed into information, in this case into words, before one can understand the meaning of the sentence. This type of code is used in computers and is transformed into words, for example presented on our computer screens. This is just an example to show the difference between data and information.

It is obvious that the data needs to be processed before it is understandable. This process is central for the transformation of data into meaningful information.

Data can be seen as:

“A representation of facts, conception or instruction in a form suitable for transfer, interpretation, or processing by humans or machines (Nationalencyklopedin, 2005). (In this case, Information can be seen as the meaning of data, which requires a receiver with the ability for data interpretation).

According to Meadow et al. (1997) data can be seen as “a less meaningful message” and more meaningful messages “are called information”.

Meadow et al. (1997) have a notation for data similar to the one regarding information. According to that, data can be seen as:

1. *”A set of symbols in which the individual symbols have a potential for meaning but may not be meaningful to a given recipient.”*

⁵ “68656C6C6F20776F726C64” transformed gives “hello world”.

2. ”A set of symbols in which the individual symbols are known, but the combination is meaningless: the semiotics are known, the syntactics are not.”
3. “Understandable symbols rejected by the recipient as being of no interest or value, typically because they are redundant or disbelieved.”

Altar (1999) supports the opinion of Meadow et al. by stating that “Data are facts, images or sounds that may or may not be pertinent or useful for a particular task.” In this thesis data will be regarded similarly to the notation by Meadow et al. presented in this chapter. That is, data can be seen as a set of symbols that have a potential for meaning but the symbols must be processed into information to create meaning for the receiver.

Information

To be able to discuss information it is important to have a clear definition in mind. When one reads some of the literature regarding the definition of information one realizes that there are a number of different definitions of information.

In an early statement regarding information, as well as communication, Hartley (1927) states that there must be symbols “*which by general agreement convey certain meaning to the parties communicating*”. Therefore, it is important that the parts that communicate, for example sender and receiver, “talk the same language”, but also that they have a common concept (Kilov and Sack, 2009). Hartley writes, “*for two persons who speak different languages the number of symbols available is negligible as compared with those persons who speak the same language*”. If this thesis were written in Swedish and not in English, it would be very hard for a person not capable of reading Swedish to understand it. This can also be a human cognition ability according to Lakusta and Landau (2005) and is a fundamental aspect of our capacity to represent events in our interaction with the world. And of course, if we send information to a receiver who does not understand the symbols, it has no meaning to the receiver (Miller et al., 2001), so this cannot be regarded as information. But, it might be defined as *Data*.

This is one important part of the definition of information and it is applicable to both human and machine. However, there must be something more than just “talk the same language”. To visualise the information flow a basic model can be used, see Figure 2.14. This model provides a view of a high level information flow at the final assembly plant.

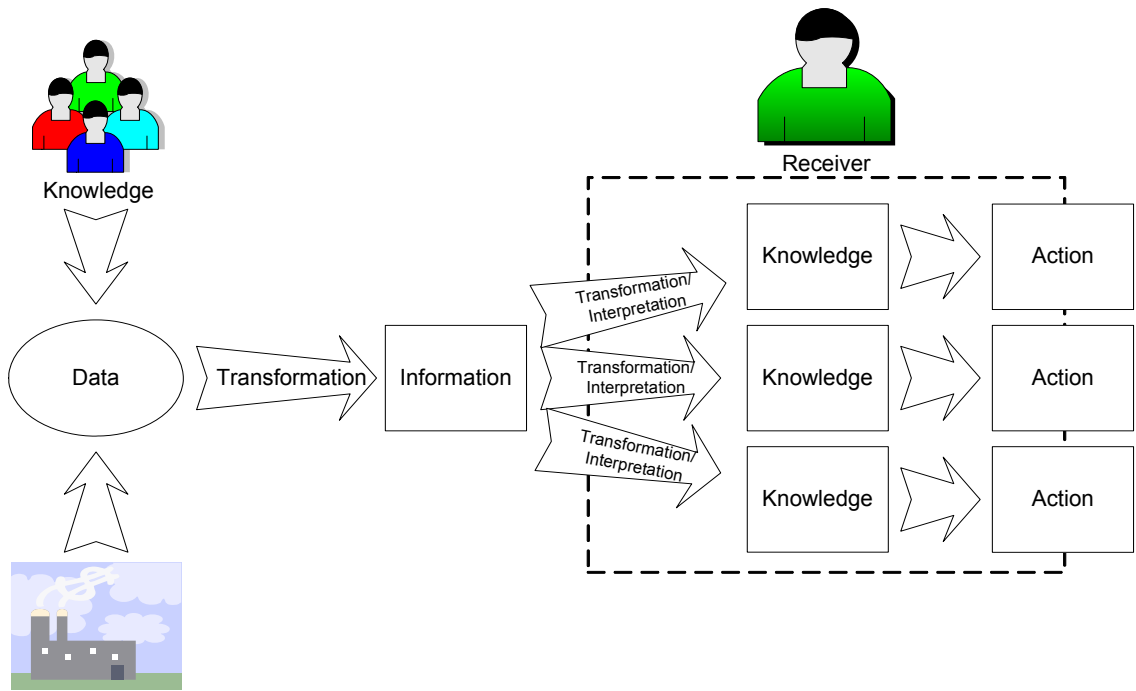


Figure 2.14: Visualisation of information flow from sender to receiver.

This model will be used in this section as a foundation for the discussions regarding the definition of data, information, knowledge etc. and is influenced by Shannon’s (channel) model, see Figure 2.15, of a communication system (Shannon and Weaver, 1963; Losee, 1990) and Hartley’s distortion figure (Hartley, 1927).

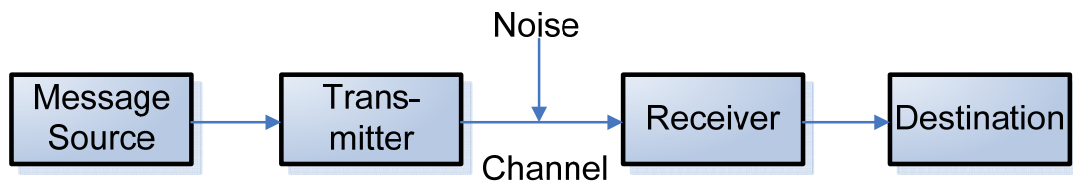


Figure 2.15: Shannon’s channel model. Based on Shannon and Weaver (1963).

As discussed earlier one important part of information is a mutual foundation of understanding, for example language (Millikan, 2001). In the paper *Measuring the Impact of Information: Defining the Concepts.* Meadow et al. (1997), state that information contains a message that is understood by the receiver and thereby changes the receiver’s knowledge base. A statement is also supported by Brandt and Uden (2003). The keywords in this statement are “understood”, “changes” and “knowledge base”. In the same paper Meadow et al. present four definitions of information. According to their

definitions there are some things that must be discussed one-by-one and can be related to for example “Data”, “Situation Awareness” etc. They are:

1. Information: *“Messages that exist but are not necessarily sent or received by a given recipient, such as books, unread, in a library, yet deemed significant by someone. In many minds there is no difference between data and this meaning of information.”*
2. Information: *“A message sent to a destination or received by a destination, but not evaluated or understood. The distinction between this and the first definition is small. This definition implies that the message is in some way called to a user's attention, but not assimilated by that person.”*
3. Information: *“A message understood by the recipient and which changes that person's knowledge base.”*
4. Information: *“Information is the process of converting received messages, data, signs, or signals into knowledge.”*

If one looks at Figure 2.14 and moves in the figure from right to left it is possible to find some similarities and differences compared with the Meadow et al. definition of information. Meadow et al state that information is deemed significant for someone. In Figure 2.14 information is important because it creates a change in the knowledge base that can cause a reaction/action from the receiver. One of the problems in Meadow et al.'s statements is that in part 4, they state that “Information is the process of converting **received** messages.....”, and in part 1 they state that “Messages that exist but are not necessarily sent or **received** by a given recipient.....”. So, in part 4, information is a process and in part 1 it can be a physical object that no receiver has yet received. Is this important? *Yes*, it can be of great importance, at least in this context, in a manufacturing environment. If one looks at Figure 2.14 again it is possible to see that if the receiver has not yet received any information it is not possible to change its knowledge base and therefore it is not likely that there will be any reaction/action. In a worst case, an action will take place, but is this action a right action? This calls for a definition of information that depends on, at least, two perspectives, a sender perspective and a receiver perspective. If one reads part 3 of Meadow et al.'s definition, there is another problem that is important to have in mind, “understood”. This implies that to be able to change someone's knowledge base it is important that this “someone” understands the

information observed (Losee, 1997). Understanding is one thing that is part of what Meadow et al. state as; “speak the same language” which can create understanding between sender and receiver. But there must be more than just the language that create and influence “understanding”. In part 4 of Meadow et al.’s (1997) definition they write about a process, that Information is a process, for converting data into knowledge.

For a receiver to change its knowledge base some fundamental conditions are important. These are:

- Awareness of a need for information. A receiver must be aware of that he/she should actively search for or receive information (Kelly and Fu, 2007; Yoon 2007).
- Perceive and observe. Perceiving the presence of information is a step towards observation (Losee, 1997).
- Understanding of the information:
 - Language (Hartley, 1927) .
 - In the context (Sawaragi and Murasawa, 2001).
- Interpretation of what action the sender had in mind when it created the information. If the interpretation is wrong, it is likely that the action carried out by the receiver is not the one that the sender/creator predicted. Machlup (1980) and Gustavsson (2000) call this interpretation *a creation of knowledge* in the receiver’s mind.
- Update knowledge base. At this stage it can be vital to talk about “receiver believed knowledge” (Machlup, 1980). Receiver knowledge is not necessarily the same as sender knowledge, although the receiver might think it is.
- Action. Act or react according to the information presented (Endsley, 2000b; Sawaragi and Murasawa, 2001). Obviously, at this stage the knowledge that the receiver possesses might lead to a non-reaction.

From the discussion above is it possible to define information as:

Information: A message that when **received**, **read**, and **interpreted** by a recipient **creates** knowledge or **changes** the receiver’s knowledge base so that an **action** can be committed by the receiver that is **predicted** by the sender.

2.4.3 Situation Awareness

When looking at Figure 2.2 it is possible to see that there is some kind of receiver interface present. This interface is the connection between the sender and the receiver. Before looking at the specific problem itself it is important to discuss “understanding” and “awareness”. If one looks at part 3 of Meadow et al’s (1997) definition of information:

Information: “A message understood by the recipient and which changes that person's knowledge base.” and the definition in the later part of Section 2.4.2, a rather important part of information “handling”, for example receiving, can be identified. The “receiving” of the information is of course an important part of an information flow. According to Figure 2.14, the receiver must interpret the information so that an appropriate action can take place. That is, one has to comprehend the meaning of the information so that an action can take place, and one has to understand how this action will affect the future status of the product.

Endsley (1996) has formalised/defined this as Situation Awareness (SA):

“the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future”.

Before it is possible to receive information, one must perceive it (Rookes and Willson, 2000; Sheridan, 2002; Feng et al., 2009). Endsley, in the paper “*Automation and Situation Awareness*” (Endsley, 1996) stresses a very important issue regarding information and information receivers. There are problems connected to production systems as well as a pilot’s work environment, i.e. the cockpit, and this is active and passive attention. This together with active and passive information seeking, passive and active reception are believed to be the main contributors to the problems in the specific work environment (Machlup, 1980; Wilson, 2000; Bäckstrand et al., 2005a).

In short (a more detailed description of attention is presented in Section 2.4.6), active and passive attention can be explained as:

- Active attention: Is connected to actively processing information.
- Passive attention: For example a process operator whose function is to observe an automated process.

According to Endsley (1999) passive attention is a state that can affect the ability “to correctly integrate or comprehend information”. One interesting part in her discussion is that in a study regarding an automobile navigation task she found that perceiving information/data correctly was affected negatively if a receiver was in a “passive attention” state. The receiver was still aware of presented data, still capable of perceiving data, but was less effective when it came to comprehending the meaning of data and relating that to the goal of a task or operation.

The next step in SA, if we assume that the receiver has perceived presented information, is to integrate the information in the context or as Endsley (1996) states: “...the comprehension of their meaning and the projection of their status in the near future”.

In Figure 2.16, SA Error Taxonomy, Endsley (2000b) describes problems related to the processing of information by a receiver. If one has perceived the information, the next step is to process the information/data, and thereby change our knowledge base. In level 2 of the taxonomy Endsley states that it is important that a receiver must be able to derive relevant meaning from the data perceived in level 1. There are a number of different reasons why a receiver misinterprets information/data or has problems with finding the most relevant parts among all the data.

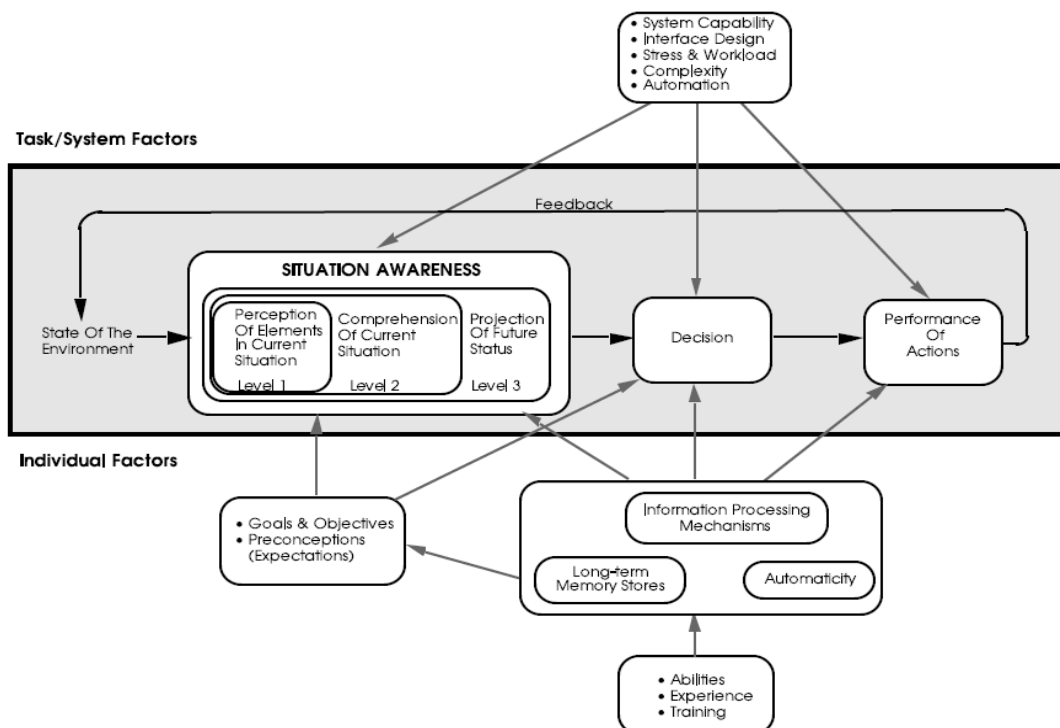


Figure 2.16: Situation Awareness model (Endsley, 2000b).

One reason, according to Endsley, can be a lack of a good receiver Mental Model (Endsley, 2000a). Moray (1998) writes “*A mental model is a mapping of the properties of the task to its representation in the mind of the worker*”. According to Besnard and Greathead (2003) an operator maintains a mental representation of different processes in a system. These incomplete mental representations of the reality, due to the limitations of a human memory, need to be fed and updated by knowledge and available data in the work environment. Other issues concerning mental models include Team Mental Models where Langan-Fox et al. (2001) hypothesise that if a team share a similar mental model, they should be more successful. Using this hypothesis together with Figure 2.16 Endsley’s suggestion regarding mental models could be extended by talking about Team Mental Models, and state that it is possible that sender and receiver in the assembly environment should be seen as a team, and thereby they should/must also share the same team mental model/s.

To summarise Situation Awareness, and using Endsley’s definition it is possible to say that SA deals with:

- Reception of data/information.
- Passive and active attention.
- Mental Models, team and personal.
- Project future state of a system.

2.4.4 Information need and demand

“Structured translation of data into action” (Johnstone and Tate, 2004) to reach a specific goal must be the main focus for the assembly personnel (Wilson, 2006b). This requires that the information is available at the right time in the right place and that the assembly personnel have identified a need for the specific information (Endsley, 2001; Wang and Forgionne, 2006).

In an evaluation of some of the workstations at the specific plant (Bäckstrand et al., 2005a) there were indications that there are problems connected to the distribution of information/data that can be related to what Bäckstrand et al. choose to define as “Delivery Vs. Demand” of information/data.

In a discussion regarding Information Overload, Wilson (2001) refers to a journal paper written by Cacioppo and Petty, “The Need for Cognition” (Cacioppo and Petty,

1982). In this discussion Wilson describes a “computer jargon” that is rather similar to “Delivery vs. Demand” and that is Information Push and Pull. Information Push and Pull or dissemination and acquiring (Rich, 1997) is according to Wilson one factor in the discussions surrounding Information Overload, but it is also a key factor regarding the information flow in the specific assembly plant. In the following discussions the terminology “Delivery” and “Demand” will be used.

Information/data delivery, is according to this author, the event that occurs when a specific type of data/information must be accessible in a specific work environment, for example an assembly workstation, and a *Demand* for information/data occurs when an “object”, in this case one of the assembly personnel, has identified a need for information/data. This need originates from a need to fulfil a goal (Figure 2.17), and maybe the satisfaction of fulfilling the goal (Wilson, 1981; Losee, 1990).

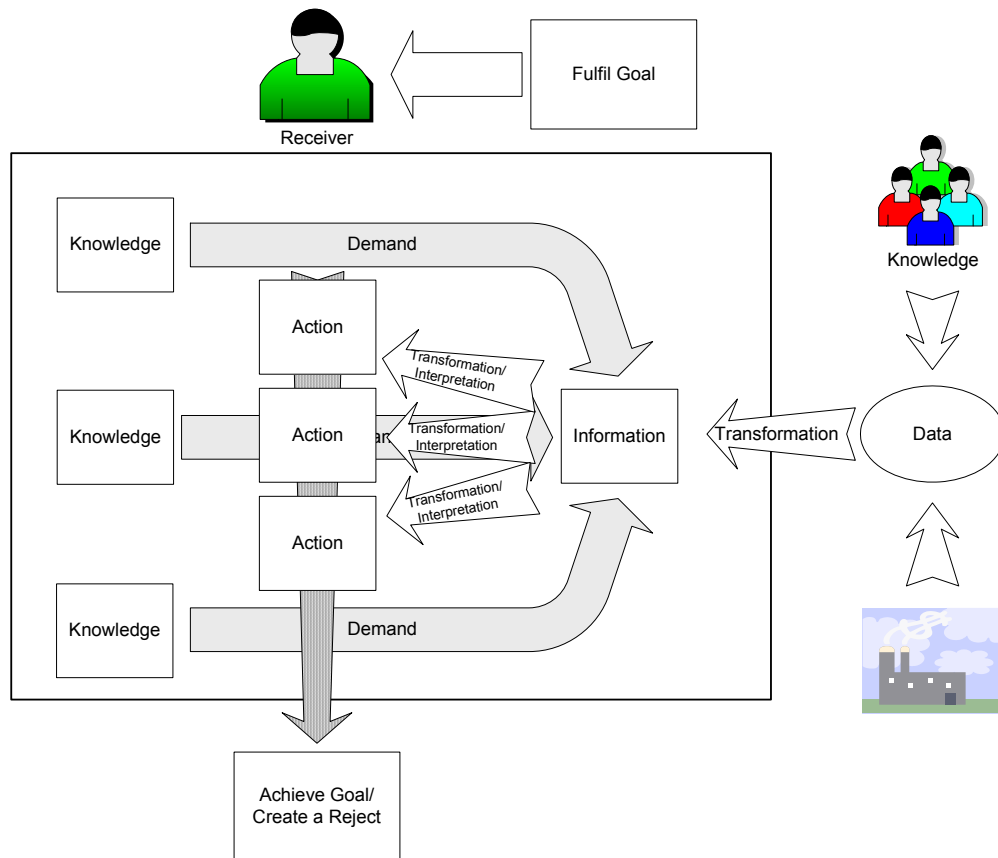


Figure 2.17: Demands and goals (Bäckstrand et al., 2006a).

One of the conclusions, from a evaluation performed by Bäckstrand et al. (2005a), was that events in the work environment started the Information Delivery process, and not an

identified information need from the personnel. These events (some of them) occurred every seventh minute, and this leads to an Information Delivery flow that was/is unique for that specific event. This event by itself would be expected to create an information need, but there are some indications that this is not the case. As discussed earlier in the text a precursor to demand could (must?) be need. Wilson (2006a) states that “need is a subjective experience that occurs only in the mind of a person in need”. According to one of many dictionaries on the internet, need is a target-oriented behaviour that is connected to for example appreciation and security (Nationalencyklopedin, 2005). This raises the question: to be able to create a demand originated from a need a goal must exist. How is this goal formulated and from whom is it originated? Should it be a personal goal? Alternatively, should it be a goal defined by the organisation? If it is a personal goal, how does this goal affect the information demands (Losee, 1990)?

Bäckstrand et al. (2005b) describe in a preparatory work why there is a need for cost calculations in the specific area. This need has created a demand for more data/information. Is this connected to reality for the assembly personnel? According to this author it is, because it builds on the same foundation, or at least it should. The demands for information should follow the same process, despite the difference in goal.

2.4.5 Information Overload

If one assumes that the flow from Sender to Receiver exists, one can also assume that like in a river, the flow of Information can overflow in a specific situation, i.e. the amount of information a receiver has to process is so large or takes so much time to process that it is not possible to process it in time (Himma, 2007). Wilson (2001) defines information overload on a personal level as:

“ a perception on the part of the individual (or observers of that person) that the flows of information associated with work tasks are greater than can be managed effectively, and a perception that overload in this sense creates a degree of stress for which his or her coping strategies are ineffective. ” (Wilson, 2001)

Information Overload can, according to some researchers, occur when a receiver of information receives so much information that it is not possible to manage the information in an effective way (Losee, 1990; Brewster, 1997; Sheridan, 2000; Himma, 2007). This can create a feeling of lack of control and thereby stress (Wickens, 1992;

Bellorini and Decortis, 1995; Edmunds and Morris, 2000). Wickens (1992) as well as Mital et al. (2004) state that there are connections between stress and errors. It seems that stressful situations can create absentmindedness as well as inappropriate coping strategies (Norman, 1990). An important effect of stress can be what Wickens and Hollands (2000) call “*increasing selectivity*”. This selectivity can according to Wickens and Hollands create a perceptual tunnel effect that makes it harder for a human to observe information on the periphery, and thereby makes it more difficult for the user to handle information outside that perceptual tunnel. This filter effect seems not to be an effect entirely of a reduction in spatial visual envelope. Subjective importance and/or priorities seems to be an important part of the filtering.

According to Meadow et al. (Meadow and Weijing, 1997) a message has to have “*been received and understood or appraised*” to be referred to as information, which “*means that we can have data overload, but not information overload.*” They also state that “*if a message must be received in order to constitute information, there cannot be an overload of unreceived data.*” This creates a minor problem in the specific case, the assembly plant, or rather with the hypothesis that tries to explain the problem. According to Meadow and Weijing it is not possible that a person can be overloaded if he or she has not received any data. Still, the assembly personnel have a problem with the handling of data and information, and thereby (sometimes) act in an incorrect way. It is possible that this problem, handling of data/information, has nothing to do with Data/Information Overload, but until a further investigation proves otherwise, overload will be regarded as one of several parameters affecting the handling of data and information.

2.4.6 Attention

Blasch and Plano (2002) present key theories of attention, Four of them are (briefly):

- Early Selection Theory (or the Filter Theory): According to this theory we only take up a small amount of information and this implies that we use limitations and selectivity as a filter. These two considerations are according to Duncan (1995) the core of the filter theory.
- Attenuation Theory: All messages are weighted and priority is given to one that will be received in full and the other messages receive only partial processing (Blasch and Plano, 2002; Hoshino, 2003).

- Late Selection Theory: All messages attended or not, undergo semantic analysis and downstream analysis. The messages are weighted and the key message is determined due to the limitation that makes it possible to respond to only one message at a time (Hoffman, 1998; Pashler and Johnston, 1998; Blasch and Plano, 2002).
- Object Based Theory: Hoshino (2003) states that according to this theory it is not possible to simultaneously perceive more than one object at a time. The visual scene is dissected into distinct objects.

Within this research no effort will be made regarding the theories or the likelihood of their substantial value. The purpose of presenting some of the theories connected to attention is to show that there are different beliefs regarding how humans handle attention and how attention can affect the information search process.

Earlier in this thesis it was stated that “to reach a specific goal must be the main focus for the assembly personnel”. According to Yantis (1998) as well as Blasch and Plano (Yantis, 1998; Blasch and Plano, 2002) there are two ways to control visual attention: top-down (goal driven) or bottom-up (stimulus driven). Attention is said to be goal-driven and stimulus-driven. Yantis (1998) exemplifies the behaviour difference between the two by presenting how a person looks for a particular product in a supermarket:

- Goal-driven (active attention): The product (in Yantis’s example, the product is a cereal) is known to have a specific marker, or a packaging, and one searches for that. This product is likely to be selected by our attention and recognized.
- Stimulus-driven: All the products in a part of an aisle tend to have the same or similar packaging, except one, that seems to “pop-out of the background and draw attention automatically”.

There is more than one issue within the attention field that is of interest to this research. One issue is how cues in our environment affect our attention. Richard et al. (2003) compare goal-driven and stimulus-driven attention and how they are affected by cues and how cues can control our attention regarding both time and space (Table 2.1).

Table 2.1: Cues and their attention control (Richard et al., 2003).

Stimulus-driven Attention Control	Goal-driven Attention Control
Associated with direct cues (a.k.a. peripheral or exogenous cues) that occur directly at a potential target location	Associated with symbolic cues (a.k.a. central or endogenous cues) that indicate a potential target location
Initiated by sensory event, such as the abrupt appearance of a cue or other transients	Initiated by cognitive operations, usually following the interpretation of a symbolic cue's meaning
Effects are rapid and transient, peaking approximately 100 msec after a cue's appearance	Effects are more gradual and sustained, peaking approximately 300 msec after the cue's appearance
Are involuntary because they are minimally influenced by: <ol style="list-style-type: none"> 1. instructions to ignore the cues 2. the predictability (validity) of the cues 	Are voluntary because they are diminished: <ol style="list-style-type: none"> 1. by instructions to ignore the cues or 2. if the cue is not useful to the subject (for example, low cue predictability)

Cues are of interest for more than one reason:

- Their effect on the way that they can help us direct our attention to a location in space where our attention is needed.
- Their ability to help us, during some circumstances, to shift our attention to a place faster and more accurately than uncued locations. That is, if a cereal box in the example has a marker, i.e. a cue, that stands out from the other boxes, it is more likely to be chosen (LaBerge, 1995; Proctor and Dutta, 1995; Yantis, 1998; Richard et al., 2003).
- Their ability to reduce the numbers of stimuli to one (Vierck and Miller, 2005).

Active (Goal-driven) and Passive (Stimulus-driven) Attention

In a previous part of this section, a short definition of Goal-driven and Stimulus-driven attention was presented. There is some difference though between Goal-driven and Active attention and Stimulus-driven and Passive attention. The difference, at least compared with how Yantis (1998) presents it, between goal-driven and active attention is minor, but the difference between Stimulus-driven and Passive attention is of more interest.

Active and passive attention are two ways to classify attention. Active attention is a state that is required of us when we need to detect information in the surroundings for our own purpose. Passive attention is the ability to identify dangerous situations in our surroundings (Kida et al., 2006). The ability to actively detect information in our environment is of great importance in an assembly context. The interesting aspect is whether or not there is a connection between attention and internal rejects. Some of the research regarding active and passive attention has been conducted within neurophysiology, for example about how a somatosensory stimuli⁶ influenced active and passive attention (Kida et al., 2006). In this example the researchers recorded Electroencephalography (EEG) results during the study. The purpose was to investigate if a change in the somatosensories stimulus frequency during active and passive attention tasks affected the EEG. The most interesting part of this research is not the results, higher amplitude (for example a higher brain activity) during active attention tasks, it is parts of the method used in the study. During the study an electrical impulse was given to the subjects left hand fingers via attached ring electrodes. Depending on the task, active or passive (defined by the researchers) the effect on the EEG's amplitude differed. The interesting part is that the electrical impulse triggered an effect on the EEG. This indicates that:

- A trigger, in this case tactile, creates a reaction in our brains.
- Depending on what stage one is in, active or passive, the reactions shown on the EEG are different, higher amplitude for active and lower for passive.

This knowledge can be used in this research in the sense that it is not necessary to study the reaction in the brain while performing active or passive attention tasks. It is also possible to in some sense define active and passive tasks:

⁶ Somatosensory stimulus, in this case was an electronic stimuli delivered to the left hand.

- Active: For example counting or button pressing.
- Passive: For example reading a book.

Kaplan et al. (2006) define attention as “ the process whereby an agent concentrates on some features of the environment to the (relative) exclusion of others.” According to Kaplan et al, this process can occur in two situations: when a salient event, such as a loud noise, triggers the attention, or when one is involved in an intentional directed process, such as climbing a mountain, where one actively selects particular features in the context.

An assembly task according to this definition is an active attention task. This task is a part of a longer assembly sequence containing a number of tasks or activities. The sequence in the research context can typically be divided as showed in Table 2.2. This example is a part of a method instruction for a specific software, AVIX (Solme, 2008), used by the reference company. The definitions in this example are the same as used by the company.

Table 2.2: Typical tasks/activities in an assembly sequence (Solme, 2008).

Activity	Explanation	Comments
Take	When you take things	Take part from e.g. rack
Place	When you prepare things	Place part on product for later mount
Handle	When you prepare things	Sort/prepare before assembly. E.g. handle pipes before assembly
Affix	When tightening, glue, clipping	Tighten screw
Adjust	When something is corrected	Only mount, not tightening
Assemble	When you assemble in right position	Only mount, not tightening
Inspect	When you check an assembly	
Return	When you return things	Return machine
Instruction		Can be first task for each position
Administration	When you document information	Write/stamp info
Wait		When you have to wait for something before you can assembly. Must be between task not as end station
Stop Watch	Used when analyse is impossible	Machine time, etc.
Stop Watch Movements	Used when analyse of movements is impossible	When use lifting tool

These activities can be divided into sub activities such as “Walk”, “Pick”, “Bend” etc. (all the activities can and should be seen as skills, something that we possess).

Some of these activities will be performed automatically, such as walking, reaching, etc. and sometimes information processing is automated (Järvelin and Wilson, 2003). This automatism is strongly connected to active and passive attention. LaBerge and Samuels (1974) state that the “criteria for deciding when a skill or subskill is automatic is that one can complete its processing while attention is directed elsewhere”. This ability, to do something automatically, that the human possesses is interesting and might be a necessity due to the limitations that exist regarding how we use the different attention modes. According to Reason (1990) attention can be seen as work performed on discrete elements in a restricted work space, our working memory. The work uses energy from a

strict limited “pool of attention resources” (Reason, 1990; Wickens, 1992; Downing, 2000; Endsley, 2001; Crawford and Cacioppo, 2002; Niebel and Freivalds, 2003), therefore is it important to use this energy in an optimal way.

If one presumes that passive attention draws less energy from the “pool of attention”, one of the goals with information must be to support the personnel in a way that makes it possible to continue working in a passive attention mode, where the use of skills and subskills is automatic. Norman (1990) describes this kind of automation as a useful advance that can replace tedious or unnecessary tasks and monitoring. This must (if one presumes that the Reason and Norman theories are correct) result in less use of resources. Less use of resources by one process, for example the Information Search process, should make it possible to use the limited resources more effectively (Downing, 2000).

When one is in an active (goal-driven) or passive (stimulus-driven) attention mode, attention is summoned exogenously⁷ (stimulus-driven) or deployed endogenously⁸ (Rafel and Henik, 1994; Coull et al., 2000). Rafel et al. present four properties distinguished by Jonides (1981):



1. Endogenous orienting of attention is vulnerable to the effect of following memory load, whereas exogenous is not affected by such cognitive demands.
2. Endogenous orienting can be suppressed voluntarily, whereas exogenously triggered orienting cannot. This statement is supported by Richard et al. (2003), see Table 2.1.
3. Exogenous orienting is not dependent on the likelihood of a peripheral signal, whereas endogenous cueing is strongly influenced by the subject's expectations.
4. Exogenous signals appear to produce stronger orienting effects (as measured by the size of the validity effects of the precue).

Later in this thesis a case study will be presented that in some senses uses these properties (Section 3.2). The study itself will be presented from a quality impact point-of-view later, but it might be useful to present the connection between attention and that study at this stage.

During that study, an alternative user interface was used. The existing interface (Figure 2.18) uses text as an information provider. It shows to the personnel what part they should assemble and in what sequence they should assemble it.

⁷ Exogenous: from outside, in this case outside the body.

⁸ Endogenous: from inside, in this case the brain.

Header		No.	Instruction text	Bcode	Confirm	Tight	Do Tight
364025		1		✓		✓	x 3
946671	SCREW M8*30	3					
20411113	CONSOLE	1					x 2
1547252	SPACER	1					
1546531	LOCKING SHIM	1					
977977	CLIP	1					
946440	SCREW M8*16	2					
STATION COMPLETED							

STATION COMPLETED :

(F2) Status CTRL (F3) Send Res. (F4) Man Input (F5) Re Do (F6) Man Corr. (F7) Reject (F8) Msgs (F9) OK (F10) Station list

15:28:45:Batch: FType: PgmSetBatch Id: 1 Name: Result: Ok Version: 1.5.5 15:28

Figure 2.18: Example of existing user interface.

The alternative interface used during the case study did not use text as an information provider but instead it used colours. The meaning, the information provided by the different interface, was the same with the difference that the interface using colours did not provide information regarding smaller and common parts, for example screws, it just provided information regarding the different main part, in Figure 2.18 it is the “CONSOLE” that is the main part.

The main goal is unaffected by the different interfaces, i.e. to “assemble parts on engine”. The difference between the two interfaces is how they affect the personnel before, during and after the assembly task and thereby the attention mode and the use of our working memory and the “pool of attention”. So how are the two associated with the different attention modes? Well, this is a little bit tricky due to the small differences that exist regarding how to define active/goal-driven/ endogenous attention and passive/stimulus-driven/exogenous attention. It is however important to understand how different interfaces are connected to different attention levels.

In this case it might be proper to look at the examples stated by Yantis (1998) presented earlier in the text. His example presents an “everyday” situation that is familiar to anyone that has been to a supermarket. He connects active attention to a goal-driven search for a specific known marker, and passive attention to a stimulus response to a “pop-out” effect produced by a difference in a marker (in the example, the marker is

product packaging that makes the product differ from the others on the shelf). According to Jonides (1981), one of the differences between active and passive attention is how they create a cognitive demand, in this case a difference in memory load. Wickens (1992) states that a failure to carry out an action can be connected to a failure of memory. This shows that a connection exists between attention, memory and the ability to perform a proper action. This connection is vital when it comes to the preparation of Case study 2 presented in Section 3.4.

2.4.7 Human Errors

In 2005 a new assembly line was built at the plant. There were technicians as well as assembly personnel working within the project. When the author worked with the preparations for the paper “Parameters affecting...” (Bäckstrand et al., 2005a) there were some discussions regarding Mental Models and if a non-uniform Mental Model could negatively affect a work place design. This discussion led to an interview session with the engineers and assembly personnel within the project. The conclusion from this session will not be discussed in detail in this section, but some things are worth mentioning.

Two of the questions in the interview were (translated from Swedish):

1. “Is it possible to use shortcuts in an assembly task and thereby lower the task time?”
2. “In what way, if any, can shortcuts influence quality?”

The answers to the first question indicated that it was possible to use shortcuts. A shortcut in this case is for example an unscheduled or unforeseen (by the production preparation engineers) preparation “act” to prepare for a scheduled assembly task. All of the interview subjects indicated that these “acts”, taking a shortcut, seldom lowered the total assembly time, and as an answer to question number two, as a rule, the shortcuts can influence quality negatively. The reason that it can influence the quality negatively is that the assembly process is defined from a quality, a productivity and a physical ergonomics perspective. If the personnel do not follow the described process, the quality risk increases. This can be seen as an example of Intentional Error, but it can also be a misinterpretation of work instructions or data and thereby it can be an Unintentional Error.

According to Pennathur and Mital (2003) there are, in general, two types of human errors:

- Intentional: Intentional errors are caused by actions deliberately conducted with a belief that they are correct or better, i.e. faster, safer, etc., than the prescribed action.
- Unintentional: Unintentional errors are actions performed with no prior thought, for example assembling the wrong parts, misinterpretation or forgetting to read an instruction, etc.

Wickens (2000) proposes four categories (Figure 2.19) and visualises where these fit in the information processing process of human errors. They are:

- Mistakes.
- Slips.
- Lapses.
- Mode Errors.

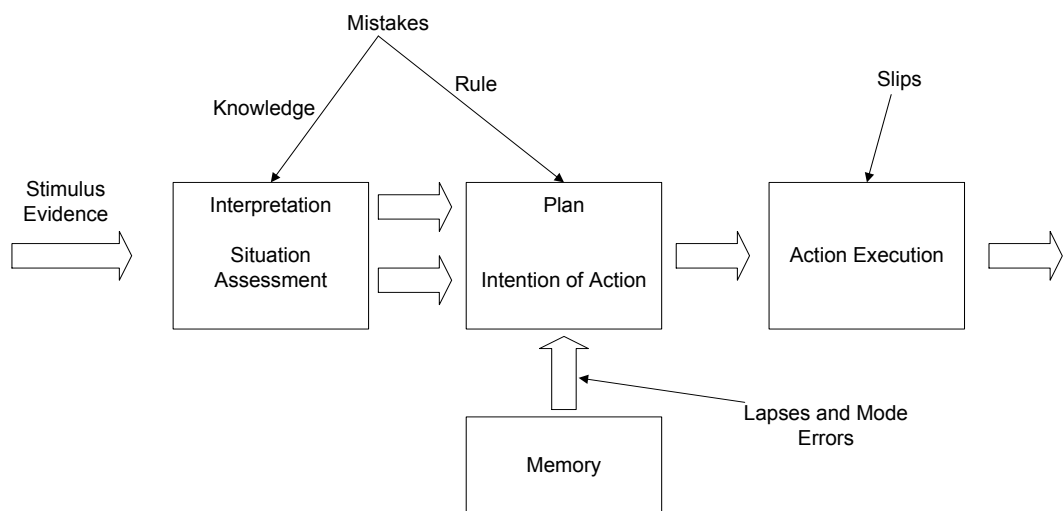


Figure 2.19: “Information Processing Context for Representation Human Errors”
(Wickens and Hollands, 2000).

Mistakes: A mistake can be seen as a “failure to formulate the right intentions”. Knowledge-Based mistakes are connected to decision-making and are caused by, according to both Endsley (2000b) and Wickens (2000), decisions based on an unsuccessful interpretation of a situation. There are connections between Situation Awareness and Knowledge-Based mistakes, although Wickens (2000) describes it as “a failure to understand a situation (i.e. incorrect knowledge)”.

Rule-Based mistakes occur when for example the assembly personnel believe that they know the situation and the environment where he or she operates and plan an action based on this knowledge, but overlook signs in the environment that can indicate other types of actions (Rasmussen et al., 1994).

Wickens (2000) describes rule-based actions with an “If-Then” notation where the “If”-condition controls the actions and a “Rule-Based mistake” occurs when this condition does not match the environment conditions. At the specific plant the “environment conditions” change “scheduled-chaotically” due to variations in production, and to changes/updates on the product. At this point it is not possible to draw any conclusions regarding what types of errors occur. This is believed to be important; identification of what types of mistakes that have occurred in the past must be an input to the solution to the problem. If this identification has not been done, there is a risk that a solution focuses on solving a Knowledge-Based problem when it actually is a Rule-Based mistake/problem.

According to Wickens, both types are characterized by an intention that is not appropriate for the situation (again, there are strong connections to Situation Awareness). But there are important differences that can call for different actions when it comes to finding a solution. Wickens states that:

“Rule-based mistakes will be performed with confidence, whereas in a situation in which rules do not apply, and where knowledge-based mistakes are more likely, the operator will be less certain.”

Slips: Slips are characterized by an action where the intentions are correct, but the action is carried out incorrectly. Wickens (2000) uses a naïve metaphor that explains in a good way the “essence” of slips. Wickens writes:

“Pouring orange juice rather than syrup on the waffles while reading the newspaper” and states that this is a perfect example of a slip. This example is very

interesting because when Wickens (2000) describes mistakes and Knowledge-based mistakes he mentions that attention is one of many shortcomings connected to knowledge-base mistakes. The example above describes a typical situation of shared or divided attention (Wickens, 1992).

Lapses: “*Failure to carry out any action at all*”. Wickens (2000) divides Slips and Lapses into two related but different categories, while Reason (1990) discusses them as one category. The main difference between slips and lapses might be that, if one looks at the orange juice example, slips can be caused by a lack of attention whereas lapses involve a failure of memory.

According to Reason, mistakes are a mismatch between the intention of an action and the consequences caused by the action, and slips and lapses are a discrepancy between the intended action and the action that actually takes place.

Mode Errors: “*Pressing the accelerator of a car to start at an intersection when the transmission is in the reverse mode*” (Wickens, 1992). Mode errors can occur when for example the assembly personnel commit an action that can be used in both correct and incorrect circumstances. According to Wickens, they are related to slips and lapses; Slips due to the right intention incorrect performed and lapses due to memory failure.

At this point it is assumed that a connection between data/information flow and internal rejects exists, but at the time, it is not possible to find the error source. Wickens (1992), Wickens and Holland (2000), Reason (1990), Pennathur et al. (2003) all discuss different types of errors, for example lapses, mistakes etc. The cause of the errors is different, and therefore one can assume that the solution for prevention to a specific error is different. This can call for not only finding the error source, but it might also be of importance to categorise the (assumed) different error types.

2.4.8 Literature study discussion

The literature study has identified a gap between theories and practical or proven use on a factory level. This does not have as much to do with the specific literature, as it is connected with the specific scientific fields. The findings when reading the literature are interesting and support the hypotheses regarding the information search behaviour, especially within psychology and attention. Attention, active and passive, seems to have a strong connection to memory and stress.

The attention theories: In this thesis, four different attention theories are presented: *Early Selection Theory*, *Attenuation Theory*, *Late Selection Theory* and *Object Based Theory*. The four theories all differ from each other in at least one important aspect and that is in how they handle the information in the work environment. Depending on which of the four one believes is the one that best describes how humans handle information, the impact on the design of an information system, or the result (the existing information system) differs. For example, according to the Early Selection Theory, see for example Duncan (1995), humans only take up a small amount of information, i.e. humans use limitations and filters at an early stage of perceiving information and thereby minimize the amount of information that needs to be processed. A possible conclusion drawn from the study of the Early Selection Theory is that the amount of information presented in the context will not interfere with the information search process, and thereby the amount of information will not influence the success of such a process. In Section 3.3, Case study 2 is presented, and the results from that study indicate that the Early Selection Theory might not be applicable within the context of the thesis. The Late Selection Theory on the other hand states that all messages attended to or not, are weighted and the key message determined due to limitations that makes it possible to only respond to one message at a time (see for example Hoffman (1998)). This indicates that all information in the work context studied are attended to and processed in some sense in our brains. The conclusion from this is that more information in our work place creates a need for more limiting and filtering by our brains. This raises a rather interesting question of thought. If humans use filters, late or early in the process, how are these filters created? Who decides how one should filter the incoming information? Is it the initial training and practicing that influence this filtering? It is not within the scope of this thesis to answer these questions, but the theories and their substances influence the experimental design of the studies presented in Chapter 3, and one must assume that they also influence the outcome of an information system design; the problem is to understand how. This is an important discussion but it has to be continued at a later stage, in this case, in future work connected to this research.

Definition of Active and Passive attention: In the literature there are at least three different terms for attention: (1) *active and passive attention*, (2) *goal-driven and stimulus-driven attention* and (3) *endogenous oriented and exogenous oriented attention*. They are rather similar except for the fact that there are different views regarding the

definition of them. For example, Kida et al. (2006) exemplifies passive attention with reading a book, while Kaplan et al. (2006) state that an intentional directed process, such as mountain climbing, is an active attention activity. This is rather confusing, since reading a book must be considered as an “intentional directed process”, although not as dangerous as mountain climbing. Despite some of the differences in the definition of attention it is obvious that attention could be the root cause for the specific type of internal rejects that are under investigation within this research, i.e. wrong parts assembled or parts missing. As mentioned, one problem with the existing literature is the lack of literature that is directly associated with assembly. Much of the literature focuses on the process industry, where the main focus for the human is to control and observe, for example paper mills, nuclear power plants and cockpits. This is not that strange as these environments are critical and the outcome of a mistake can be catastrophic. The outcome of an error in an assembly environment such as the one studied in this research, might not cause a disaster, but may have large economic consequences. There is a major difference in the tasks though, if one compares the work in a control room with the work on an assembly line. The main difference is that in a control room the main task is usually surveillance, a passive task, while in an assembly environment the main task is the active task of assembly. This difference puts different demands on the information systems, and on the humans using the systems. One difference is the amount of information the person has to handle, but the most important differences are in the tasks. If one focuses on the need of information for the assembler, and not on the comparison of work environment, one realises that there are some differences that the discussion regarding active and passive attention can explain; active attention is triggered by an exogenous event that cannot be suppressed or ignored by the assembly personnel (or by anybody else for that matter). This event is the trigger that should start an Information Search Process, and nothing else. Therefore, an information system that triggers the information search process is essential and when the information search process has started it should support a passive attention mode. This means that the need for an active (active from an attention perspective) use of the information must be kept to a minimum.

Situation Awareness (SA): Much of the work within the SA field has so far focused on military, aviation and process industries, for example nuclear and chemical plants. The emphasis is on process monitoring, supervisory control and not on active task performance. A rather interesting conclusion can be made when one studies SA, and that

is the absence of the important issue regarding triggers and their role regarding how triggers create change of state, from passive to active attention and from active to passive attention. For example in Endsley's three level SA model (Endsley, 1999), triggers should be a predecessor to the model, or a part of level 1. Endsley (1999) describes "Critical cues related to key features" as an important part of a system design. Endsley also states that due to several factors, although the information is directly available it is not observed or included in the scan pattern, due to for example not looking at the information, attention narrowing etc. This is according to Endsley the main contributor within SA level 1 to SA related errors. This is where this author believes triggers can be a major contributor to preventing this type of human error. The trigger in this case is the event that creates awareness of the presence of important data or information and draws the personnel's attention to the correct data or information source. A remark is that the trigger can be different, an example is within the engineering field where 51% of the respondents answered that solving a problem triggered their need for information (Kwasitsu, 2003).

Endsley is the main contributor to the SA science field; still there are some important issues that Endsley does not discuss including:

1. How can triggers contribute to error prevention connected to SA level 1 problems?
2. How can a good SA be maintained over a time period, with a minimum of work effort, i.e. how can a proper attention level be maintained so that a good SA exists and continues to exist over time.

Human Error and Stress: The literature review has briefly included human errors and stress. However, it is neither possible nor interesting to exclude human errors or stress as error sources that have an influence on the internal reject rate. A reflection is that it seems that automatism perceptual tunnel affect, increased selectivity, stress and filtering, all have something in common and that is that they all can negatively affect the ability to observe information. However, Wickens and Hollands (2000) write something that is extremely interesting. According to them, a study conducted by Houston (1969) showed that the stress-produced perceptual tunnel influence, although this influence usually affect the task performance negatively, in some circumstances it facilitates performance when focused attention is desired. This gives rise to the question if it is possible to use this filter effect in some way and is it possible that, depending on the stress levels

experienced by the assembly personnel, this can dynamically affect their performance? It is clear that a (too) high stress level can affect the performance negatively, but is it also possible that a (too) low workload can influence the performance in a negative way? Sutcliffe (1995) states that non-stimulating tasks should be avoided. According to Sutcliffe the reason for this is that it can be hard to enforce attention on an uninteresting task. This statement is connected to a discussion by Sutcliffe, where he addresses stress and fatigue, where stress can cause fatigue. The discussion is interesting for many reasons, but especially where he states that:

- Fatigue may result from continuous mental activity in overlong, mundane tasks.
- Fatigue may result from intensive concentration on tasks demanding difficult mental reasoning.

However, according to Sutcliffe it is not the case that task complexity always leads to fatigue. The number of stressors that can affect the outcome of an information search process are many, for example noise, vibrations, heat and psychological factors such as anxiety, fatigue, frustration and anger (Wickens and Hollands, 2000). According to Wickens and Hollands they all affect information processing, see Figure 2.20.

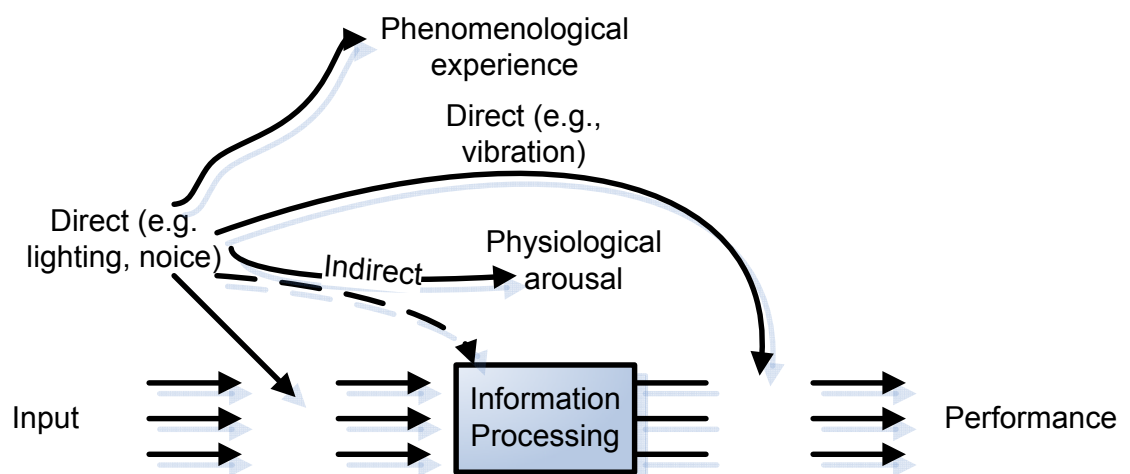


Figure 2.20: A representation of stress effects according to Wickens and Hollands (2000).

These factors, such as stress, fatigue, the ability to handle information and their affect on the information search process, are extremely interesting. However, the focus for the

further work within this research will be on attention as this is believed to be the main issue regarding the start of a successful Information Search Process. That is, if the assembly personnel are unaware of changes in the information flow, the likelihood of an upcoming quality problem increases.

The influencing factor from stress is of great interest, but in order to understand how it influences quality separate studies should be performed and such studies are not possible to conduct within this research.

Attention is an extremely interesting area from a manual assembly perspective. A problem, or rather an opportunity, that the industry is facing is how to get as much as possible out of the information and the information systems. Much of the literature regarding attention presents findings that have their origins in laboratory experiments within the field of psychology. One of the problems with this is that it is rather hard to state “the problems we are facing in the assembly plant have their origins in the lack of attention support”. To better understand how attention affects assembly systems, studies should be performed within or in close contact with these kind of systems. These studies should better support understanding regarding the influence that attention might have on the assembly process.

The conclusion is that attention (passive, active etc.) is an important component that influences quality output; it is obvious that if an assembly worker is not aware of a need for information a correct information search process will not be started. This will result in a quality risk that can influence the internal rejects severely.

In the literature addressing cognitive aspects, much effort is used to describe how humans use and process information and very little on how to use cognitive science to create effective work environments from an information demand point-of-view. There are several cognitive related evaluation methods, for example “Cognitive Work Analysis” CWA (Rasmussen et al., 1990; Vicente, 1999; Bäckstrand et al., 2005a) which can be used to evaluate work environments. One problem with CWA is that it is very time consuming and thereby, from a cost-benefit or a safety perspective, only useable or applicable in evaluation of complex information systems, for example helicopter cockpits, process control interfaces etc. In the literature survey it was recognised that one major component was rarely covered and that is how important information awareness is to successful goal fulfilment. The discussions regarding information, data, interface design etc. are often focused on how to design an interface so that a user can quickly find and use information. The real problem is how to create awareness of a need for

information, for example active attention with the purpose of achieving a specific defined goal. Endsley (2001) presents an interesting guideline, “SA-oriented Design” that can be useful for the evaluation of work environments. Unfortunately it seems that this guideline is also lacking the major component of how to handle active and passive attention, but nevertheless it is interesting enough to evaluate and develop in the future.

2.5 DISCUSSION OF THE ANALYSIS

In this chapter a presentation has been made regarding the industrial related research environment and literature closely connected to human-information interaction, for example attention, situation awareness, human errors etc. The main purpose with the analysis work was to try to find information that could explain the problems that occur in the assembly environment, and if this was not possible, try to understand how information and the use of information can influence humans in both negative and positive ways. In addition, an intention was to try to make assumptions that can support the hypothesis and the research objectives.

The conclusion from the analysis is that there are two main areas that are affected in the assembly plant: productivity and quality. The analysis revealed that it is, at this stage in time, not possible to measure the impact that the information flow has on the productivity in the assembly plant. This is not entirely true since it depends on how one measures productivity. On a general level productivity is the ratio output divided by input. Output could for example in this case have been selected as quality output, and input as hours worked, or output could have been selected as the value of the assembled product and input as the specific product cost. So, if one can measure the quality, one can in at least one way measure the productivity. In this case, the quality is more interesting than the productivity, so therefore the possible impact from the information flow can be evaluated against the quality output. Productivity, in the form of engines produced per worker, and how the information flow affects that productivity, would have been very interesting to measure, but in this case is it not realistic to identify this correlation due to too many parameters, for example personnel changes, order intake etc., that can affect the productivity output.

So, can the quality output be affected by the presence (at this point, one must assume that the information provided is of a quality that makes it possible to use, i.e. we

assume that insufficient information can affect the quality in a negative way, but this is considered not being the case) and the use of information?

In chapter one, it was stated that the common opinion among management was that the personnel did not use the information provided in an appropriate way and thereby created some of the quality problems that occur. It was not possible to find explicit evidence in the literature that pointed to lack of information as a negative parameter regarding quality. However, an absence of information can create a quality risk. The interesting part is not the information itself, instead it is the combination of in what form, for example text, colour patches, symbols etc, the information is presented and how one interacts with the information provider and how this interaction affect humans.

At this stage in the thesis it is important to try to understand how the different theories presented in the literature can be connected to specific problems at the assembly plant if these problems can cause quality problems and if the theories can be applied in the specific research environment.

Earlier in this chapter Figure 2.14 was introduced as a help to visualise the complexity of the information flow. This figure can be used as a support when one tries to understand the effect the different theories can have on an information flow. The final goal of a search process must be to fulfil an action. To produce that goal, a number of steps must be taken, such as, from right to left: update of knowledge base leading to a decision and to an action, interpretation of information lead to an update of the knowledge base, transformation of data leading to information.

To be able to define information four different parts must, according to Meadow et al. (1997), be fulfilled:

- Existing message.
- A message sent received by a destination.
- A message understood by a receiver, which creates change in that person's knowledge base.
- Information should "process" data into knowledge.

The first and second criteria seem reasonable; to be able to use the information, the message including the information must exist and it must be sent to a receiver. One could assume that in an assembly environment, the message containing the information is always sent and should therefore be available to the personnel when needed. The system

that has sent the message has identified a need for information, should a demand for information occur at the same time.

In the paper *Attention, Interpreting, Decision-Making and Acting in Manual Assembly*, Bäckstrand et al. (2006a) four situations are presented that can occur and that are connected to the above criteria. The purpose of any rational action should be to achieve a goal (Wharton and Lewis, 1994; Wilson, 1999; Johnstone and Tate, 2004). This should normally create a demand and a need for information. In principle, four situations can occur regarding information need versus demand:

1. There is a need but no demand. In this situation, an error will sooner or later occur.
2. There is a need and a demand. This situation is the preferred one. In this situation, the error risk due to a lack of information is lowest. However, this situation still requires that the information available matches the need. Furthermore, if there is a mismatch between need and demand, then a residual state (1) or state (3) will eventually emerge.
3. There is a demand but no need. This situation can be frustrating for the personnel. They have identified a need and have a demand, but the context of for example the assembly station does not provide them with the (subjectively) needed information. This is a potential future error source; frustration can result in the absence of active information seeking behaviour in the future, even when an information need is identified.
4. There is no need and no demand. This situation is more or less trivial.

Figure 2.2 presented earlier in this chapter visualised an information seeking process. In that process, a decision has to take place. This decision is important for the outcome of the information seeking process and is likely to affect the quality output. The decision is triggered (or at least should be) by a need from the system that an information search process should be started, but it can also be triggered by a demand from the human. If a message is sent to a receiver, and this receiver fails to identify the information need, the risk of a quality problem increases.

In Meadow's (1997) definition of information, the remaining two parts that must be fulfilled are: (1) message understood by a receiver so that a change can be made in the knowledge base, and (2) the information should make the receiver "process" the data into knowledge and from that make decisions. That is, the decisions are driven by the

information as presented (Miller et al., 2001). A note has to be made regarding transmitted and received information. According to Losee (1997), a situation where there is a message deemed as having no value to a receiver should be seen as no information having been received nor transmitted. This can be rather important because it indicates that a receiver's subjective opinion regarding an information demand can create a situation where no information is received and thereby no change in the knowledge base will occur.

According to Hartley (1927), two people that speak different languages have a limited amount of symbols and thereby the possibility to transfer information into knowledge is limited. This indicates that there is a need for some kind of mutual knowledge base among the user/receiver of specific information. This knowledge base should be acquired by training and education, and in some sense it will be acquired/updated by experience. In the assembly plant, it is impossible to sustain quality without training, but the focus should be on having an information system that can be managed by the user in a way that minimizes the training and the quality risks.

According to Nembhard and Uzumeri (2000), a manufacturing worker is constantly forced to learn new skills, technologies and processes in order to keep up with the increasing demands within the industry. Therefore it is important to design information systems so that they are easy to use, do not need constant updates and do not need advanced training. The opposite would be an information system that is advanced, in need of constant update due to for example product updates and an information system that constantly is changing where the changes are connected to part numbers. There are several problems connected to this and the one of most interest is connected to minor changes, such as new part numbers on parts that still look the same, that create a change in the product set up. These changes sometimes make very little impact on a user interface layout and that is a problem. According to Marsden and Green (1996) one of the main reasons why systems fail to perform well is that their desired objectives are poorly designed. The effect of a combination of small changes in product set up and a poorly designed interface might be seen in the quality output.

It might be important to reflect on "Human Errors" and the four error categories presented in Section 2.4.7 and how the quality problems at the assembly plant are related to these categories. According to Park and Lee (2007) there is a problem in obtaining empirical data within industry, which forces a heavy reliance on judgement from experts. It is not possible to understand how much empirical data Park and Lee believe it is

necessary to have to be able to do investigations of the root cause for an error. This research is not conducted by an expert in the field of Human Errors, therefore the focus will be on the human error definition *Mistake* and *Rule-Based Human Errors* and the reason for this is that it is possible without any expert skills to find quality problems that are related to this definition. The definition of Rule-Based Human Errors is:

Rule-Based mistakes occur when a person believes that they know the situation and the environment where they operate and plan an action based on this knowledge, but overlook signs in the environment that can indicate other types of actions (Rasmussen et al., 1994).

The question is, is it possible to apply this in some way to data/information, Situation Awareness, and Attention? To summarise some of the problems that are connected to these three aspects:

- Data/information:
 - Failure to identify information need.
 - Failure to identify information demand.
 - Have the knowledge but overlook signs/change in the information flow.
- Situation Awareness: Endsley and Robertson (2000) describe and divide the different causal factors between the three levels.
 - Level 1: Failure to correctly perceive the situation.
 - Information not available.
 - Information difficult to detect.
 - Information not observed.
 - Misperception of information.
 - Memory error.
 - Level 2: Failure to correctly comprehend the situation.
 - Lack of/incomplete mental model.
 - Incorrect mental model.
 - Over-reliance of defaults values in the mental model.
 - Level 3: Failure to correctly project situation.
 - Lack of/incomplete mental model.
 - Over-projection of current trends.

- Other.
- Attention:
 - Missing exogenous signals.
 - Suppressed endogenous signals.

It is possible to identify two major causes from the listing above: *knowledge* and *attention*. Knowledge and how to gain it is an important part of manufacturing, but in this case, attention is the subject of interest. This is because of the strong connection between attention and the investigated internal rejects.

The problems connected to attention are, summarized from the text above:

- Failure to identify information need and demand.
- Users do not perceive the information in their environment.
- Missing exogenous signals.
- Suppressed endogenous signals.

What type of error (quality problem) can be connected to attention? A interesting part of Jones and Endsley's causal factors is that 76% of the errors in situation awareness are in their study caused by problems in perception of needed information (Endsley, 2000b). If one assumes that there is a connection between "problem in perception" and attention, one can argue that there is a high risk of omission due to changes of state in the information flow. This omission can be caused by a framing (that creates boundaries) effect that limits the possibilities to choose information (Beach and Connelly, 2005), or a failure to observe provided information. The framing can be connected to a suppression of endogenous signals so that the information for some reason is not observed, i.e. a person misses the exogenous signals in the work environment.

The answer to the question "is it possible to connect data/information, Situation Awareness, and Attention to Rule-Based mistakes somehow?" that was made earlier in this section, must be yes. In Section 2.2.5, a description was presented that describes the different internal rejects and their denomination. The interesting ones in this work are internally at the plant called:

- Component missing.
- Wrong component assembled.
- Extra component assembled.

These three have one thing in common and that is that they all are an effect of a Rule-Based mistake, at least according the definition presented by Rasmussen et al. (1994). Therefore, the conclusion is that a connection exists between them and that the common part is attention.

Based on the findings from the literature review, it is now possible to extend the information seeking process model that was presented in Chapter 1 in more detail, see Figure 2.21.

An Information Seeking Behavior

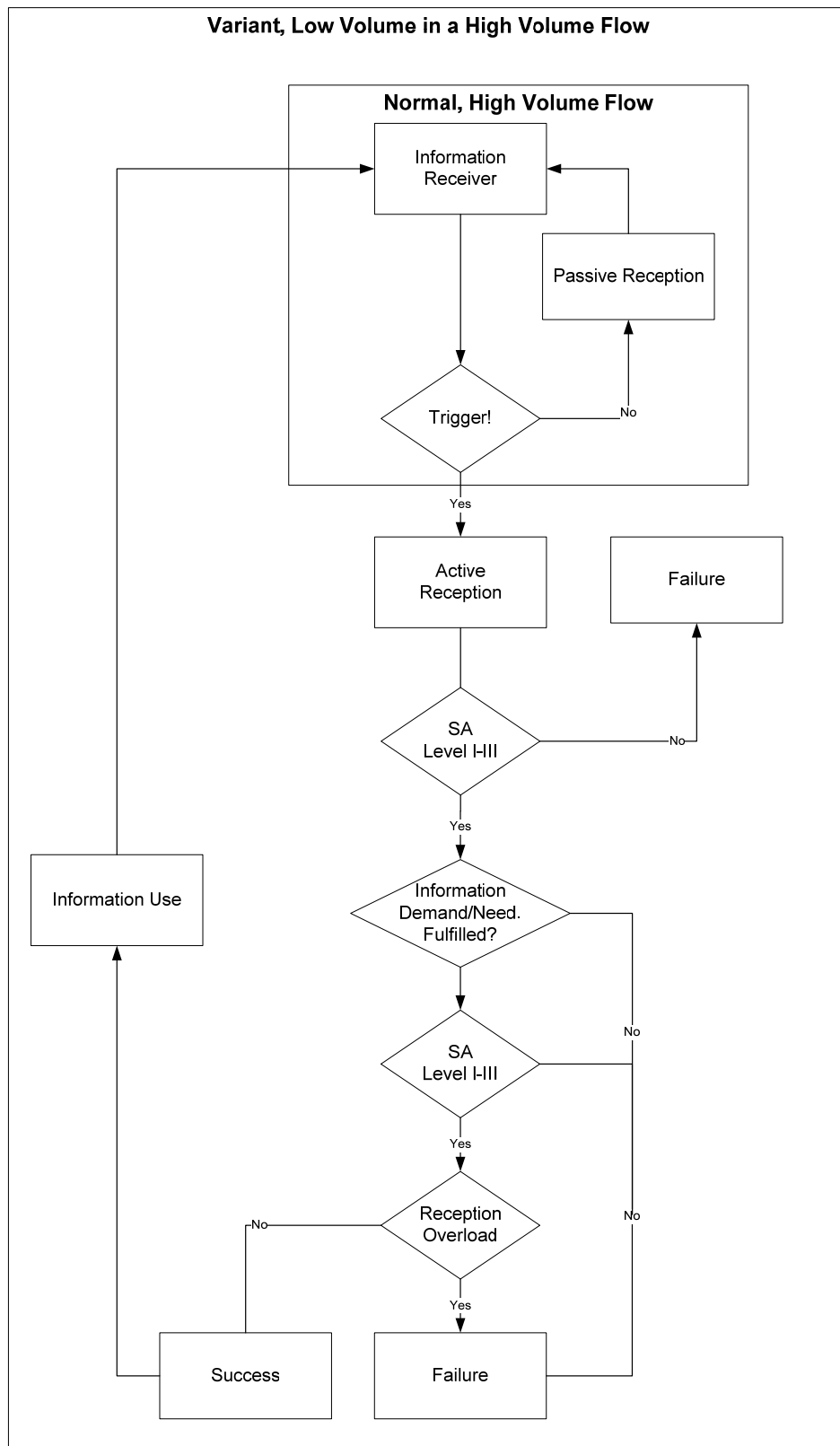


Figure 2.21: Elaborated model of an Information Seeking Process.

The model still contains the main components, *the trigger, passive and active reception*, and it has been updated with two *Situation Awareness* components, a failure due to *non-fulfilment of a demand/need* and *Reception Overload*. The important part of the model is the trigger and its effect on the following search process. Attention is not viewed in the model as a single step. Instead, it is a part of Situation Awareness as well as in the trigger.

The conclusion is that SA largely influences the outcome from a search process, and that attention is a part of SA as well as attention is a part of triggers. The three levels of SA: “Perceptions of Elements in Current Situation”, “Comprehension of Current Situation”, and “Projection of Future Status” all include parts that can influence the process and thereby the quality output.

Information Demand/Need, Fulfilled is the next step (Figure 2.21). Is it possible that there is a connection between the demand and the fulfilment of the demand and internal rejects? How does one know if a demand has been fulfilled? Is it the processor of data that determines if the demand has been fulfilled, or is it the orderer of task/action that has that responsibility? This is connected to goals and how they affect the performance and will not be addressed further in this thesis, but it still is an important part of a successful information search process.

As mentioned in Section 1.3.1, it is unlikely that an Information Overload is present, but there can be an overload from a perception point-of-view. Is it possible that all impressions from the work environment such as talk, music, heat, chill and noise can create an overload that prevents the object’s possibility of perceiving, processing and acting on data/information in its surroundings? In a table presented by Wickens (1992) “Noise” is a parameter that can negatively affect, amongst other things, the short-term-memory. “Noise” can be both sounds and a data flow (with a purpose to be informative). It is possible that this noise prevents us from perceiving vital data in the work environment, making the use of our short-term-memory less effective, and creating stress (Wickens, 1992; Dubischar et al., 1999). Therefore, it is likely that Reception Overload (Figure 2.21) can exist in spite of the conclusion that it is unlikely that Information Overload is present.

If the *process* is successful the information is used in a correct, sufficient way and the outcomes from the *assembly process* are successful, we are back in the “High Volume”-area and the process starts over again (Figure 2.21).

The main issue is why the personnel do not use the data and the information provided by the information system. This together with the predictions based on historic facts and trend analyses, which state that the working environment within the assembly area in general and at the plant specifically, indicates that the assembly area will be facing an increase in complexity. Insufficient use of information combined with complexity is already today a contributor to the creation of internal rejects. It is notable that the production volumes produced today would not be possible without the existing information system and the work environment complexity is a function of the demand from the customer.

The knowledge gained from the analysis phase together with questions raised by the same was used in the case studies presented in Chapter 3, and in Chapter 4, where a work method is presented.

2.6 CONCLUSIONS

The conclusions from the analysis stage are that the amount of information, the way the information is presented, and most importantly, attention are the main influences on the internal reject rate of the described categories as well as productivity.

The amount of Information

The theory regarding Information Overload is supported by the theories of Late and Early Selection and show that it is likely that information is weighted and filtered before a human processes it (Section 2.4.6). The conclusion is that the quality of information affects the assembly personnel in a negative way. The study of the assembly work context together with the findings in literature supports this conclusion, and it also supports the Information Search Process that was developed in more detail and presented in Section 2.5.

Information Presentation

The conclusion is that the way the information is presented can affect the use of the short-term-memory in a negative way. This is connected to the statement above, but is more focused on the way a specific message is designed. If a message is designed in the wrong way, the working memory can be affected in a negative way.

Attention

Before an actual Information Search Process, a trigger must be present to start it. If this trigger is absent or not observed by the assembly personnel, the quality risks (influencing the internal reject rate) increases.

This conclusion is based on the findings in the analysis chapter, and is the base for the next step in the research, the investigations (Chapter 3). These investigations will include tests of how different types of information trigger a search process and how this and the information itself affect the quality and productivity.

CHAPTER 3

INVESTIGATIONS

This chapter presents the investigations performed, the conclusions from them, and the possible solutions to solve the problems identified.

The conclusions from Chapter 2 state that there are three major issues related to:

- the amount of information.
- the way the information is presented.
- and most importantly attention.

These are believed to affect the internal reject rate of the specified categories.

They are connected with attention and the amount of information in different levels of the information search process and need to be investigated further.

The investigations are divided into:

- Case study 1: The purpose of the study was to evaluate how and if a drastic change in the user interface would affect the assembly workers and their ability to handle attention and information, and if this would affect the rate of internal rejects.
- Case study 2: The purpose of this study was to evaluate, in a laboratory environment, to what degree the user interface would affect the quality as well as productivity.

In this chapter some of the data connected to internal reject rate will be recalculated from a percentage to a value compared to a baseline. There are two reasons for this. Firstly, some of the data connected to quality issues are classified and cannot be used outside the company. Secondly, the recalculation of the internal reject rates so that they can be compared to a baseline makes them more readable and understandable.

3.1 INVESTIGATION METHODS

The research methods used have varied depending on the studies performed and differences in the research environment. The general approach is that the studies are performed from a mixed methods research perspective. Mixed methods research involves in general research that collects, analyses and interprets qualitative and quantitative data in a single study or in a series of studies investigating the same phenomena (Leech and Onwuegbuzie, 2009). The methods utilised in the research will be described in this section.

Triangulation

Triangulation is described as “the combination of methodologies in the study of the same phenomenon” (Denzin in Beach, (2001). According to Beach (2001), there are two forms of triangulation, within-method and between-method. For example Case study 1 presented in Section 3.2 is a between-method study where quantitative and qualitative methods are combined to interpret and study the data retrieved. Triangulation implies a fixed point in space that is scrutinized from different angles/directions (Patton, 1980; Decrop, 1999; Stake, 2000; Bratthall and Jørgensen, 2002) or a point in space located by the knowledge of two angles and a side in a triangle (Nationalencyklopedin, 2005). According to Decrop (1999), there are four different types of triangulation:

- Data Triangulation: uses a variety of data sources in a study.
- Method Triangulation: uses different types of methods, for example Quantitative and Qualitative methods.
- Investigation Triangulation: several researchers interpret the same data.
- Theoretical Triangulation: uses a number of perspectives to investigate a single set of data.

Quantitative and Qualitative

According to Danzin and Lincoln (2000) the difference between quantitative and qualitative research is that while quantitative research focuses on the measurement and the analysis of the connective relationship between variables, qualitative research focuses on the processes and qualities of entities that are not experimentally examined or measured. In quantitative methods the data are characterised in terms of, for instance, quantity, amount, intensity or frequency. Some of the common methods of collecting

qualitative data are by observation, interviews and/or examination of documents (Lyons, 2002). In qualitative methods the data are characterised in terms of, for instance, process, social structure, inquiry, direct observation or interviews.

Interviews and Questionnaire Surveys

Interviews can be used in all stages of a research process (Breakwell, 2002). The main use for interviews is when there are no clear answers or numerous answers and the population is limited (Andersen and Schwencke, 2002). According to Andersen and Schwencke (2002) the method is interesting when it comes to creating trust between the interviewer and interviewee, which is very hard to accomplish with quantitative surveys. This can be of great importance if the data one wants to retrieve is of a more sensitive nature, for example how persons act regarding work quality.

In this research work, two types of interview methods are used:

- Structured Interviews: the interviewer uses a fixed set of questions in a fixed order.
- Unstructured Interviews: the interviewer has a number of topics but the questions and their order are not fixed.

According to Patton (1980), the purpose of an interview is to find out what is in a person's mind. The important part is that it is not possible to observe everything, for example feelings, thoughts, etc. Therefore, interviews are a possibility for the interviewer to enter the interviewee's world.

In this thesis, the qualitative data was gathered by interviews, both structured and unstructured, and questionnaire surveys.

One of the purposes with a questionnaire survey is to gain knowledge about peoples' thoughts and feelings (Shaughnessy et al., 2003). The results from a questionnaire survey are often used to describe peoples' opinions and attitudes. Major benefits with surveys compared to interviews are according to Andersen and Schwencke (2002):

- That it makes it possible to get answers from a large population.
- That the influence of the interviewer on the interview subject is minimized.
- That it makes it possible to reach people that are geographically spread.

The drawbacks can be according to Andersen and Schwencke (2002):

- Problems with low response rate.
- Problems with knowledge regarding the interpretation of the questions, i.e. how did the person answering the survey interpret the questions asked?

3.2 CASE STUDY 1- INDUSTRIAL ENVIRONMENT

This section describes Case study 1 and the different parts within the study, how and why they were conducted. It also describes the outcome and results from the different parts and how they contributed to knowledge.

3.2.1 Study outline

The aim of the study was to find evidence supporting one of the hypotheses “generated” from the research aim (Section 1.3):

The aim of this research is to find or develop a prototype work method that can support the design of Information Flow based on product and process demands.

The hypothesis:

Hypothesis 1 - ‘Information Seeking Behaviour’

The degree to which Active Information Seeking behaviour is supported/triggered has a large influence on the number of internal rejects.

EXPECTED RESULTS

The expected results are practical knowledge regarding how active and passive attention affect the internal rejects, knowledge regarding how the assembly personnel interact with the information flow present in their work context and how the information affects quality via the assembly personnel.

PERFORMANCE INDICATOR

To evaluate the knowledge value it is important to identify performance indicators. A definition of a Performance Indicator is: “Performance indicators compare actual conditions with a specific set of reference conditions” (Dantes, 2008). In this case the main reference performance indicator is the historic data regarding the internal rejects.

The historic data covers the period 13th March 2006 to 22nd December 2006 and includes approximately 33000 records. This data includes (the most relevant presented here):

- Date and time: Every reject registered gets a date and time stamp. This is used by the company and its quality department within the quality work to trace the error source. It will be used in the study to connect the rejects to a specific time period, i.e. when the actual study takes place in the work environment these time stamps will connect the internal reject to the study time frame.
- Engine family and engine variant: The data covers the five engine families, 6, 7, 12, 13 and 16 litre engines. The engine families exist in different variants (named in the historic data as “engine type”). Approximately 500 variants exist. The focus is the 13 litre engine, but data for 12 and 16 litre engines was a part of the preparation and evaluation work.
- Effect number: This number is a code used for identifying different types of rejects.
- Effect description: The study focused on effect numbers 141, 142 and 144 described as:
 - 141: Component missing.
 - 142: Wrong component assembled.
 - 144: Extra component assembled.
- Part number: A number connected to a specific individual part used for identification.
- Free text field: This field can/should be used by the quality assurance personnel to describe the cause of rejection. Unfortunately the personnel do not use this option in a reliable way; therefore this data is used with caution within the study.

DATA RETRIEVAL PROCESS

The historic reject data process (Figure 3.1) starts with a discovery of a divergence of the assembled engine compared to the order specifications. This is done at the end of the line and in the test zones. If a divergence is discovered, the personnel make a note in the computer system and save it in a database. After registration, depending on the severity of the divergence, the engine is transported to a reject area where the problem is solved. The manually registered data is stored in a database.

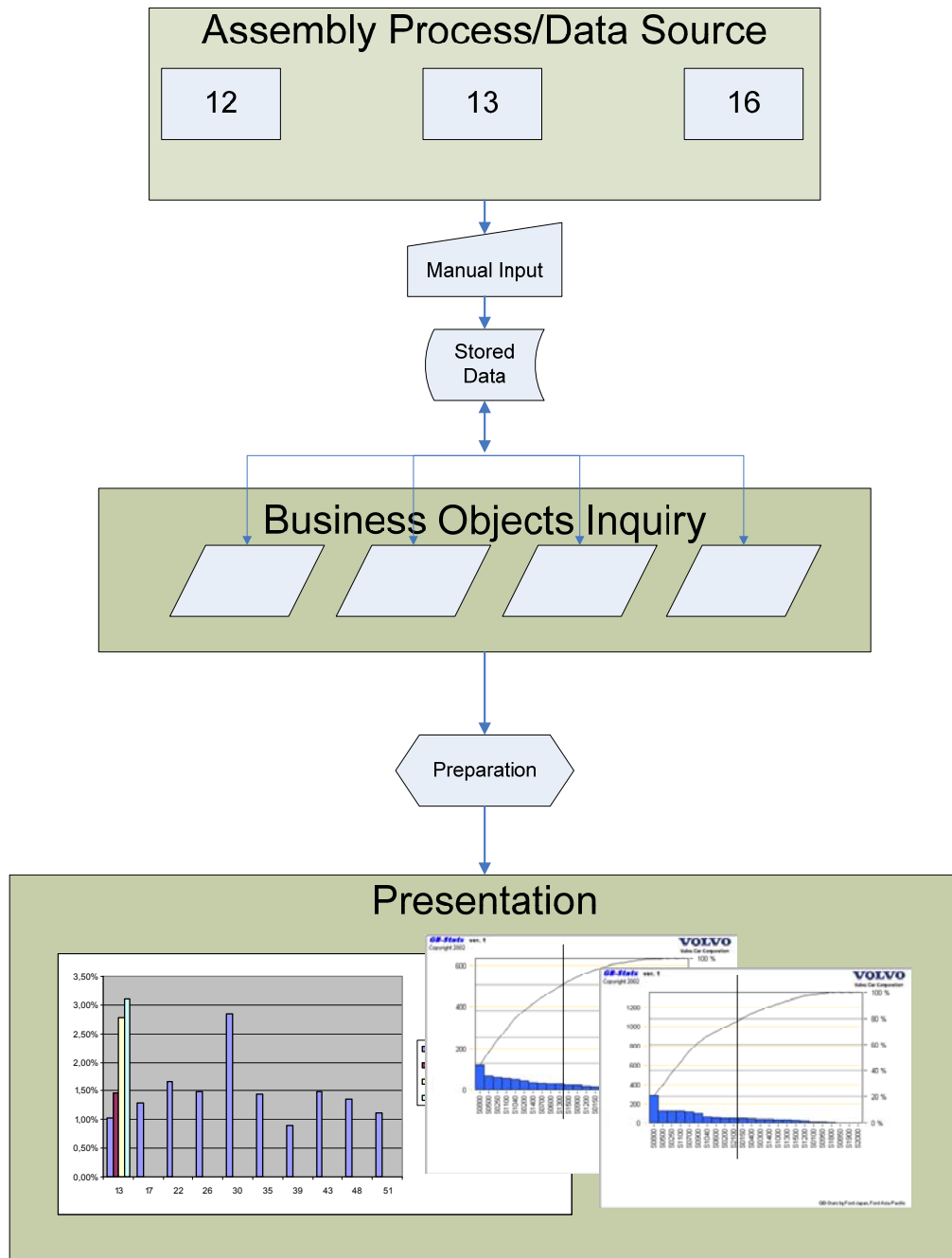


Figure 3.1: The reject report flow, from reject finding to historic data presentation. The numbers 12, 13 and 16 refer to the engine size.

The most common way of retrieving data from the database is via a Business Objects (BO) inquiry. The result, the data, can be copied and inserted into an Excel spreadsheet. This data has to be prepared for viewing, i.e. the retriever must process the data into information and the data is compiled and viewed in for example a Pareto diagram (will be further addressed and explained in Section 3.2.2).

PREPARATION

In this case, the data can be sorted in a way that makes it possible to identify:

- Engine family: 12, 13 and 16 litres.
- Station: For example, the 13 litre engine line is divided into basic and final assembly (two parallel flows). This makes it easy to connect a reject to a specific assembly station. In this work most attention was focused on four assembly stations (2 stations S0800 and 2 station S1100 on parallel assembly lines):
 - S0800: Main component is servo pump.
 - S1100: Main component is cable harness.
- Date and time when the quality problem was detected.

PRESENTATION

Three different applications were used to create usable information from the historical data. The applications are:

- Excel: Used to compile data and create diagrams.
- GB-Stat: A tool created for Volvo Cars and used by Volvo Powertrain to create statistical diagrams.
- Minitab 14 (Minitab, 2009): The application was used to calculate and present suggestions regarding the power and sample size required.

3.2.2 Experimental design

The experimental design was based on a quantitative field experiment in an assembly environment. The analysis part contains both quantitative and qualitative evaluations.

EXPERIMENTAL ASSEMBLY ENVIRONMENT

The experiment was conducted in the actual production environment. That is, the experiment took place in the assembly line and only small changes were made to the environment. The production at the assembly line continued and the conditions were more or less the same as on a regular production day. This included such things as carriers, forklifts, hand tools, material racks etc. The personnel involved in the study were all employed by the company and performed their regular duties.

The case study was presented to the personnel on a total of four occasions during their regular information meetings. During these meetings, the personnel were introduced to the experiment and had the possibility to ask questions and discuss the study.

The experimental environment and the assembly environment, as it was before and after the case study, differ only in the part that is included in the study, in this case a *trigger*. The triggers were magnetic rubber sheets with a size of approximately 300x300x0.85, 300x50x0.85 and 60x60x0.85 millimetres (length, width and thickness) attached to the carrier (Figure 3.2 and 3.3) and 400x300x0.85 attached to the material racks (Figure 3.4 and 3.5). The trigger had two purposes: firstly, to create awareness that a different engine variant was to be assembled: secondly, to give information regarding what part should be used.



Figure 3.2 and 3.3: The location of sheets on the carrier for the triggers.

The sheets were attached to the pallets and shelves in the material racks with a simple metal hook. This made it possible to quickly move the sheets when new parts arrived at the station.



Figure 3.4: The location of the rubber sheets on the material racks in assembly station S0800.

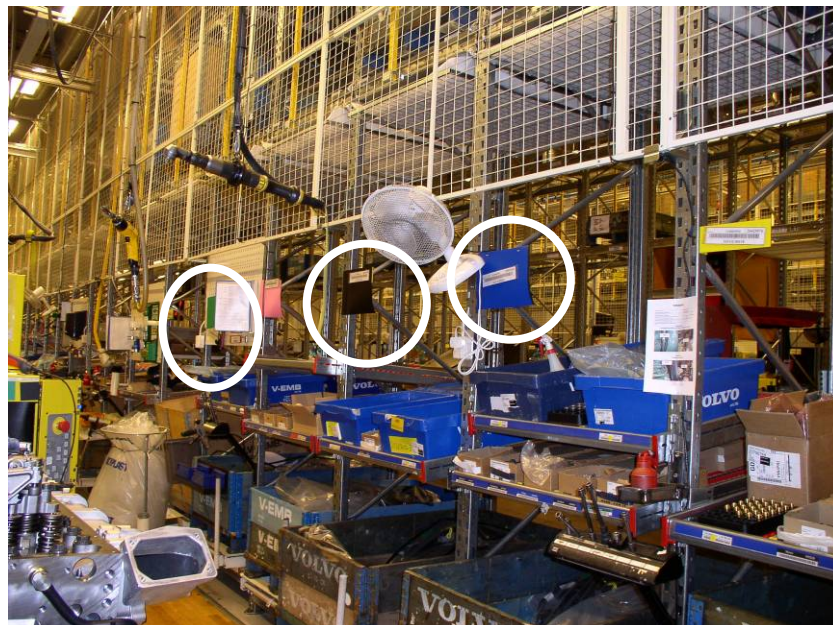


Figure 3.5: The location of the rubber sheets on the material racks in assembly station S1100.

At the beginning of the assembly line, see Appendix A for the layout, a station was built specially for case study purposes. This station was manned day and night during the study period, 12.00 24th May 2007 to 00.00 6th June 2007, and was responsible for engine identification, attachment and detachment of the triggers to the carriers (Figure 3.2 and 3.3). The changes made to the assembly stations can be seen in Figure 3.4 and 3.5. The only updates to the four stations were the rubber sheets that gave information regarding the position of specific parts.

COLLECTION OF QUANTITATIVE DATA

The results from the study were obtained by comparing the performance indicator before and after the study. As mentioned earlier in the text, this indicator is a part of the reject handling system and was recorded for approximately 9 months during 2006.

HISTORICAL DATA

The data gathered during the period of 13th March 2006 to 22nd December 2006 shows that the performance indicator for the period has a mean value of 1.46% (Figures 3.6 and 3.7). However, depending on the sorting of the reject data two more values must be considered with a higher mean, in this case 2.77% and 3.12%.

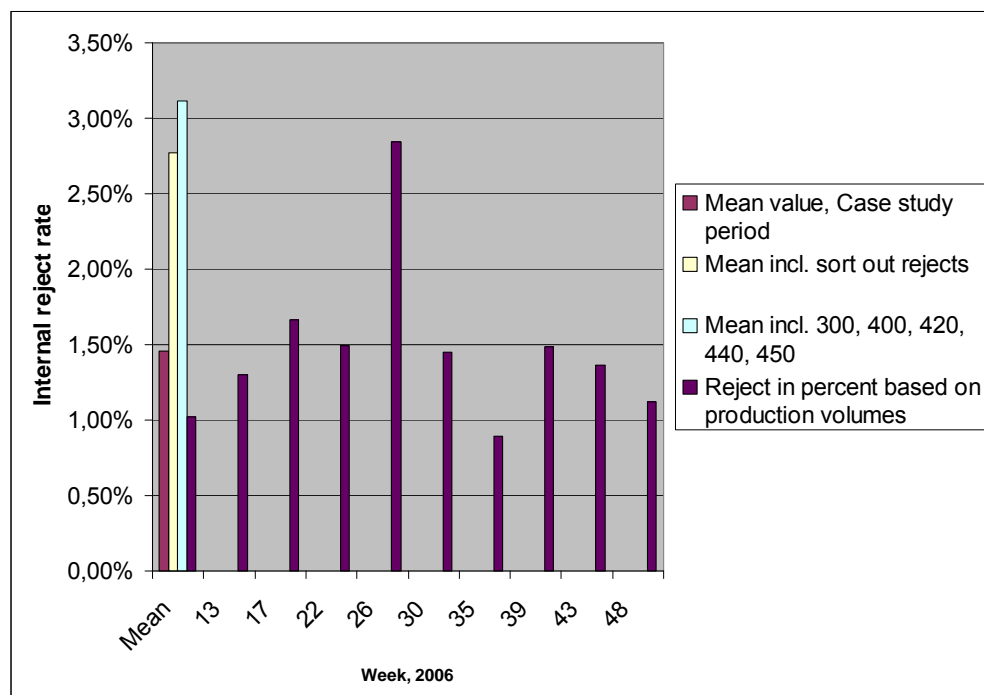


Figure 3.6: Performance indicator sorted per week.

Performance indicator, value:

- 1.46% (from now on known as $H_{\alpha 0}$): The result for this indicator includes only rejects with the effect number 141, 142 and 144 (for a detailed description, see Section 2.2.5).
- 2.77% (from now on known as $H_{\beta 0}$): The result for this indicator includes $H_{\alpha 0}$ and rejects that have a non-assembly related attribute. A “non assembly related attribute” is an attribute that is used by the quality inspection personnel with the aim of categorizing the reject to a specific part of the assembly process. Attributes can be for example method, material or machine.
- 3.12% (from now on known as $H_{\gamma 0}$): The result for this indicator includes rejects from $H_{\alpha 0}$, and $H_{\beta 0}$ as well as rejects connected to categories 300, 400, 420, 440 and 450. These types of reject effect numbers indicate leakage of oil and water. Parts missing or wrong parts assembly (141, 142) can, if not found earlier, lead to a leakage in the final test zone. If this occurs, the reject registration will not be in the category “parts missing” or “wrong parts assembled”, it will be “leakage” or “deviation from specification”.

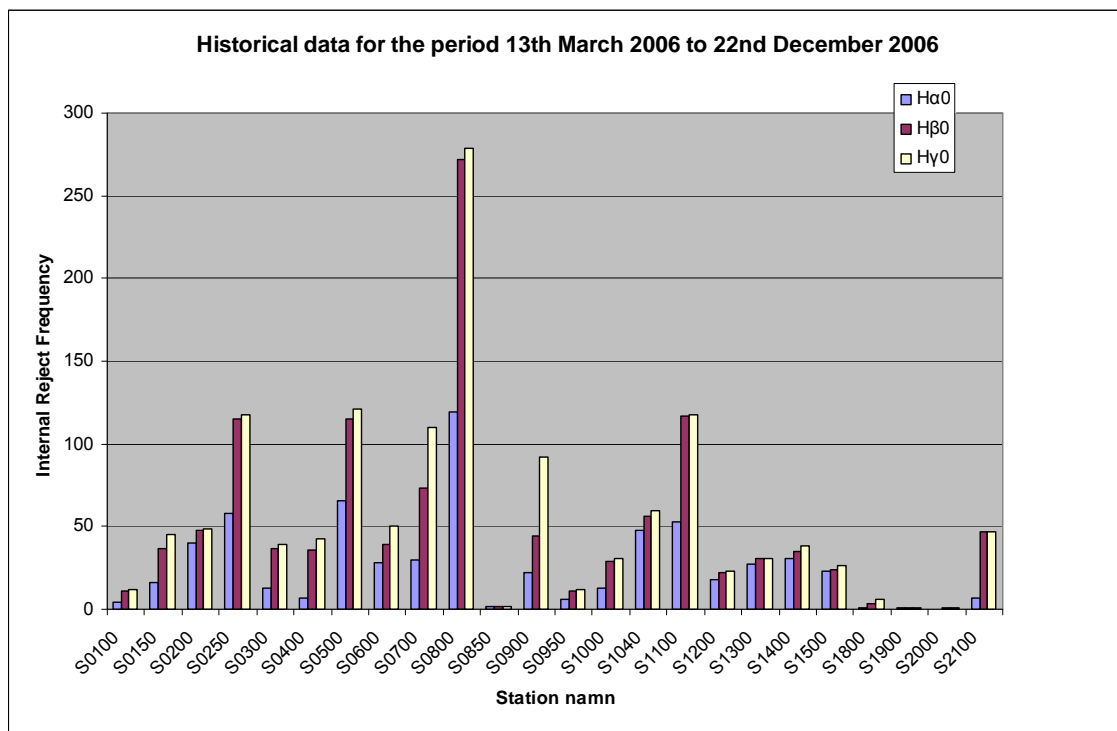


Figure 3.7: Performance indicators, $H_{\alpha 0}$, $H_{\beta 0}$, $H_{\gamma 0}$, sorted per assembly station.

A Pareto diagram is used to view the most important factor. This is done by simply applying the 80/20 rule that suggests that generally 20% of causes in any given situation will account for 80% of the problems. Pareto analysis ranks categories of items in order of occurrence or severity and the form of the bar graph is referred to as a Pareto Diagram or a Pareto Chart (Greenall, 2004; Galaktionova et al., 2006).

A Pareto Chart can be used to:

- Display the relative importance of factors.
- Compare the extent of problems before and after improvements.

This helps to:

- Select the starting point for problem solving.
- Identify major causes of problems.
- Prioritise improvement actions.
- Facilitate resource allocation decisions.
- Monitor improvements (Greenall, 2004; Galaktionova et al., 2006).

In the Pareto diagram in Figure 3.8, the left vertical axis shows the number of internal rejects connected to the different assembly stations in the assembly line during a time period. The right vertical axis shows the percentage of total internal rejects associated with each station. The horizontal axis lists the station name in order, starting with the station with the highest internal reject frequency on the left moving to the least frequent on the right. As a general rule, the tallest bar should be tackled first, moving on to the second once the first problem (station in this case) has been successfully reduced.

According to the Pareto diagram (Figure 3.8) and the above, the focus should be on stations S0800, S0500, S0250, S1100, S1040, S0200, S1400, S0700, S0600 and S1300. The analysis of the historic data in the Pareto chart⁹ (Figure 3.8) shows that the internal reject rate on station S800 represents almost 20% of the total number of internal rejects.

⁹ A Pareto chart can be used when the relative importance of all problems must be graphically represented with the purpose of viewing the most important factor. (Galaktionova, Y., A., Ibraqimova, E., K. & Bekisheva, E., V. (2006). On product quality control. *Fibre chemistry*, 38 (1), 79-82.

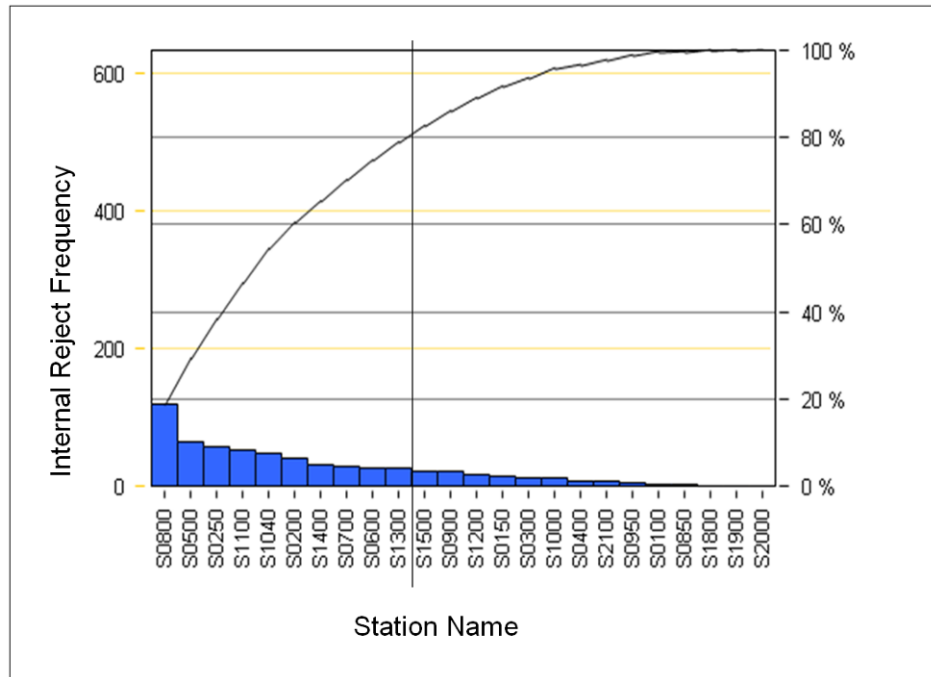


Figure 3.8: The Pareto diagram for the internal reject rate during the reference period. All data are of the $H_{\alpha 0}$ category.

The historic reject data for station S800 were further investigated and the results for the station can be seen in Figure 3.9. In the figure, the results for two periods are presented, the reference period and the amount of reject during the month of June 2006, a period within the reference period. The purpose of investigating and presenting data for June 2006 is to determine if a major difference could be present during the month of June. The pilot study was partly performed during that month. The baseline¹⁰ (Hornby, 1997) for the reference period is set to 100. All results or measures regarding the internal reject rate will be compared to that baseline. In Figure 3.9, the internal reject rate for the period of June 2006 is 185 in the relation to the baseline.

¹⁰ A line or level used as a base for measuring or comparing. The values is calculated by dividing the measured results, e.g. 68 with the value of the baseline e.g. 32, the and then multiply the result with 100 (baseline value). In this example, would the results be $(68/32)*100=212,5$.

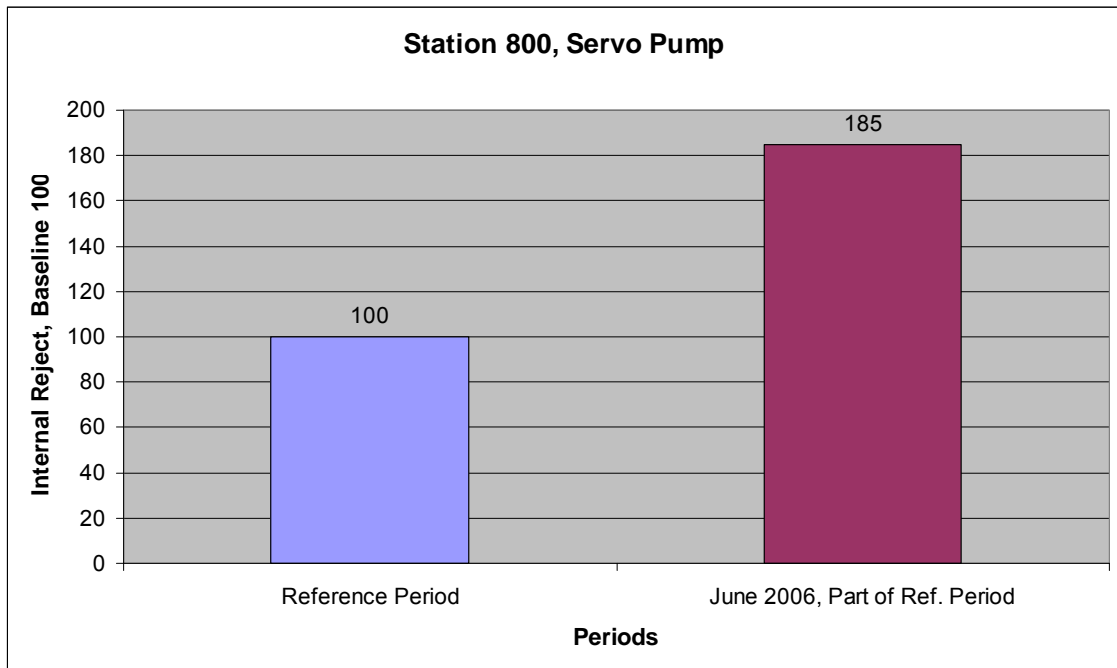


Figure 3.9: Results from the investigation of station S800 and its internal reject rate.

Station S1100 actually has only the fourth highest rate of internal rejects but nevertheless was chosen as the second station in the study. This decision was based in part on the internal reject historic data, but in this case interviews with the production technicians also influenced the station choice. According to the production technicians there were some problems connected with this station that were rather severe. The problem was that if an internal reject occurred it could cause a high level of rework on the engine. Figure 3.10 shows results for two periods, the reference period and the reject index for the month of June 2006, a period within the reference period.

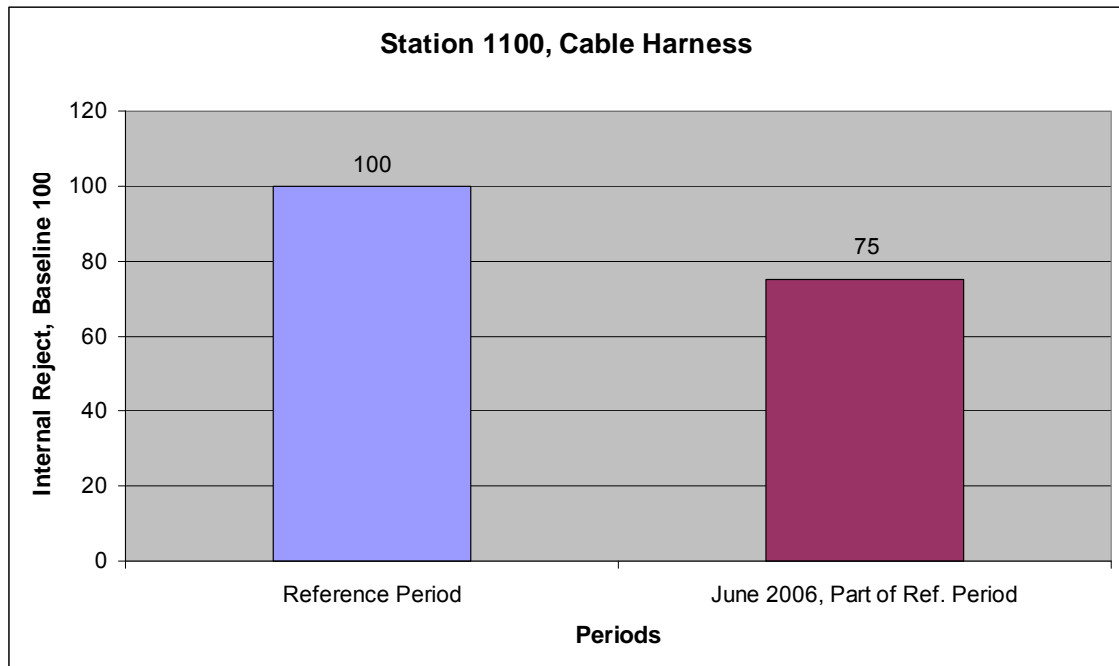


Figure 3.10: Results from the investigation of station S1100 and its internal reject rate.

PARTICIPANTS

Participants and their roles in the study were:

- Experimenter:
 - Designed experiment, defined scope and frame for case study.
 - Informed participants, production leaders, factory management and technicians about the study and how it could affect the daily work.
 - Created and gave instructions to participants regarding how they should act during the study.
 - Trained and assisted participants that had an active role in the study.
 - Compiled and assembled work orders used by assistants at the beginning of the line during the study.
 - Gathered and compiled data before and after the study.
 - Analysed data, reject statistics, before and after the study.
 - Actively worked within the study with the experiment.
 - Conducted interviews with participants after the study.
 - Created and distributed information regarding the results.
- Assembly workers:
 - Assembled the engines according to the defined assembly process.

- Reject data registration was conducted by assigned persons from the assembly personnel. This is part of the regular assembly process.
- Assistants:
 - Applied and removed the triggers on the production equipment. Registered engine numbers and colour coding, i.e. connected the specific engine individual to a specific trigger colour setup.
- Management: The assembly plant managers had an indirect but important part in the study. Their role was to support the work and thereby create the possibility for the study to be conducted.
- Technicians: Their role was to support the study with their expertise regarding the assembly process.
- Material handling personnel: The material handler was indirectly an important person, as his/her main responsibility was to deliver material to the assembly line. The handler also moved the colour coding material from the empty material containers to the new full containers.
- Quality coordinator: Expert regarding the work quality in the assembly line.

The experimenter, case study leader and author were the same person, and performed the roles based on previous experience and training.

The experimenter had knowledge regarding:

- Manufacturing environments:
 - General: General knowledge regarding manufacturing from previous experience within the industry. Work close to the assembly process as a maintenance engineer and builder of automated assembly machines for a period of approximately three years. Work as a consultant for approximately two years within the field of systems engineering at the plant where the study took place.
 - Specific: Work at the assembly plant for a period of more than three years in the Research and Development department.
 - Projects: A total of five projects have been conducted at the plant that have contributed to the preparation of the study.

It should be noted that a majority of the assembly personnel responded very positively to being a part of the experiment. Typical reactions were:

- Interesting to see if the colour coded interface would affect their work situation in any way.
- Positive to the fact that someone was working with problems that they had to handle every day.
- That it might be easier to introduce new personnel to the assembly environment.

FIELD EXPERIMENT

The field experiment was conducted day and night during the period 12.00 24th May 2007 to 00.00 6th June 2007

Assembly process, before study

This process is presented in Section 2.2.1 and in Figure 2.9.

Assembly process, during the study

The process during the study is in a sense the same as before the study except in one important aspect, and that is the trigger. The trigger is a predecessor to “1. Identification of parts.....”

0. Trigger.
1. Identification of part to assembly. This identification process is not necessary on 100% of the stations as some of the assembled parts are identical on all engines.
2. Retrieval of part to assemble. The personnel gather part to assemble.
3. Assemble part on engine.
4. Repeat steps 1 to 3 until all parts are assembled.
5. Confirmation of task. The personnel confirm that they have done all assigned tasks at the station; this is done via an IT-system.
6. Carrier departs from the assembly station to the next station.

Equipment used

The experiment was performed on site in the assembly factory, in a production assembly line. Therefore, the equipment used was the same as during regular production. This includes such things as:

- Carrier.
- Information System.
 - Computer interface.
 - Paper instructions.
- Lifting aids.
- Etc.

No prearrangements were executed that influenced the production context, except arrangements for the handling of the triggers (the magnetic sheeting). A workstation at the beginning of the assembly line was built (see Appendix A: Layout assembly). This workstation contained a table, notebook computer and a chair.

Accessories

Accessories used within the assembly environment specific for the case study:

- Magnetic rubber sheets.
- Notebook computer.
- Production schedules.
- Paper instructions specific for the study.

Case study influences

In all experiments there is a possibility that the experiment itself influence the results. In this study four experiment groups were used with the purpose of creating an understanding of how this particular study might influence the personnel and thereby the results. The different experiment groups were separated by two different variables:

- A: Interaction: Interaction will be varied between A1:“High”, experimenter actively interacts with the assembly personnel at their workstations (ask questions, starts discussions about their work etc.), A2:“Low”, very little or no interaction between the experimenter and the assembly personnel.
- B: Trigger: B1:Present or B2:Absent. The triggers are the magnetic rubber sheets attached to the carrier mentioned earlier.

Control group A2B2: The results from this group are the historic data from the period 13th March 2006 to 22nd December 2006. These results will be used as a reference value for the experiment groups.

Experiment group A1B1: High interaction and trigger present.

Experiment group A1B2: High interaction and trigger absent.

Experiment group A2B1: Low interaction and trigger present. The experimenter will be situated at the beginning of the assembly line.

3.2.3 Results

Quantitative evaluation of the results

The evaluation of the data showed:

- **Quality:** A decrease in the number of internal rejects from assembly station S800 and S1100 during the period 12.00 24th May 2007 to 00.00 6th June 2007, compared to the reference period 00.00 13th March 2006 to 00.00 22nd December 2006.
- **Productivity:** No effect could be found regarding the station time, i.e. there were no differences, before, during or after the study regarding the assembly time.

The data showed that the rejects during the study decreased to 59 (baseline = 100, Section 3.2.2) for station S0800 (Figure 3.11) and to 0 (baseline = 100) for station S1100 (Figure 3.12).

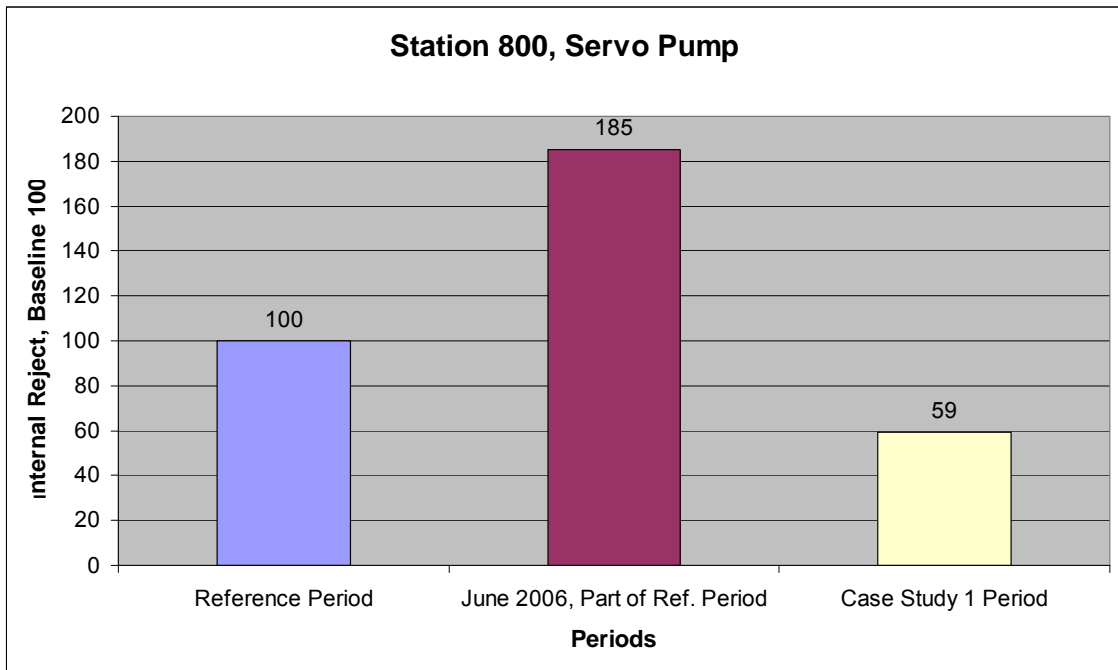


Figure 3.11: The internal reject rate for station S0800.

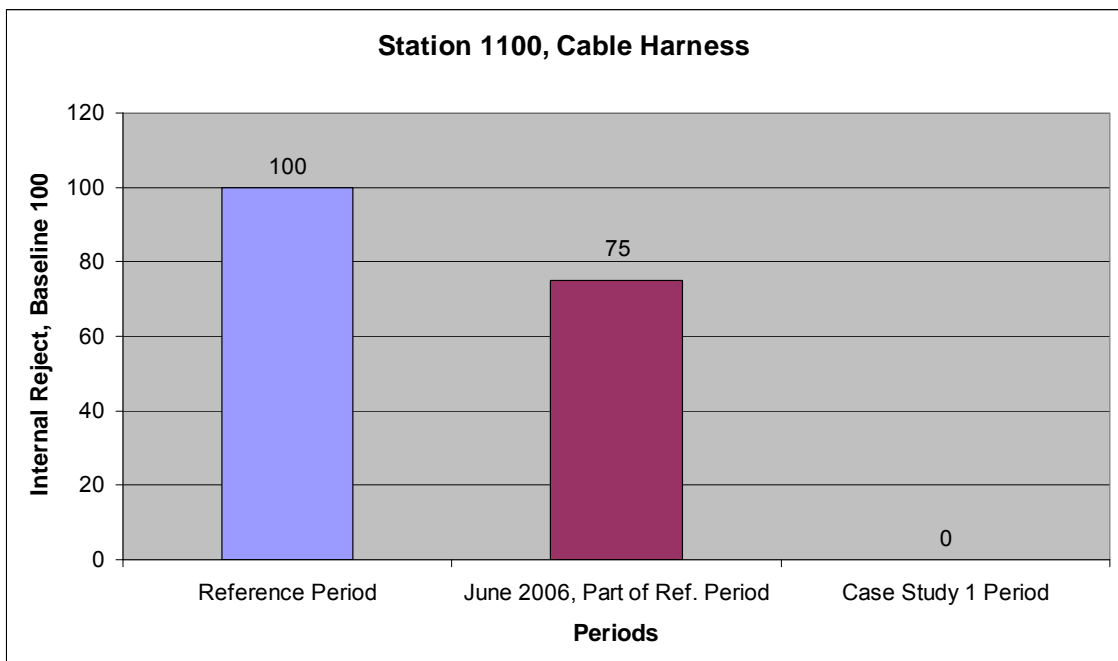


Figure 3.12: The internal reject rate for station S1100.

The decrease during the study for station S0800 was approximately 41 points compared to baseline (Section 3.2.2.) while for station S1100 the decrease was 100 points, i.e. no rejects occurred during the case study period.

Qualitative evaluation of the results

A qualitative approach was added in the later part of the study. The main reason for this was to gain a better understanding of what caused the results - the decrease in the number of internal rejects.

There were two parts to the qualitative evaluation, a questionnaire survey and an interview. The survey was conducted among the personnel that were directly affected, those who work at station S0800 and S1100, and indirectly affected those who in some way were a part of the manufacturing system in question, the assembly line for the 13 litre engine. The interviews focused mainly on the persons from the support organisation, for example line manager, quality technicians, production technicians.

Questionnaire Survey

The questionnaire survey was conducted among 171 persons that worked or work in the manufacturing system in question. The questionnaire was in Swedish, but a translation to English can be found in Appendix C.

- 171 individuals participated in the questionnaire survey.
- The response rate was 100%.
- The questionnaire contained 36 elements.
 - The elements were formulated in two different ways:
 - As a statement: for example “The use of Colour Coding worked very well”, and the alternative (in this case) was on a 7-point scale, from “Agree Entirely” to “Disagree Entirely” with “Neither or” in between.
 - As a question: “Do you feel secure with the Colour Coding that was used in station S0800 and S1100?”. The answer alternatives were; “Yes”, “No”, “Sometimes”, “Sometimes not”. The two latter alternatives had follow-up questions where the individual was asked “When?” and “Why?”
- The personnel were encouraged to write as many remarks as possible. The last page in the questionnaire was a blank page which the individuals could use for feedback to the researcher.
- The questionnaire survey took place on four occasions, one time for each shift and once per subject. The researcher was present during the time when the personnel filled in the questionnaire.

The questionnaire was divided into sections. In the first section the personnel were asked to state year of birth, gender, main assignment, years at the company, years in the assembly department, shift (day, evening, night, weekends) and if they had worked on station S0800 and/or station S1100. If the answer was No on the last question they were directed to question 2.8 in Section 2. The data collected regarding year of birth, gender, main assignment, years at the company, years in the assembly department and shift were not used further in this thesis, but might be used in the future as foundation for experimental design purposes.

Section 2 started with specific questions for those who had worked at station S0800 or/and station S1100. There were seven questions that were directed towards the Colour Coding. One of the purposes with the questions was to establish if there was some connection between the results from the quantitative evaluation and what the assembly personnel had experienced, but also what the personnel felt when they worked with the colours. The results were interesting in more than one respect; the first question that the individual had to consider was if the Colour Coding had any positive effect on the quality and 87% answered that it had affected it and 23% stated that it affected it “to a very high degree”.

The answer alternatives to the question (Figure 3.13):

“Do you believe that the Colour Coding used on station S0800 and S1100 influenced the quality in a positive way?”

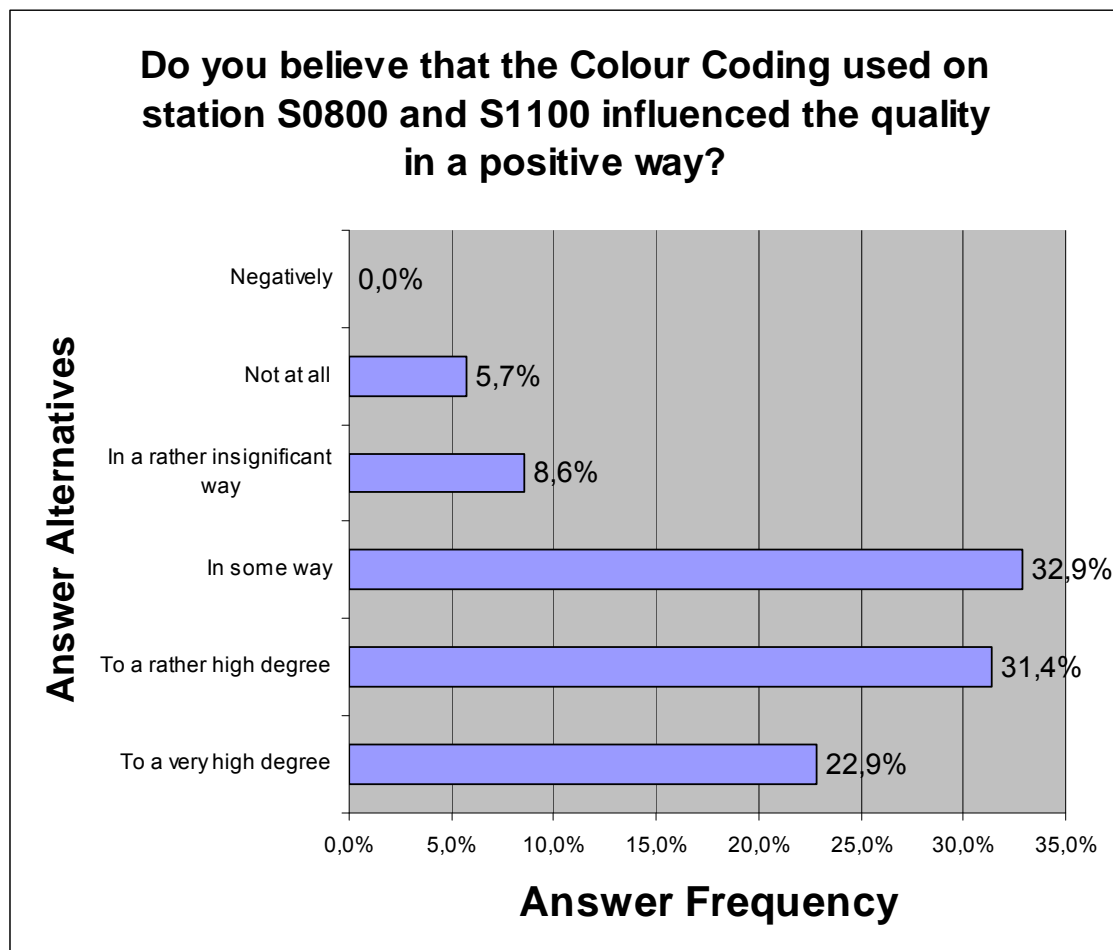


Figure 3.13: Answer distribution for question 2.1 in Appendix C.

When the assembly personnel answered the questionnaire, they did not know for a fact that quality was the performance indicator used in the study to measure the results. This can be of importance if one believes that a placebo/Hawthorne¹¹ effect can in any way influence the participants in a study.

On the question (Figure 3.14):

“Did you feel secure with the Colour Coding that was used in station S0800 and S1100?”

¹¹ The Hawthorne effect: an increase in the output due to experimental manipulation. For more information see e.g. Holden, J. D. (2001). Hawthorne effects and research into professional practice. *Journal of Evaluation in Clinical Practice*, 7 (1), 65-70.

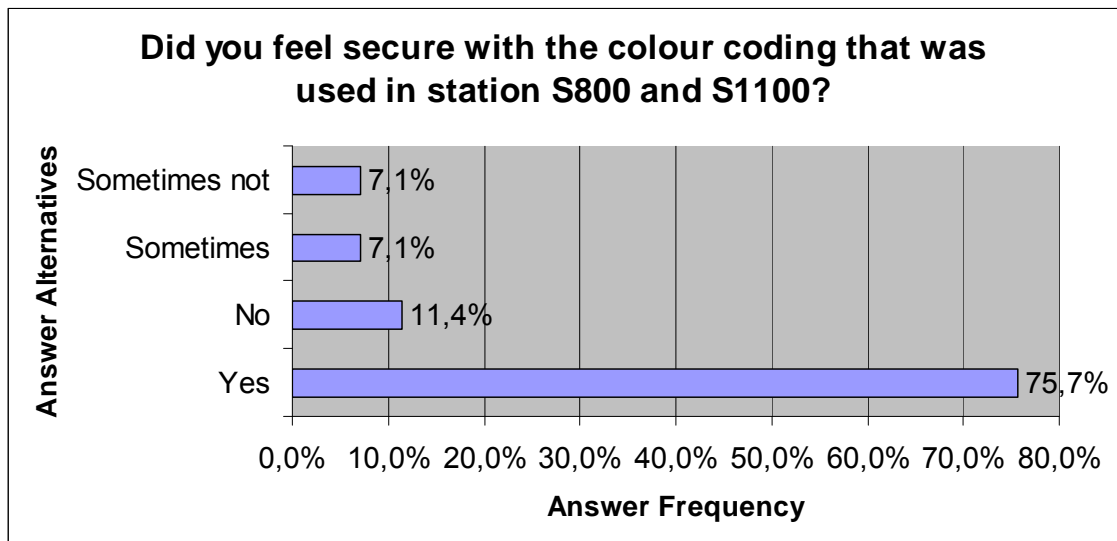


Figure 3.14: Answer distribution for question 2.2 in Appendix C.

When they were asked why they did not feel secure or trust the colour, the answer was that they did not trust the persons applying the Colour Coding to apply the right colours. Some made a remark in the questionnaire at the question and stated that the colour coding applying process was a manual process and that this could be negative from a human error perspective.

A core issue is whether or not the information presented supports the assembly task in a correct way. The results from the survey (Figure 3.15) show that a majority of the personnel is of the opinion that the amount of information that they receive via colour coding was enough for them to successfully perform an assembly task.

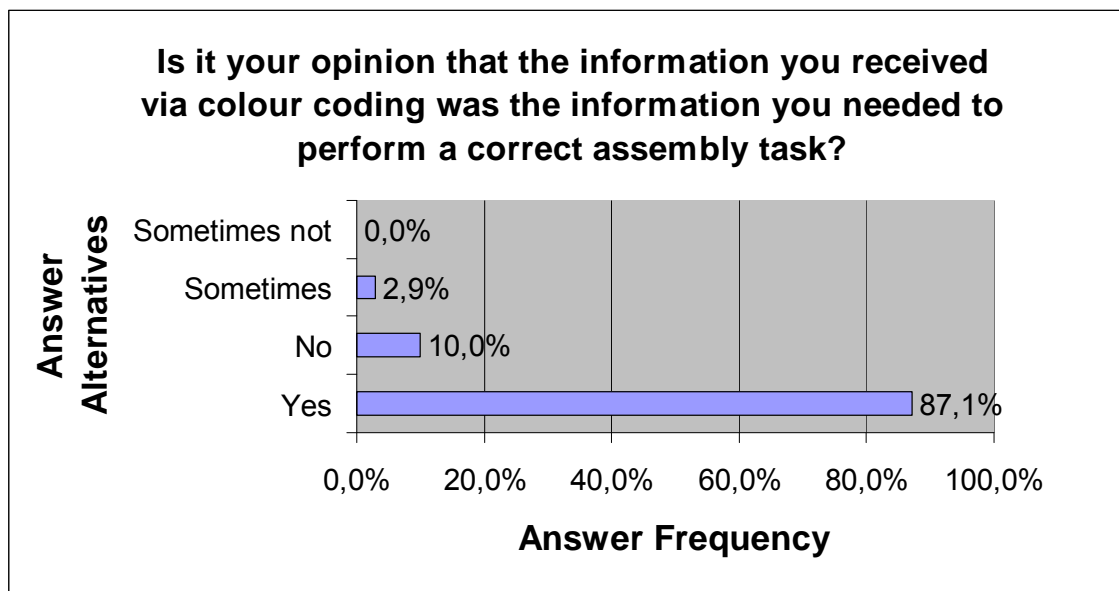


Figure 3.15: Answer distribution for question 2.3 in Appendix C.

The remarks and the answer distribution show that the information provided via the colour was sufficient from a task performance perspective. Examples of the remarks made by the assembler (descriptive comments in brackets)¹²:

... facilitates a lot on Station 1100 [cable harness]. It [the colour coding] provided a much better feedback on which cable harness I had to assemble. Very positive to the reduction of information regarding what to assemble on the engine...

...I think that colour coding was a superb way to view information; you are spared from unnecessary information...

...colour coding makes it possible to quickly see what to do...you are a lot more attentive [with colour coding], can focus on the important...

...harder [without colour coding] to pick parts, many part numbers are rather similar, easy to read on the wrong row [graphical user interface]...

To minimise losses connected to assembly it is important to eliminate waste. An important part of information presentation is to present the information at the right time, when the information is needed. There is more than one reason for this, in this case it is interesting from the two perspectives of quality and productivity.

¹² The quote translated by researcher.

In the questionnaire the personnel were asked if the colour coding could contribute to their knowledge regarding what to assemble next (Figure 3.16).

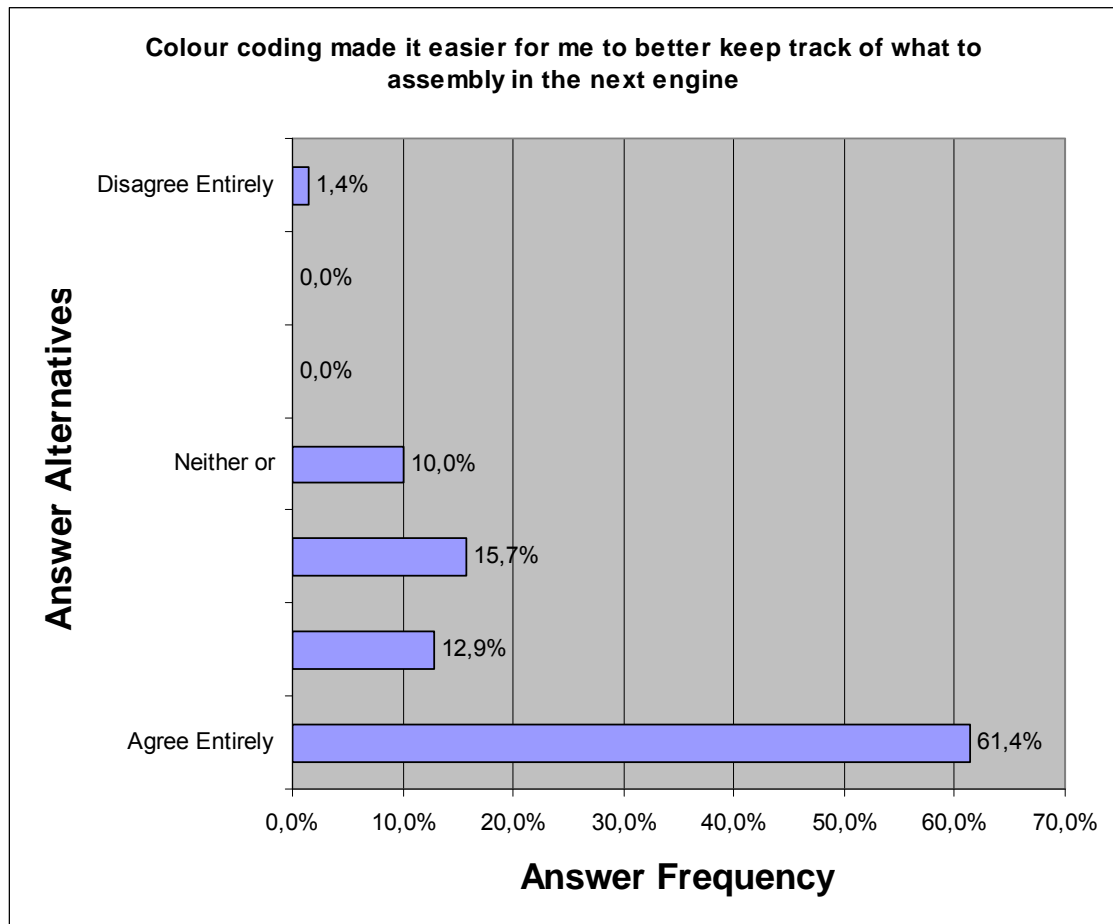


Figure 3.16: Answer distribution for question 2.6 in Appendix C.

Some of the remarks, oral and in writing, state that a problem exists regarding when the information is presented to the personnel. In the existing system the information is presented to the personnel when the carrier arrives at the assembly station, but according to the personnel the need actually arises when they are finished with the current task. Since the information is absent until arrival of the carrier the personnel are forced to either:

1. Wait until the carrier arrives at the station. That is, do nothing until the carrier arrives.

2. Walk to the previous assembly station and by looking at the engine on that station try to, by using their knowledge, investigate what to assemble at their station (the next station).
3. Try to predict what is to come and prepare for it.

The first and second alternatives create waste and contribute to the productivity in a negative way. The second and third can directly affect quality negatively. According to the personnel having the information present at the right time is important for an effective assembly process. A suggestion showing a user interface that contributes to the work process with an early information presentation will be presented in Chapter 4. The study has shown that an information system which supports early information presentation is beneficial for productivity as well as quality, and is an important support for the personnel.

3.2.4 Discussion of case study results

The information process and the colour coding used within the study enhanced the information search process by:

1. Presenting the information so that the assembler can see the information from their station (Figure 3.17).

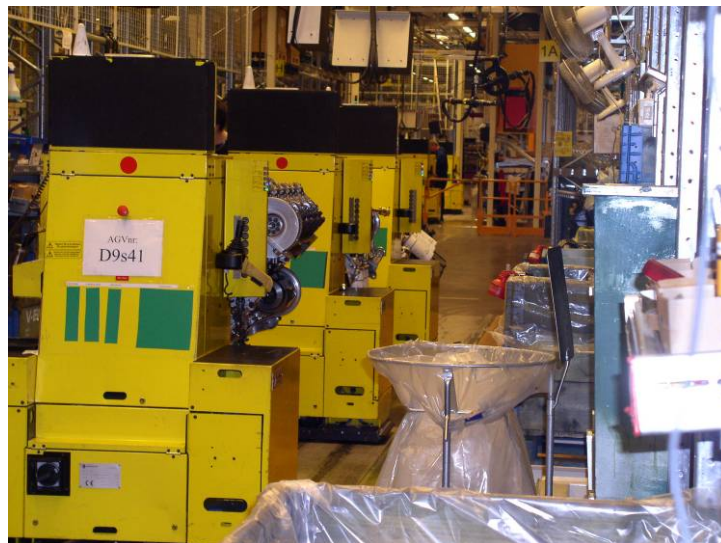


Figure 3.17: Example of what the personnel can see regarding what type of variant is approaching their assembly station.

2. Making it easier to identify from a distance what to assembly.
3. Providing the information so that the information is presented when a need has occurred.
4. Eliminating the need to learn by heart where in space the parts that should be assembled are located.
5. Creating a less demanding workload due to the elimination of noise (i.e. redundant information).
6. Triggering an information search process when it is needed.
7. Supporting part changes, for example when a design change note is initiated. When this occurs, it is possible to make the change without changing the colours in the work environment. If a new part is added new colour can be added. By using the existing colours or just adding a colour, the need to learn by heart where the parts are located, the productivity losses during the learning and the training needs are lowered in a significant way.

These enhancements are directly connected to the quality and are also believed to considerably affect the productivity.

An interesting addition to the productivity evaluation was initiated by a remark from one of the participants. According to this statement the assembler could decrease the station time from seven to three and a half minutes during the study, i.e. a productivity increase was an effect of the use of colour coding.

Therefore, an evaluation of the station time was conducted, and was a direct effect of Case study 1, but was a part of the results evaluation process.

This evaluation included a Business Object question that made an inquiry based on the date and station, in this case 24th May 2007 to 6th June 2007 and stations S0800 and S1100. The results from that inquiry were compared with inquiries for a period before and a period after the study. The results showed no affect on the station time during the study. In an interview session with the production technician, quality coordinator and production manager one of the quality coordinators described this as (descriptive comments in brackets)¹³,

...I have worked on the station [cable harness station] in question before I became a quality coordinator, and the first thing that struck me was that I felt more

¹³ The quote translated by researcher.

relaxed and that I work much more calmly ...the pre-work [pre-work is a way for the personnel to prepare themselves for the next task. If the pre-work is used in a wrong way, the quality can be affected] changes, I did not feel a need to prepare myself in the same way [compared with the way he did when there was only data/information provided by the computer screen]...the number of pumps [servo pumps] that I needed [“need” in this case is a subjective conclusion that differs from person to person and is not a part of the described assembly work process] to prepare could be “lowered” because by just looking at the previous station and the carrier at that station I knew what was to come...

The comments from the quality coordinator indicate that the pressure from the assembly tasks on him was less when he could use the colour coding. It also indicates that the task could take less time, but in this case the person used the time savings to change his work process in a way that lowered the work burden. The missing evidence that time was saved could be explained by the fact that the personnel did not use lowered station time to assemble more engines, but instead they used the time to lower their work burden. Another issue that it is important to keep in mind is the design of the report system and the production system. In this case the assembly line layout did not support an evaluation of the assembly time due to a queuing affect before and after the assembly stations. This statement is supported by the results from a question in the survey. In the survey the personnel that used the colour coding were asked to reply to:

“It was faster to use colour coding when I assembled”

They could reply to this statement on a 7-point scale that covers from “Agree Entirely” to “Disagree Entirely” (Figure 3.18).

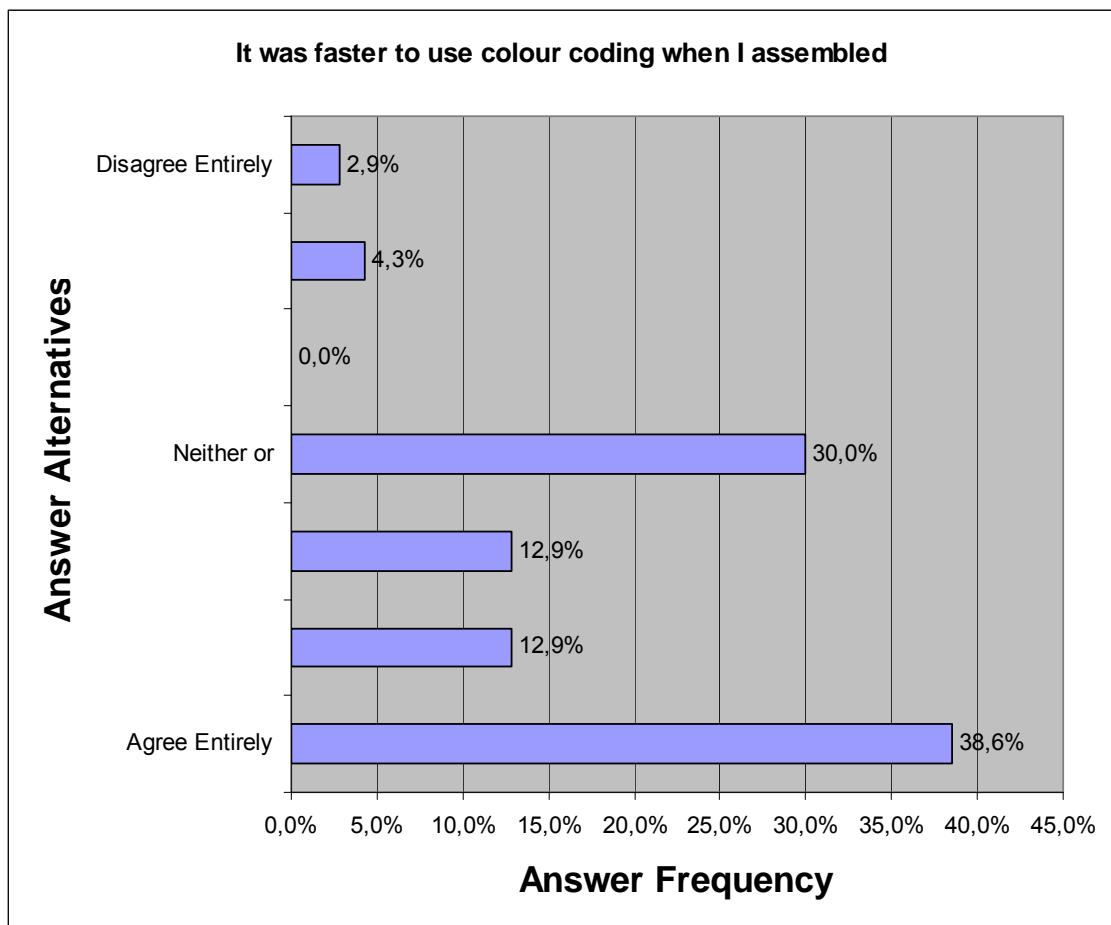


Figure 3.18: Answer distribution for question 2.5 in Appendix C.

38% “Agree Entirely” that they could lower the assembly time by using the colour system.

The conclusion is that although it is not possible to show quantitatively that the cycle time was affected, it is possible to qualitatively suggest that it is plausible that such an affect exists. The statements made by the assembly personnel as well as the statements made by the quality coordinators should be weighted highly due to their great experience regarding the assembly context.

The results from the study clearly indicate that information has a strong affect on quality as well as the ability for the assembler to identify information needs. They show a possibility of increasing productivity. This will be addressed further in Section 3.3.

The study supported the conclusions from Section 2.5 where it was stated that the amount of information, information presentation and attention influence the internal reject rate as well as the productivity. There are however some interesting issues that were not possible to see during the literature review. It was not possible to understand

that the timing of the information had an important influence on the assembler during their assembly tasks. The way that the information system was designed revealed that the feeling of control was an important aspect for the assembler. The system used during the study made it possible for the assembler to get information regarding what was to come and thereby it was possible for them to prepare both mentally and physically (gather parts etc.).

There are issues in this study that are hard to measure. The reaction among the personnel directly involved is one of those issues. One common reaction was that the reduction of the amount of information was one of the main benefits with the colour coding. This made it possible for the personnel to quickly find relevant information without noise from redundant information.

The feeling of control that the personnel expressed is also an important result from the study. It is difficult to measure how this might influence quality and productivity, but it is still an important input that supports hypothesis 2 (Section 1.3.1).

The main conclusion is that the study supported the substantiation of both hypothesis 1 and 2. By showing that a trigger, in this case a change of colour, affects quality in a positive way and that issues like the amount of information as well as the timing of the information might have been identified if a evaluation method had been used during the design of the information system.

During the analysis of case study results, four interesting issues were discussed with the personnel involved.

1. The case study effect on the internal reject rate, according to the quality coordinator (Figure 3.19).
2. An effect on the internal reject rate directly after case study finished (Figure 3.19).
3. The use of case study information in other parts of the line.
4. Case study affecting other types of quality problems at station 800 and 1100.

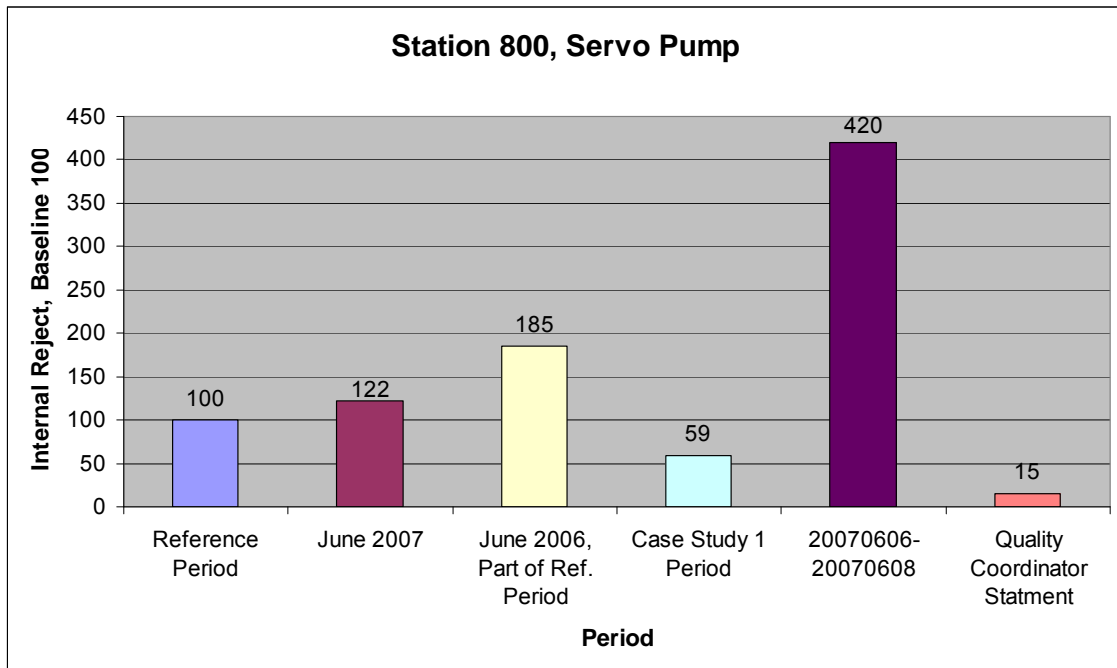


Figure 3.19: Case study results including reject rates for a two day period after case study finish and quality coordinator statement.

The quality coordinators (in this case there were two) are personnel with long experience of the assembly line. They need to have knowledge regarding how to assemble an engine as well as how quality work should be performed. Their knowledge was used in the analysis phase of the study. According to their analysis of the internal reject rate for the case study period some of the problems counted should not be a part of the results. Therefore, according to the quality coordinators, the actual internal reject rate for the case study period should be as low as 15 point (baseline 100). Their conclusion should be highly weighted in this discussion due to their expertise, but the results from the study will still be presented as 59 points.

During the analysis phase, data from periods directly before and after the study were investigated. The data before the study do not reveal any major differences compared with the reference period. However, when investigating the data for the period 00.00 6th June 2007 to 23.59 8th June 2007 directly after the case study, some interesting findings were made. During this period the internal reject rate increased from 59 (15) to 420. It decreased in the following days to a level similar to that before the study. This increase is significant. An investigation was made regarding the manning of the stations, to see if any major changes had been made on the assembly station and if any new products/parts had been introduced during the period. This investigation revealed that no such change

had been made during either the case study period or the period directly after. No evidence could be found that could explain the significant increase. However, a reflection regarding this is that the personnel might have adapted to the colour coding during the study and that the high reject rate for the period after the study could be connected to the fact that they had to go back to using the information system used before the study. This indicates two things:

1. It is a demanding task to learn or refresh knowledge using the existing information system.
2. The learning curve and its influence on the assembly time can also affect the quality.

These indications are in some sense supported implicitly by results from Case study 2 (Section 3.3.4 and 3.3.5), but will not be addressed in depth in this thesis.

In discussions with the assembly personnel during and after the study it became clear that the information provided by the colour coding was used on assembly stations that were not part of the study. In particular one station, assembly of oil pan, used the information in a way that made it possible for the personnel to prepare the assembly task before the carrier with the engine arrived at the assembly station. This made it possible, according to the assembly personnel at the station, for them to lower their workload significantly. The task of preparing the oil pan is time consuming and can be a bottleneck if any problem occurs during the preparation work. Colour coding made it possible for the personnel to use the information earlier and thereby was it possible to use the time they had between engine departure and arrival in a more effective way.

The quality coordinators had also identified other effects that according to them were a spin-off effect caused by the study. The effects that they identified were on quality issues other than the ones that were a part of the study. According to the coordinator a quality problem connected to a cut o-ring (used as oil sealing between the servo pump and engine) decreased or vanished totally during the case study period. Their conclusion is that the time saved by the use of colour coding can lower the assemblers' workload and this can affect the way the assemblers perform their tasks.

These four issues are all an effect of Case study 1. Issues 2-4 were not part of the study initially, but they are an effect of it.

3.3 CASE STUDY 2 – LABORATORY ENVIRONMENT

In Case study 1, presented in Section 3.2, no effect on productivity could be measured. This is not that strange when one studies the production line. There are different ways to move a product through a production line:

- “Stop and go”: the personnel for example press a button that indicates that he/she has finished with the assembly and that the carrier can move to the next assembly station. If the following station is occupied, the carrier will have to wait until the station is cleared.
- Paced line: all the carriers move at the same time.
- Continuous moving: the carrier is slowly moving forwards at a constant speed.

On the specific production line a Stop and go system is used. The station time is balanced for an assembly period of seven minutes, i.e. it takes approximately seven minutes to complete all tasks at an assembly station. This system makes it difficult to measure the time it takes to finish all tasks at a station due to uncertainties regarding the trustworthiness from such a measure. There are too many parameters that can affect the results. Therefore a laboratory experiment was initiated with the purpose of investigating if different types of presented data and/or information could influence productivity in any way.

Case study 1 showed that information could influence quality in a positive way. Unfortunately, it was not possible to evaluate if the same affect could be found connected to productivity.

Case study 2 used different user interfaces for the same assembly task and the hypothesis was that different interfaces could affect the quality and productivity.

3.3.1 Study outline

The aim with the case study was to find some evidence that supports the two hypotheses presented in Section 1.3.1:

Hypothesis 1 - ‘Information Seeking Behaviour’

The degree to which Active Information Seeking behaviour is supported/triggered has a large influence on the number of internal rejects.

Hypothesis 2 – ‘use of evaluation methods’

The use of an evaluation work method in a design process of an information flow will affect the internal reject rate in a positive way.

EXPECTED RESULTS

The expected results from the study were further knowledge regarding how information affects productivity and quality and whether or not the outcome supported the hypothesis.

PERFORMANCE INDICATOR

In Case study 1 presented earlier in the thesis the main performance indicator was the historic data gathered at the assembly plant. Due to the nature of Case study 2 no such data existed. The performance was measured between the three groups, described in detail in the experimental design, Section 3.3.2.

3.3.2 Experimental design

The experimental design was based on a quantitative laboratory experiment.

EXPERIMENTAL ASSEMBLY ENVIRONMENT

The experimental environment was specially designed for the experiment. It was located in a controlled area where only the participants had access.

PARTICIPANTS

Participants and their roles in the case study:

- Experimenters:
 - Designed experiment, defined scope and frame for study.
 - Informed participants, production leaders, factory management and university personnel (those affected) about the study, and how it could affect the participants work during the study.
 - Created and gave instructions to participants regarding how they should act during the study.
 - Gathered and compiled data before and after the study.

- Analysed the available data before and after the study.
- Actively worked within the study with the experiment.
- Conducted unstructured interviews with participants after the study.
- Compiled and distributed results.
- Assembly workers:
 - The assembly personnel assembled the product according to the defined assembly process.
 - Assistant/experimenters:
 - There were two assistants/experimenters during the study. Their main tasks were quality control, process control, timekeeping and disassembly.
 - Pilot tryout participants:
 - Tested the set up before the case study was started. The purpose was to find problems etc. with the set up before the actual start of the case study. These persons were not involved in the later stage of the case study.

The experimenter, one of the assistants and author were the same person and performed the roles based on previous experience and training. In total there were two experimenters, three pilot tryouts and 30 participants. A total of 35 participants were directly involved in the study.

Assembly process

The assembly process during the study:

1. Identification of part to assemble.
2. Pick part to assemble. The participant gathers part to assemble.
3. Assemble part.
4. Repeat steps 1 to 3 until all parts are assembled.
5. Confirmation of task. The participant moved the finished product to the quality control area.
6. The participant uses the order form on the computer to find out what to assemble next and the process starts over from 1.

Equipment used

The experiment was performed in a temporary laboratory (Figure 3.20) that was equipped specially for the case study. The equipment used was:

- Material front: metal set of shelves, three shelves high.
- Material boxes.
- Lego: within the study, Lego was used as parts to assemble.
- Information System:
 - Computer interface. Three different interfaces were used.
 - Paper instructions.
 - Microsoft Excel.
- Assembly area.
- Video camera and video stand.
- Timer.

Study execution

The study was divided into four major phases:

1. Preparation: The preparation phase included design and building of a laboratory environment (Figure 3.20).
2. Test: A pilot test was conducted with the main purpose of evaluating the setup and to get feedback on the same. Three persons, one student and two employees at the university performed the test.
3. Execution: The study was conducted by 10+10+10 assembly workers, i.e. three groups with ten individuals each, all workers from the reference assembly factory. Each worker started with a two minute training session followed by a 20 minute assembly session.
4. Follow-up: During the study the experimenters performed quality control of each final product and noted the assembly time for each finished product. This data was studied to evaluate if there were any differences in the assembly time and quality between the three groups.



Figure 3.20: Laboratory environment.

3.3.3 Execution

The study was divided into three sessions over a three-day period. There were 30 assembly workers that performed an assembly task and they were divided into groups of ten, ten each day. The task was to assembly a Lego design, see Appendix B, created specifically for the study.

The study started with a two minute training session where the assembler used paper instructions, see Appendix B, to guide them through the assembly task. As a support during the assembly task there was an assembly order presented on a laptop computer (Figure 3.21).

Rubrik	Antal	Instruktionstext
• 56109282	2	
• 55724016	2	
• 56109282	1	
• 57046203	1	
• 55724016	1	
• 57046203	1	
• 60668495	1	
• 56109282	1	

Figure 3.21: Example, user interface.

Different interfaces were used for each of the three days. They all informed the user on what to assemble and when, but they each had a different appearance. The framework for the design of the interface had its origins in the interface used at the assembly plant. The information presented in the interface was what part to pick, assemble, how many of the specific part. The numbers of parts in the assembly was the same but the parts could vary. This variation of parts (they differ from each other by colour and part number) in the assembly made it possible to create a real assembly situation.

The variants and their assembly order were randomised. The main purpose for this action was:

1. To simulate some of the framework existing in a real assembly environment where there are many product variants (Engstrom et al., 1995; Jinsong et al., 2005).
2. To create an environment where automated behaviours could be used (or rather be created) and the outcome from such behaviour could be measured.
3. To evaluate if variants influenced the productivity.
4. To evaluate if the quality of output was connected to specific variants.

After the assembler had been trained, the assembly process started. The first step was that one of the experimenters gave the user access to the interface so that the assembly process could be started. The assembler started gathering parts to assemble according to the order presented in the interface. As mentioned earlier, there were variant orders present that were randomly ordered, so the assembler had to always refer to the interface during the task to make sure that they assembled the correct final product. It was not possible to learn by heart what product to assemble.

After the assembler had finished assembly of a product he/she sent the product to the next station, quality control (refer to Figure 3.22 for layout and process flow).

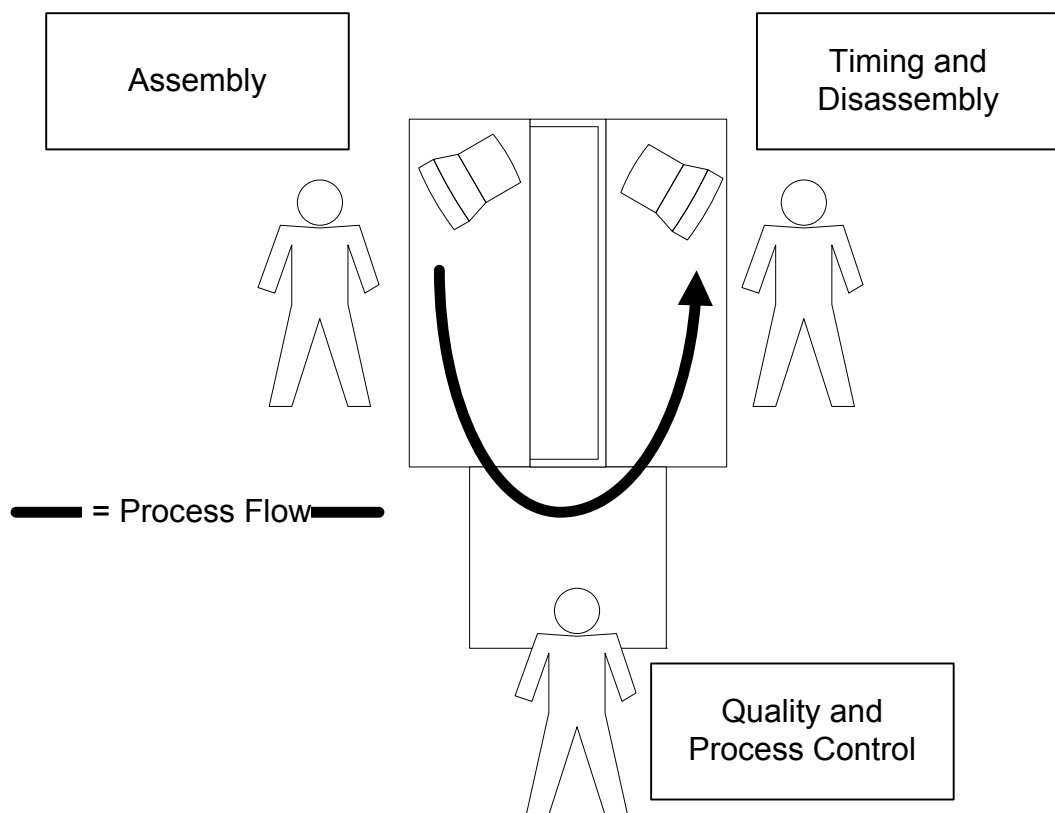


Figure 3.22: Layout and process flow.

The quality control station managed two tasks, quality control and assembly process control. The experimenter studied if the different interfaces effected the process and if so how. The assembly process was documented via a video recorder. This made it possible to study the assembler and the assembly process in the analysis stage.

When the product had passed quality control, it was moved to the next station, timing and disassembly. This station measured the time it took for the assembler to

assemble the final product. The experimenter started the timing when the assembler updated the interface, so that assembly of a new product was ordered. The timing stopped when the assembler sent the final product to quality control. The disassembly task includes disassembly of the final product into parts and putting the parts in the right place in the material rack.

The process was the same during each of the three days of the study. The difference, as mentioned earlier, was the user interface. In figure 3.21, the first day's interface is shown. The three interfaces had one thing in common and that was the information. During the three-day study, the final product that the worker had to assemble was the same. A pilot test was conducted where one of the purposes was to evaluate if a change of interface affected the assembly process. The results from that test showed that the ability to assemble the product was not affected by the different interfaces, although the time it took to assemble the product varied.

Day 2 had an updated user interface, Figure 3.23, where the difference was the presentation of information.

Rubrik	Antal	Instruktionstext
• 56109282	4	
• 57046203	2	
• 55724016	3	
• 60668495	1	

Figure 3.23: User interface day 2.

The same product was assembled with the same number of parts. The interface was updated so that it was possible to minimise the amount of information.

Day 3's interface, Figure 3.24, was updated with a change from numbers to symbols, this was also the case with the material fronts.

Rubrik	Antal	Instruktionstext
• 😊	4	
• ♂	2	
• 😊	3	
• 🎵	1	

Figure 3.24: User interface day 3.

3.3.4 Results

The results, Table 3.1, from the study were measured by the outcome of the two parameters quality and the change in productivity.

Table 3.1: Results from case study.

	Day 1	Day 2	Day 3
Quality, faults detected	3	0	0
Productivity (average)			
• Time/assembly	48.3	34.5	31
Productivity (average)			
• >30s/assembly	33	113	217
Number of assembled	240	330	371
Average time for the assembly of first part	126	66	56

The productivity time average is the time it takes for the assembler to assemble the product. The productivity $>30/\text{assembly}$, is the number of products that were assembled in less time than 30 seconds, and numbers of products assembled during a period of 10 times 20 minutes.

3.3.5 Discussion of case study results

The results show that the effects on the quality were negligible. However, during the first day some of the assemblers used an assembly strategy that created a quality risk that was not measurable. This risk was connected to the fact that some of the assemblers tried to pick the parts first and put them on the table, and after that assemble the product. Some of them lost track of where in the interface they should look for information, and that led them to forget what parts they had picked already. The strategy “pick all parts first then assemble” was successful during day 2 and 3, but was not the right strategy during assembly day 1.

The conclusion is that the case study supported the one made in Chapter 2, i.e. that the amount of information, the way the information is presented, and most importantly, attention are the main influences on productivity. It did not support the hypothesis from a quality perspective in a direct way. However, by showing that information can substantially affect the productivity where the amount of information (totally and in each message) is the main issue it is possible to conclude that a large amount of information indirectly affects the quality. Thereby the case study supported the hypothesis indirectly by showing that the information flow affected the assembly personnel, especially during day 1, in a negative way and made them use more assembly time to find and process information. The results from the case study gave interesting and valuable insights into how the presentation of information can affect productivity and quality. It is rather clear that the total amount of information in a user interface affects productivity, as well as how the information in each message affects the productivity. An interesting fact is that the quality was affected negligibly by the changes in the interfaces. This is believed to be connected to the product that was, from a quality perspective, a rather easy product to assemble. However, during the study variants were assembled.

That the productivity was affected by the changes on the interface is obvious. But is it possible to connect the results to the hypothesis?

In Section 2.5, it was stated that there were three aspects, according to the analysis, that influenced the quality and the productivity; the amount of information, information presentation and attention.

In the case study it was not possible to evaluate if attention was an influencing factor on the outcome of the results. According to the information search process presented in the Section 2.5 attention affects the ability to enter the search process due to automaticity. It might not been possible to produce this automaticity during the short assembly time.

However, there are some interesting indications that automaticity did occur during the study and that this affected the productivity positively. As mentioned the product was easy to assemble and the variant only varied regarding the colours on some of the parts in the assembly. The size and where to assembly the part on the product were the same.

The data gathered during the study included assembly time for the high volume product (Figure 3.25) as well as for the variants, low volume products (Figure 3.26).

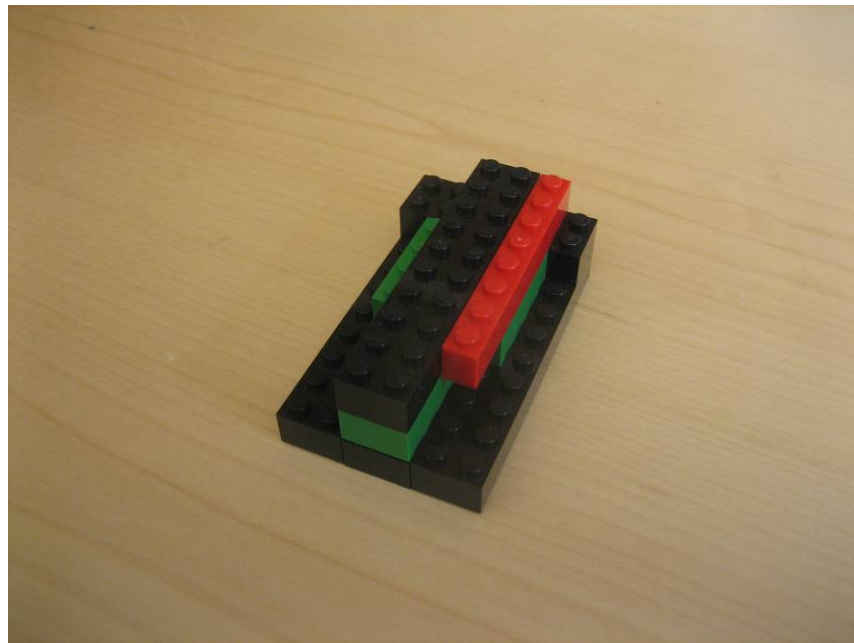


Figure 3.25: High volume product.

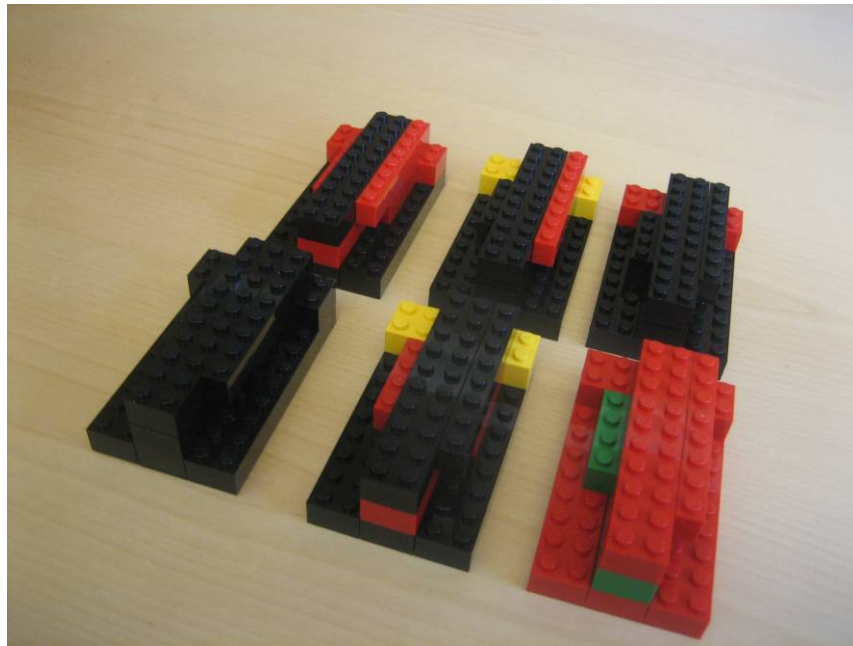


Figure 3.26: Variant, low volume products.

There are indications that productivity was affected negatively when the assembler assembled the variants. By comparing the assembly time for the product assembled before the variant with the time it took to assemble the variant (Table 3.2) is it possible to see that in some cases there are increases in the assembly time.

Table 3.2: Variants and their affect on assembly time.

	Day 1	Day 2	Day 3
Average assembly time index for variant	1.033	1.152	1.064
Number of variants assembled	52	79	88
Number of product variants assembled with a index >1	26	58	57
The distribution for product with a assembly time index >1	50%	73%	65%

It is not possible to draw any final conclusion from this, but the indications show that there might be an effect on productivity. The indication (Table 3.2) is that the variant average assembly time is 3-15% higher than the assembly of the volume product. The distribution for the number of variants with an assembly time index higher than 1 varies from 50% to as high as 73%.

It is possible to see that 50%-73% of the variants assembled took between 3.3% to 15.2% longer time to assemble than the previous high volume product. It is believed that this might be connected to the handling of information and it also might be connected to attention. The reason to believe this is that the product itself is easy to assemble and this is not affected by whether or not the product is a variant. It is also possible to see an effect on the high volume product assembled directly after the variant. It seems that the assembly time on that assembly is affected as well. This negative affect levels away after a while.

The study of how variants affected productivity was not part of the case study, but is interesting and will be addressed in future research together with attention.

The decrease of the amount of information presented in the interface had a large influence on productivity (Table 3.1). The results show that an initially large amount of information can affect productivity significantly, in a negative way. It also shows that an interface design that considers human limitations and strengths, such as working memory, is more efficient.

One issue that was not a part of the initial case study scope was if different designs in the interface could affect the training. It is not possible to determine how the information flow affected the outcome of the short training session that proceeded the assembly session. The fact is that an affect can be seen on the results where the first product average assembly time decreased by more than 50% during day 2 and 3. This is very important from a training perspective and will be addressed in other projects connected to this research but it will not be addressed further in this thesis.

3.4 CONCLUSIONS

The conclusion from the studies conducted is that quality as well as productivity are affected by how well an information search process is initiated and performed, and how the information search process is support by the IT/IS-systems (including paper instructions, computers etc.). The results from Case study 1 shows that the initiation of a correct information search process directly influences quality in a positive way. It also shows that there are other effects that can be difficult to measure, but are still important contributors. The affects that the personnel experienced during the studies, and expressed in interviews and surveys, are important results. The feeling of control, decrease in presented information, the feeling of a productivity increase, the belief that colour coding influenced the quality positively, support for the personnel in their strategic planning, are all examples of results that can be hard to measure from a quantitative perspective, but are obvious from a qualitative perspective.

The results from Case study 1 support the two hypotheses, see Section 1.3.1:

1. The number of internal rejects decreased during the study. The reason for this is that the personnel interacted better with the information as a correct information search process was initiated by the colour coding. The changes in the colour made the personnel more aware that a variant was approaching their assembly station. That is, the personnel's attention was affected by the colours so that they could interact with the information system in a better way.

2. If an evaluation method had been used during the design of the information system, some of the design flaws might have been found. Examples of flaws are the amount of unnecessary information the timing of the information, and the problems with finding relevant information on the computer screens.

Case study 2 clearly showed that information and how it is structured and viewed have a large influence on the productivity. This obviously is the most important part of the outcome from that study. However, the study also indicates that there are more, less obvious, aspects that are of interest in future research. As mentioned in Section 3.3.4 it is likely that there is a connection between productivity and product variants. This might seem obvious, as if the product variant had been different in more significant ways and the difference would influence the assembly process more. In this case the only difference in the products was that the colours changed. This change influences the assembly process so that the assembler must adapt his/her information search behaviour. The adaption creates a need for an active search for information that can guide the person to the right part on the material fronts. It seems that although the assembler uses the information in a much more effective way during day 2 and 3, an affect can still be found on the productivity during variant information handling. A conclusion from this discussion is that one of the reasons for this is that during day 1 the need for an active (including active attention) search process was much higher and that caused the higher assembly times.

CHAPTER 4

DERIVED EVALUATION WORK METHOD

In this chapter an evaluation method will be presented and a description of how this method can be used for analysis of information need. A proposal regarding how evaluation work should be performed during a product lifecycle (PLC)¹⁴ is also presented. The aim is to draw attention to some of the underlying problems of evaluation work in different product lifecycle stages. The discussions are supported with results from a study where an evaluation work method was used.

4.1 INTRODUCTION

Two important conclusions have been made when it comes to the need for information in the assembly line. The conclusions are that two different types of information are needed and they are connected to *decision support* and *process support*.

- Decision support: Whilst decision support is needed during the whole assembly process, what is meant in this case is the support that makes it possible for the assemble personnel to pick the right part variant. For instance, by supporting the worker to pick the right variant out of a selection of five different servo pumps.
- Process support: Process support, in this case, is the support that guides the assembly worker through the assembly task. The focus is on how each part should be assembled on the engine.

In an assembly line, like the one in the reference plant, a number of product variants are assembled. To choose the right variant the assembler needs to consult the information in the assembly context, i.e. the assembler needs decision support. A successful outcome from an assembly task is based on a successful information search process. In earlier chapters a conclusion that has been reached is that attention is an extremely important part of the initiation of an information search process. There is a connection between

¹⁴ The product lifecycle is rather often thought of as the stages that a product go through, from “Introduction” to “End of Life” from a sales perspective. The stages are for example “Introduction”, “Growth”, “Maturity”, “Decline” and finally “End of Life” Ryan, C. & Riggs, W. E. (1997). Redefining the Product Life Cycle: The Five-Element Product Wave. *Journal of Product Innovation Management*, 14 (3), 227-228.

variants that create a decision point, attention and the quality output. Therefore, it is important for a production technician to identify this decision point.

The parts included in a variant can be visually almost identical. They may have the same design and have the same numbers of connections (electrical, hydraulic etc.). But, despite the fact that they possess the same functionality, the design can differ in a way that influences the process, and thereby creates a process variant.

The part variant and the process variant demand different types of information. The part variants create a decision point where the assembler needs information of *what* part to assemble, the process variant creates a need for *how* to assemble according to a specific process that is a result of, for example, a part variant.

4.2 COGNITIVE WORK ANALYSIS

Usability Inspection Methods (a generic term) (Mack, 1994), Human-Computer Interface Design (Sutcliffe, 1995), (Cognitive) Systems Engineering (Rasmussen et al., 1994), Usability Evaluation Methods (Liljegren, 2006) all have one thing (at least) in common, and that is that they all use rather complex analysis methods. These analysis methods and cognitive system designs are well defined, for example in Cognitive Work Analysis (CWA) (Rasmussen et al., 1990; Vicente, 1999; Bäckstrand et al., 2005a), and is an important part of the design phase during the development for example of a new user interface. Examples of the use of CWA for the design of user interfaces can be found in domains like nuclear power plants, aviation, military use and medicine (Vicente, 1999; Sanderson, 2003; Liljegren, 2006).

During an investigation in the early stage of this research a study (Bäckstrand et al., 2005a) was conducted at the reference company with the purpose of evaluating if the workload from the information presented could be one of the sources that affected the internal reject rate. In that case study Cognitive Work Analysis (CWA) was used as a work method for analysing an assembly workstation. In short, the actual CWA was preceded by a 21-hour passive observation where the work on one of the assembly stations was analysed. There were two purposes:

1. To find indicators that showed if CWA could be used in the pre-design phase for an information system, not from a designer's perspective, but rather from a procurer's

perspective. That is, could it be possible to use CWA to evaluate design suggestions submitted via tenders.

2. To determine if it is possible to find and predict tasks, strategies etc. in an existing system and thereby find tasks and strategies that could be helpful for the personnel to adapt to, or which in a worst case could create quality problems.

The results from the study indicated that it is likely that CWA could be used for the purpose described above. This is obviously one of the reasons for the creation of a work method such as CWA. Sanderson (2003) discusses the connection between CWA and first-of-a-kind system. This is interesting because many of the systems in an assembly plant are of that type, first-of-a-kind or “the only”-of-a-kind. Sanderson presents two cases where CWA is used, one where the focus was on interface design and the other focused on systems evaluation. Both cases presented systems where the final product were highly advanced systems, a nuclear power plant and an air defence platform.

The examples above are meant to put the case study performed at the plant, in general and CWA in particular in a wider perspective. It seems that CWA is a method that is very useful and that CWA and similar methods are sometimes a necessity as an analysis tool during system design, where the final solution supports dangerous or complicated work. Compared to a nuclear power plant an assembly environment is rather uncomplicated and the consequences of a failure are far less critical.

One important conclusion from the study at the reference company was that it is extremely time consuming to perform a CWA.

The first part of the analysis was to gather data regarding the use of the existing system, this during 21-hour (This is not possible of course if the final product is a first-of-a-kind system). The next step was to use the syntax that CWA provides and by doing that, evaluate if the problems encountered could be found by using CWA.

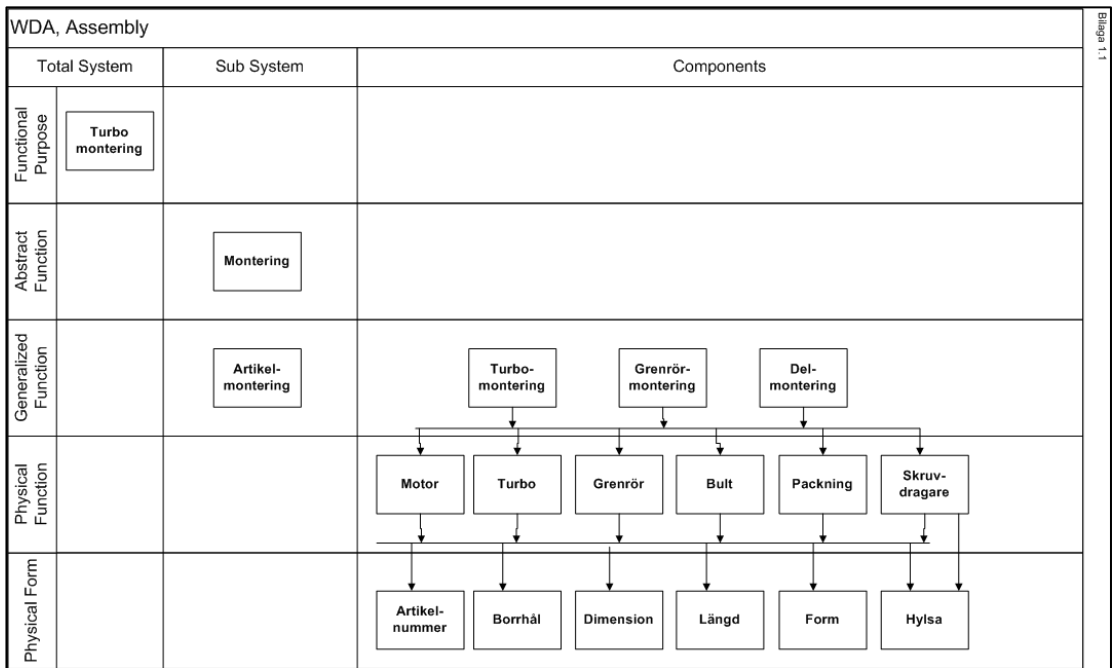
The aim of CWA is to find situations and strategies for unanticipated events that the human operator may face, and to identify these situations/strategies in the interface design phase. This makes it possible to design information systems that support the operator better. One fundamental idea behind CWA is that constraints in the work environment and the cognitive competences of the operator shape work activities (Sanderson, 2003). But, it is also a method that is useful when discrepancies are observed between design intentions and actual use of a system (Rasmussen et al., 1990). This fundamental idea includes seven dimensions; “Work Domain, Task Space”, “Activity

Analysis in Domain Terms”, “Decision Analysis in Information Terms”, “Information Processing Strategies”, ” Allocation of Decision Roles”, ” Management Structure”, “Mental Resources, Competency, and Preferences of the Individual Actor” (Rasmussen et al., 1990). These dimensions form the five-phased framework of CWA. The five phases are (Sanderson, 2003; Fidel and Pejtersen, 2004):

1. Work Domain Analysis (WDA): Identification of physical and purposive (defines why technical system exists) constraints for the workplace where the activities take place, in this case an assembly station.
2. Control Task Analysis (CoTa): Defines what needs to be done within a work domain independently of how the task is to be achieved or by whom.
3. Strategies Analysis (SA): Identification of different strategies for accomplishing the task or work defined in the CoTa.
4. Social-organizational analysis (SOA): Identifies how the responsibility for the execution of different strategies is divided among humans and between humans and automation.
5. Worker Competencies analysis (WCA): Identifies the worker competence needed to accomplish the identified tasks.

There is no hierarchical or strict sequential order between the different dimensions. Therefore, the user of CWA does not need to follow a strict execution order when performing the CWA. Instead, the user can define a path and method suitable for a specific problem (Fidel and Pejtersen, 2004).

The data gathered should be mapped and used in the five phases presented above. In CWA this mapping is done with support from different diagrams, see figure 4.1 and 4.2 for examples.



Bilaga 1.1

Figure 4.1: Example of WDA. This example is taken from the case study and views the different components at the specific assembly station.

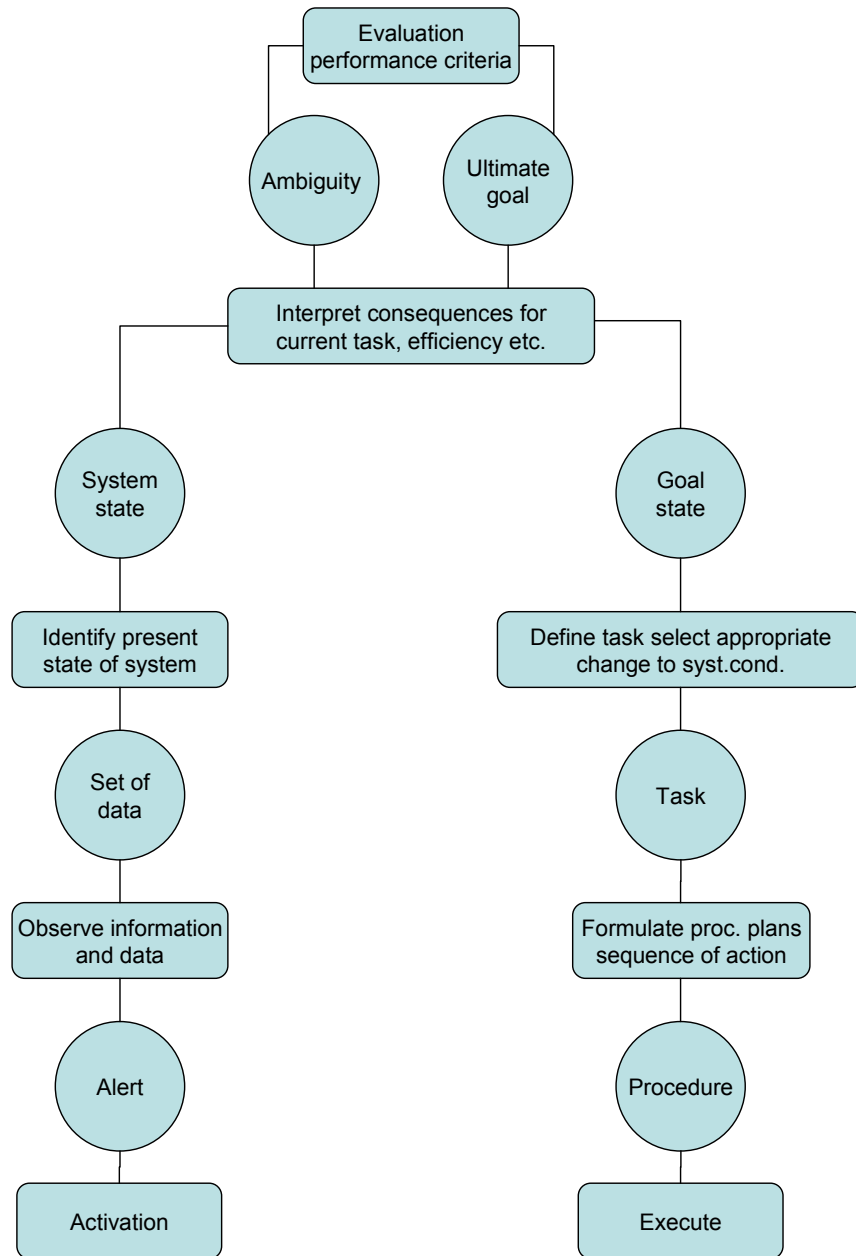


Figure 4.2: Example of flow chart that supports the mapping of CoTa.

These diagrams, flow charts etc. are very useful during the analysis work and without them the work of creating meaning from the vast amount of data gathered is difficult.

The problem with CWA is the time it takes to do the analysis work and create the documentation. The time it takes to gather all the data needed and to create the documentation is far too long when it comes to system updates.

4.3 EVALUATION NEEDS DURING PRODUCT LIFECYCLE

There is no doubt that it is of great importance that an analysis method is used during the design stages of a system as well as during the entire system lifecycle (Bias, 1994; Nielsen, 1994; Wharton et al., 1994; Sutcliffe, 1995). The problem is that an analysis method like CWA is far too advanced to be used by technicians in their daily work. As a method used to create a system, yes, to use it as a method to decide what to view on the interface used by the assembly worker, no. At this point, it might be appropriate to define what a change is. A change is not a change that affects the interface itself. In this case, it is a change in the final product in a way that affects the information presented on the computer screen. This change can be minimal from a product perspective, the product's shape is the same, but the characteristics are changed. This can trigger the creation of a new part number and often that is the only visual change made to the product. These changes are a natural part of a product evolution process. An existing information system has to be able to handle this kind of change in an effective way. An IT/IS-system has to be easy to update when this change occurs, but that is not of interest in this case, the important part is how the technician can understand in an easy, fast way how a change will affect the assembly worker and the system's ability to handle the changes.

The methods above all evaluate a work environment, an existing or a future one, from a human perspective where human factors is in focus. This makes the analysis work rather complex and time consuming and the results provide the analyst with a vast amount of information. These are the fundamentals that the new system is based on, and they exist and continue to exist during the lifetime of a system. The conclusion from the analysis is based on the knowledge of how humans act and react due to our strengths and limitations. These human characteristics will not change during the system's lifecycle, i.e. the results and findings that the initial analysis gave in the design phase of a support system will be valid during the whole system's lifecycle, if we assume that the initial analysis work was performed in a correct way.

If one assumes that the human has the same abilities and limitations during a system's lifecycle, then one can assume that a system update is not required due to changes in those abilities and therefore a new CWA analysis should be unnecessary. With this in mind, one has to ask, if the human is a constant, what is not? The assembly system includes some fundamental parts:

- The human.
- The information system.
- The product.
- The process. The process includes such things as:
 - The assembly process.
 - The material facades.
 - The product transport system, in this case a carrier.

The human could be seen as a constant. The information system is based on the product and process demands. That is, if there are changes to the product or in the process, this can create a demand for an update of the information system. The information system itself can go through changes due to for example IT-platform changes, but these changes are connected to the IT-developer and not to the production technicians.

The product and process changes that affect the information system are the ones of interest in this case. The product changes constantly, from small changes that do not affect the assembler in any way, to larger changes in the work environment that can demand training activities, new user interfaces, new material racks etc. These changes, initiated by a Design Change Note (DCN), see Section 2.2.3, have increased in recent years and the management have the opinion that these changes will be at least constant in number, and probably increase in the future. A change in the product can also be initiated by new product introductions, such as product introductions in new markets, new in brand (AB Volvo companies) customers, changes in the environment legislations etc. Continuous improvement work (Kaizen), see for example Berger (1997) and Doolen (2008) can affect both the product (if a DCN is created) and process, and by doing this, the information needed in the work environment can change. It is possible to indentify two major “stakeholders” that can trigger an information need: *product* and *process*.

These stakeholders and their needs/demands can be described as follows:

Product

The product can create a demand on the information system due to the need for an assembler to choose the right parts that should be assembled. If there is only one part variant to assembly at a specific time, the need originates from the process rather than the product. If a number of part variants exist, the need originates from the part itself but it still can affect the process. This need creates a *decision point*, i.e. a decision demand is

put upon the assembler where he or she has to decide what part to assembly on the specific engine.

Process

A variant dependent process can include different parts to assemble and/or include different amounts of parts to assemble, but it can also differ as to the order in which the part should be assembled. The later is less likely if a Design For Assembly (DFA) Dalgleish (2000), process is used to verify the assemblability of the product. This creates a *process support* information demand where the information presents how the part should/must be assembled and is different from the above where the information system must support the decision on what to assembly.

The keywords here are “what” and “how”, what part to assembly and how to assemble the parts. This is the basic knowledge that a production technician has to possess to be able to perform evaluations regarding changes in the information need. The technician does not need to understand exactly what tasks or activity an assembly operation contains, i.e. he/she does not need to analyse exactly what activity an assembler needs to perform during an assembly task, he/she only needs to evaluate from a product perspective if a “what” and a “how” decision is triggered by the product change.

The product changes trigger an evaluation on how the changes affects the work environment from an information needs perspective. This evaluation process needs different methods depending on where in the product lifecycle the change takes place. A typical product industrialisation project process (Figure 4.3) at the reference assembly plant contains a number of steps; each of them proceeded by a gate. A number of issues have to be solved before a gate opens that starts the next step in the development process. Depending on project stage, the amount, form, and quality of the available data¹⁵ varies.

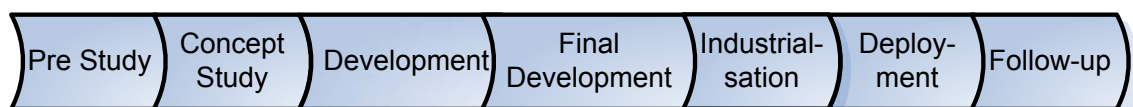


Figure 4.3: Typical project flow at the reference assembly plant.

¹⁵ Data in this case are date that can be used to evaluate information needs. For example number of variants, assembly process etc.

This process is strongly connected to the project. After the project is finished, the production part of a product lifecycle starts. The responsibility for the product and its assembly process is transferred from the project, which no longer exists, to the production department. During the lifecycle, changes are triggered that create needs for assembly process updates. These triggers vary and can for example be quality problems, product updates, legislation changes, environmental issues, etc. They can influence the impact (amplitude) (Figure 4.4) of the amount of work needed for the development of a solution.

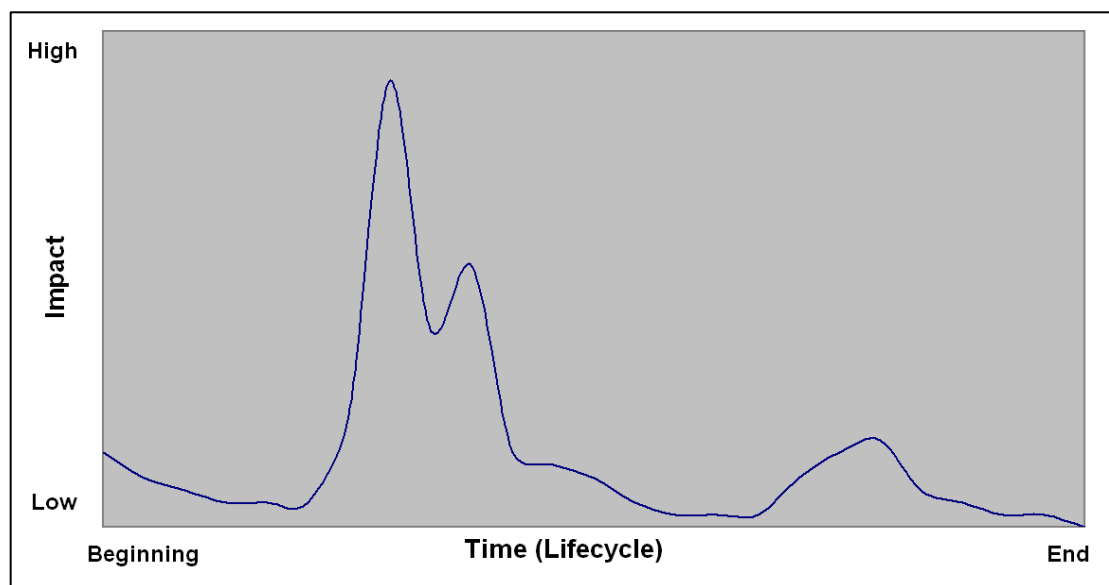


Figure 4.4: Visualisation of impact from changes during a product lifecycle, an example.

That is, in the industrialisation project, the available data can vary, during the product lifecycle and the impact and availability of data from a change can vary. These variations demand different evaluation methods as well as different mindsets. During the project stages the human must be in the centre of the evaluation. That is, the evaluation methods should focus on human abilities, such as cognition, human behaviour and psychology. During the production phase of the lifecycle, the evaluation methods should focus on the variable that goes through changes, i.e. the product.

The development process¹⁶ at the reference company includes the steps presented in Figure 4.3. The philosophy behind this method is that:

¹⁶ The description of the process is based on company reference material.

- It focuses on process and business needs.
- It describes what to do (activities) and when to do (phases and gates), but not how to do it.

Four key areas need to be managed by the process. They are:

- Promote issues to raise critical risks before they become a problem. Focus on prediction and prevention.
 - Business objectives management.
 - Understand and agree on the problem definition based on a diagnosis.
 - Identify the business value and set business targets.
 - Develop the vision, scope and business case to be used throughout the project.
- Solution management
 - Develop processes that are in line with business objectives.
 - Provide the technology necessary to reach the business objectives.
 - Find a technical solution that matches the new or modified processes.
 - Perform verification and validation.
- Business change management.
 - Drive the organizational transformation needed, through communication, training and roll-out.
 - Transform business targets into matching business results by active involvement of all stakeholders.
 - Ensure that technical solutions, processes and organizational changes meet to form a complete solution.
- Project control.
 - Integrate above areas.
 - Balance quality, time, cost and content.

All the above must be taken into consideration. However, at the moment it is possible to neglect the issues connected to project management, and focus on aspects such as prediction and prevention, input to technical solution, process (for example assembly process) and training.

The development process does not describe how to analyse the risks etc. However, it gives support regarding what issues need to be solved before it is possible to enter the

next stage of the development process. The issues are an input to the gates. These gates (Figure 4.5) and their content all control the process by providing a steering committee with information so that it is possible to open the gate to the next process stage.

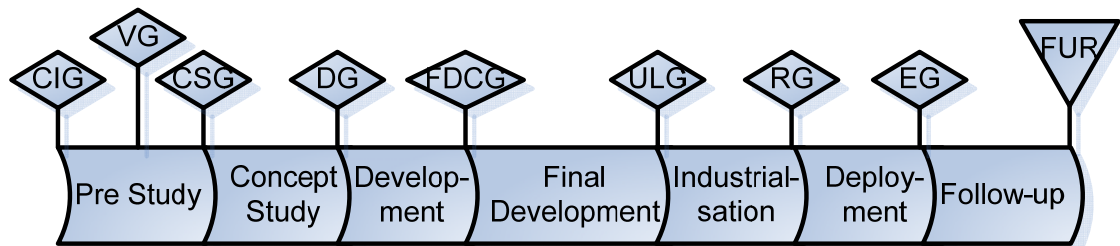


Figure 4.5: Development process including decision gates.

Gates description:

- Change Initiation Gate (**CIG**): approve the business value and formally start a pre-study.
- Vision Gate (**VG**): approve the project vision and the diagnosis.
- Concept Study Gate (**CSG**): decide which solution to investigate further. The gate marks the end of the pre-study phase and starts the project.
- Development Gate (**DG**): choose one solution, and approve its ways of working in combination with technical concept.
- Final Development Contract Gate (**FDCG**): freeze the overall solution and sign the contract.
- User Launch Gate (**ULG**): approve that the solution is ready for user validation tests.
- Release Gate (**RG**): approve that the solution is ready for deployment and the organisation is ready to receive it.
- End Gate (**EG**): approve that solution contents and deployment are achieved according to the contract, hand over the responsibility to the maintenance organisation, and close the project.
- Follow Up Report (**FUR**): validate that the business objectives have been achieved and, if needed, decide action plans and further change management activities.

In the **CIG** (Figure 4.5), a high level vision for the project is presented. At this stage of the process the focus is on pre-study business objectives and business change management, and project control. At this stage, the focus on solution management is at a

minimum. Between the CIG and the **VG** (Figure 4.5), the actual evaluation process, in this case called “Diagnosis”, is conducted. Issues such as interviews, measurement of current system (if such exists), best practice review, SWOT analysis, white book review (lessons learned from previous projects), and presentation of possible improvement areas are conducted and reviewed. The output from the diagnosis is the needs identified. These needs can be for example improvement of quality of the information stored, to secure the information flow in the assembly lines etc. During the work between the VG and the **CSG** (Figure 4.5), an evaluation method must be used to ensure high-level verification of information demands on future systems. The output from Pre-study is a decision regarding one or more solutions that will be further detailed in the next stage of the development process, the concept study phase. Before opening of **DG** (Figure 4.5), a decision has to be made regarding one solution that will be further developed in the Development Phase. In the Development Phase of the project the focus is on development of details necessary to freeze the solution. **FDCG** (Figure 4.5) opens the Final Development phase, which aims to develop the technical solution and prepare for deployment. Between FDCG and **ULG** (Figure 4.5) the project is in its final development phase. The major development is done during this phase. The confirmation of deployment and validation test plans is also an important part of this phase. The industrialisation phase with its **RG** (Figure 4.5) includes validation of tests performed on the processes and system/-s. The results from them influence the approvals of the deployment plans. **EG** (Figure 4.5) is open if there is approval regarding the functionality of the process and system and that they are fully operational. During the Follow-up phase ending with **FUR** (Figure 4.5) focus is on confirmation that the process and systems are working and delivering expected results.

This was a brief description of the phases and gates included in the development process. Absent in this description is business values. This is always the main driver, at a high level, for a development project. However, in this case, the interesting part is the analysis of information need, and therefore the business values are excluded from this discussion, even though they are related through information need influencing the product quality and hence the overall business objectives.

It is possible to visualise the evaluation needs and its connection to available data during the development project (Figure 4.6).

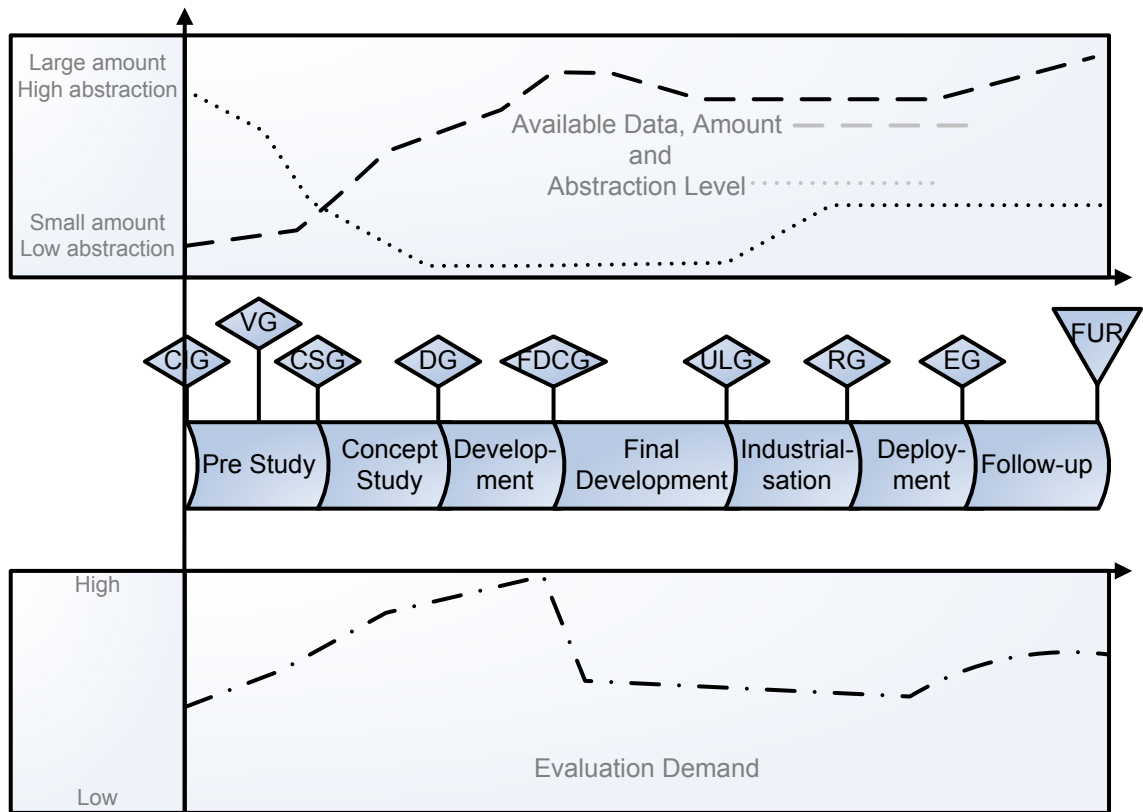


Figure 4.6: Visualisation of a relationship during the development process, between the available data, abstraction levels, and evaluation needs.

The data available (small amount), the abstraction levels (high abstraction), and the demand during the initial project phases have an impact on the evaluation that will be performed at these stages. However, the evaluation demands increase significantly during the later part of the pre-study phase to the development phase. The evaluation must be finished in the development phase so that it is possible to open FDCG. The need for an evaluation should be significantly lower during the later part of the process, but a need for evaluations can again be higher in the follow-up phase if problems occur. The available data will increase during the project, and will continue to increase during the product lifecycle.

One of the problems connected to development, product as well as process, is that it is extremely important to do evaluations as early as possible in the project. There are problems connected with this need:

1. As visualised in Figure 4.6, in the beginning of the project the available data is at an abstraction level and at an amount that can make it difficult to do in-detail evaluations.
2. The available data, amount and abstraction level, will increase in later stages of the process, with its peak in the development phase.

That is, in the beginning of the process, the lack of data lowers the possibility of influencing the final product. In later stages of the process it is possible to do in-detail analysis, but the possibility of influencing the final product decreases due to time limits for the project.

The evaluation work during these early stages should focus on human abilities and limitations and their impact on the process. The work during the later part of the product lifecycle should focus on demands originated from the product.

4.4 PROPOSED WORK METHOD

A work method that spans a product lifecycle should emphasis different aspects depending on where in the lifecycle an analysis is conducted. It is of great importance that it is simple to use and gives the production technicians the information needed to chose a suitable user interface from productivity as well as quality perspectives.

It is possible to divide the lifecycle into these major stages (Ryan and Riggs, 1997):

- Introduction.
- Growth.
- Maturity.
- Decline.

From a manufacturing point-of-view the project phase, i.e. the development project should be included in the product lifecycle.

In this case, it is possible to divide the PLC into two major parts:

- Development phase: During this part the project flow presented in Figure 4.3 should be followed and the focus should be on humans.
- Production phase: During this part should focus be on the product and its demands.

Development phase

The work process at this stage is relatively straightforward and should use one of the existing evaluation work methods, for example Cognitive Work Analysis. When, how and to what extent must be determined by company procedures. In the example presented in Section 4.3 the evaluation work must be done before the Final Development Contract Gate (Figure 4.5).

Production phase

The analysis work during the production stage of the PLC is triggered by different events. Events can be:

- Quality issues.
- Productivity demands.
- New product.
- New product variant.

The quality and productivity issues are often connected to the introduction of new products and product variants.

The proposed evaluation process in the production stage is much more simplified in comparison with the one used during the development work.

The proposed process includes steps according the workflow shown in Figure 4.7.

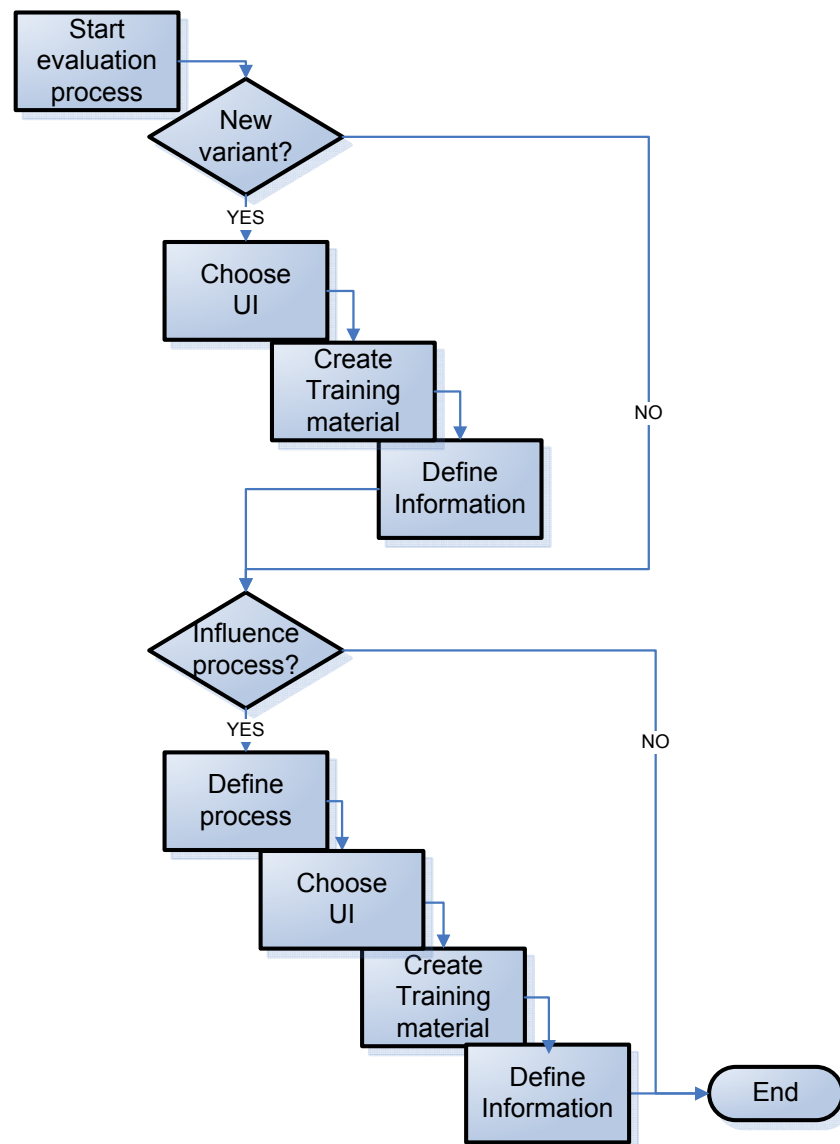


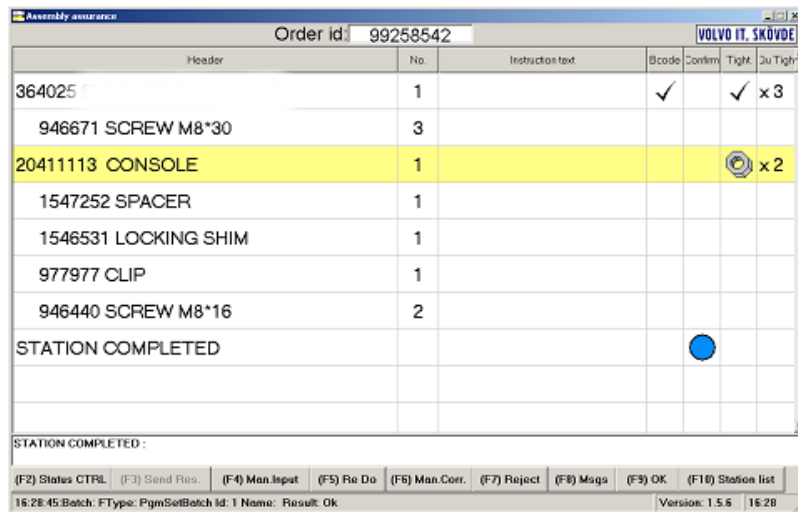
Figure 4.7: Proposed work process/method for the Production Phase.

Process steps:

- Start evaluation process: triggered by, for example, a design change note (DCN) (Section 2.2.3).
- New variant: evaluate if a new variant is introduced. More than one variant of a part creates a need for decision support.
 - Choose user interface: in this proposed work process a number of interfaces have been identified. Some of them are used at the plant in other applications:
 - Paper order form. The paper contains order number and the amount. An instruction form that “translates” the order number to part numbers is found at the assembly station and includes part numbers and assembly

instructions. Often used in pre-assembly stations without computer support.

- Interface presenting part number and assembly order (Figure 4.8).



The screenshot shows a software interface for an assembly workstation. At the top, it displays 'Order id: 99258542' and the company name 'VOLVO IT, SKÖVDE'. Below this is a table with columns: 'Header', 'No.', 'Instruction text', 'Bcode', 'Confirm', 'Tight', and 'Ju Tight'. The table contains the following data:

Header	No.	Instruction text	Bcode	Confirm	Tight	Ju Tight
364025	1		✓		✓	x 3
946671 SCREW M8*30	3					
20411113 CONSOLE	1				⊗	x 2
1547252 SPACER	1					
1546531 LOCKING SHIM	1					
977977 CLIP	1					
946440 SCREW M8*16	2					
STATION COMPLETED					●	

Below the table, there is a 'STATION COMPLETED:' section and a row of function keys: (F2) Status CTRL, (F3) Send Res, (F4) Man Input, (F5) Re Do, (F6) Man.Coer, (F7) Reject, (F8) Maga, (F9) OK, (F10) Station list. At the bottom, it shows '16:28:45 Batch: FType: PymSoftBatch Id: 1 Name: Result: Ok' and 'Version: 1.5.6 16:28'.

Figure 4.8: Interface with part number and assembly order.

- Pick lights (pick-by-light). A light (Figure 4.9) indicates what part to assemble. It is possible to add functionality that makes it possible to verify that the part has been picked. This can be done via a photo cell that indicates that the assembler has picked the part. It is possible to use pick lights in at least two ways: 1, parts are identified one by one and the picking is registered by the system. 2, all parts are identified simultaneously by the system and the assembler can choose which part to pick first.



Figure 4.9: Light indicating what part to pick next. This specific installation includes a photocell that when affected, registers when a part is picked.

- Colour Coding. A colour marking (Section 3.2 and Figure 4.10) is used to guide the assembler to pick the right part.



Figure 4.10: Example of colour coding in an assembly environment.

- Voice picking. The assembler uses a headphone where he/she receives a number that is connected to a location in the material racks.
- Sequencing and kitting. These techniques are connected to logistics and how the material is presented to the assembler at the assembly station. In sequencing (Figure 4.11) the part is presented to the assembler so that he or she does not need to decide which part should be assembled next. Figure 4.12 illustrates a kit where parts are gathered and presented to the assembler all at once.

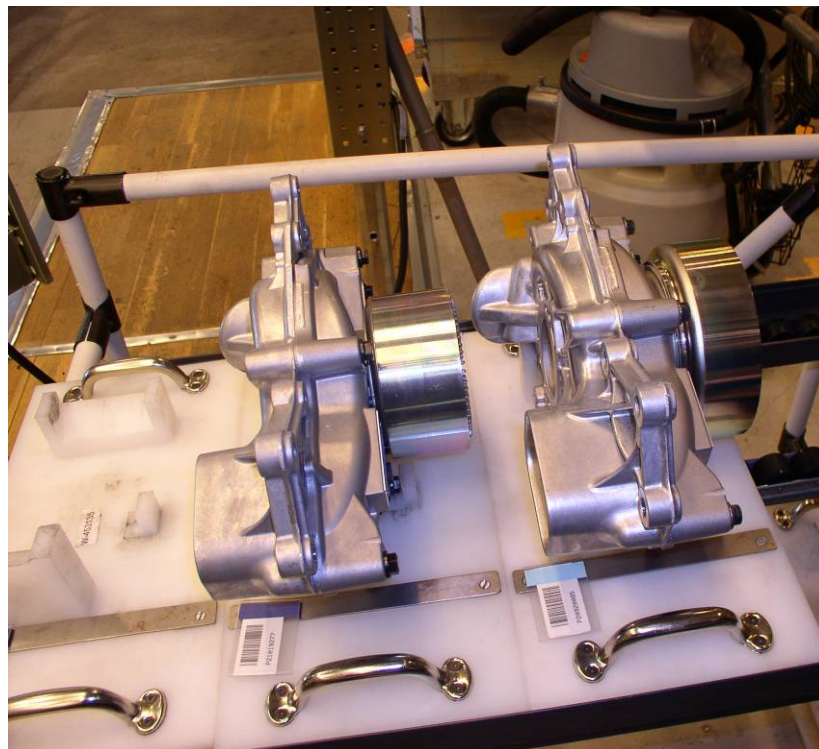


Figure 4.11: Sequencing example. In this case is it water pumps prepared for assembly.



Figure 4.12: Kit presented at the assembly station. When the parts in the box are assembled the box is removed and a new box is presented to the assembler.

- Create training material. The training material should be based on the information presented in the chosen interface.
- Define information. The information needed is defined and prepared for the chosen interface.
- Influence process. If the change in the production influences the assembly process, an update is required for the process information.
 - Define process. Define new assembly process.
 - Choose user interface: in this proposed work process a number of interfaces have been identified. Some of them are used at the plant in other applications.
 - Paper instructions. The process is presented in a paper instruction available at the assembly station.
 - Video recording. A video recording is made that shows the assembly task. (This has to be done after the new changes have been made in the assembly environment). The recording is presented on a computer screen at the assembly station.
 - 3D-recording. A 3D-recording is made that shows the assembly task. The recording is presented on a computer screen at the assembly station.

- Pictures. Pictures are present on paper or on a computer screen. The pictures show the critical parts of an assembly task.
- Create training material. The training material should be based on the information presented in the chosen interface.
- Define information. The information needed is defined and prepared for the chosen interface.

One of the problems a production technician will face during the evaluation is to understand the consequences of their choice of interface. The interfaces presented earlier in this section all have their pros and cons. Although tests have not been performed on them all, some characteristics can be identified for each of them. These characteristics must be taken into consideration during interface choice.

The characteristics for:

Paper instructions

The benefit with paper instructions is obvious in that there is no need for a computer in the work context. This makes it possible to quickly distribute information and set up new assembly stations if needed. The drawbacks are that it is almost impossible to determine if the instruction, in this case, is the latest review or not and it needs to be physically changed when an update is required. It has also been noted that the assembly personnel do not use them in an effective way, and sometimes not at all. One problem with paper is where to put it, in an assembly context that is. It is also difficult for an assembler to understand when to use paper instructions.

Video recordings

There are different ways to use video recordings. At the reference plant recordings are used in the rebalancing¹⁷ work for the assembly stations. A video recording is made that can be used in conjunction with software to find and define wastes, necessary activities etc. This recording can also be used during the introduction of new personnel. It is possible to use the recordings as information and process support directly in the assembly context. The major drawback is that it is not possible to create a recording before the assembly context and the product physically exists in the assembly context.

¹⁷ Balancing an assembly station is to make sure that the assembly time for all stations in an assembly line has the same station time. This is, in short, managed by moving parts and tasks between the assembly stations. A rebalancing task is initiated for example when a new engine variant is introduced.

Consequently, it is not possible to create e.g. training material and therefore it is not possible to start the training at a stage where there is no effect on the production.

3D-recordings

A 3D-recording, based on video or pictures, is created in a computer environment where the basis for it is the CAD-data showing the product and equipment. The benefit of using 3D-material is that it is possible to create instructions, training material etc. earlier than is possible when the information is based on physical objects. Consequently, it is possible to prepare an assembly station with the instructions needed before start of production. It is also possible to start training activities earlier compared with training on physical objects. The major drawback is the need for deep computer knowledge in the field of virtual manufacturing. It is both time consuming and skill demanding to create the virtual environment needed to create the information. However, it is possible to see instruction and training material as a spinoff benefit from other analysis needed in the development phase of new assembly stations. That is, it is easy to create the material if the virtual environment already exists. There is a need for early ergonomic evaluations and a decrease in physical mock-ups (Bäckstrand et al., 2005b; Bäckstrand et al., 2006b; Bäckstrand et al., 2007; Högberg et al., 2007; Bäckstrand et al., 2008; Högberg et al., 2008). The output from that analysis, evaluation data and virtual environment is very suitable as a foundation for instructions, training material and process support information.

Pictures

Pictures of specific task or assembly related details are a good and simple way of distributing information in an assembly context. It is easy to use a camera, most people can handle a camera after a short introduction. Photographs are easy to distribute, both on paper and via a computer. The major drawback is the same as for video recordings in that it is not possible to take a photo without physical objects.

Interface presenting part number and assembly order

A graphical user interface is an effective way of distributing information and creating knowledge. Computer support makes it possible to distribute information at the right time and place. It is possible to trace where and when the information is viewed, and this is important regarding traceability e.g. in quality work. The major drawback is cost. The

cost for the development or purchase of software, license cost, hardware, installation, maintenance etc. can be very high and sometimes hard to estimate in early project stages. Compared with paper instructions the payback time can be long.

Pick lights (pick-by-light)

Pick lights can be an effective way to influence productivity in a positive way. It is easy to understand, just pick the part where the light is lit. It can be easy to view the assembly order, and it is possible at the same time to view the amount of parts to pick. Compared with the other interfaces a pick light system is the least demanding together with Colour Coding, on the short-term-memory as well as on attention levels. The major drawback is that it is rather inflexible. If the assembly environment is changed the pick light system might need to be reprogrammed and moved etc. It also needs qualified personnel that can maintain the system.

Colour coding

There are many resemblances between Colour coding and pick lights. Colour coding is one way of viewing decision point information without using computer support, although it can be more efficient using computers. The benefit of using colours, or symbols, is that it makes it possible for the assembler to find the parts needed with less attention compared with using systems where part numbers is the information carrier. It is inexpensive but needs to be attended to so that no mistakes are made, e.g. the wrong colour on a box. This problem is not unique to Colour coding in any way, the same problem can also occur in a computer supported system. The major drawback is that a believed upper limit for the number of coloured fields used at an assembly station is four, after that a pick light is preferred. This has not been tested, but if the number of fields exceeds four, the problem of keeping track of where in the process the assembly takes place increases. Case study 2 (Section 3.3) indicates that this is the case.

Voice picking

Like Pick lights and Colour coding the benefit with Voice picking is that the user does not need to know what to assembly next. A position in space is presented to the user via a headset. The part to assembly next can be found at this location as well as a code. This code is read by the assembler and registered by a microphone and compared with a code stored in a computer. If the assembler reads the right code the system continues to

present the next part to assemble. If the assembler reads the wrong code, he/she receives an error message and is urged to redo the task. The benefit is that it is possible to distribute information to locations where no computer exists, although a wireless network is needed. It is easy to use, no specific training is needed in the use of information. A drawback is that, according to initial tests at the company, the user feels isolated from their colleagues etc. It is too early to say how this affects human in the assembly context but if further tests initiated this is one of the issues.

Sequencing and kitting

Sequencing and kitting have been described earlier in this text, but it is possible to add that both sequencing and kitting lower the workload for the assembly personnel.

However, an important issue is that the burden on the preparation personnel increases as well as their information need. The preparation personnel need the same information that the assembly personnel needs. Therefore, the techniques presented earlier, e.g. pick lights, although the assembly personnel have no use for them in this case, are needed by the preparation personnel.

4.4.1 Prototype User Interface

In order to test the exemplified work method, a prototype user interface was designed where the work method worked as a foundation for the design. The first view (Figure 4.13), the assembly view, is the main part the interface where the assembler can find decision support information about what to assembly next. The three (coloured) fields, “Rör Nedre”, “VCB-Mellandel” and “Servopump” are where the assembler can find two types of information:

- In what order the parts should be assembled, reading from left to right.
- What part variant should be assembled.

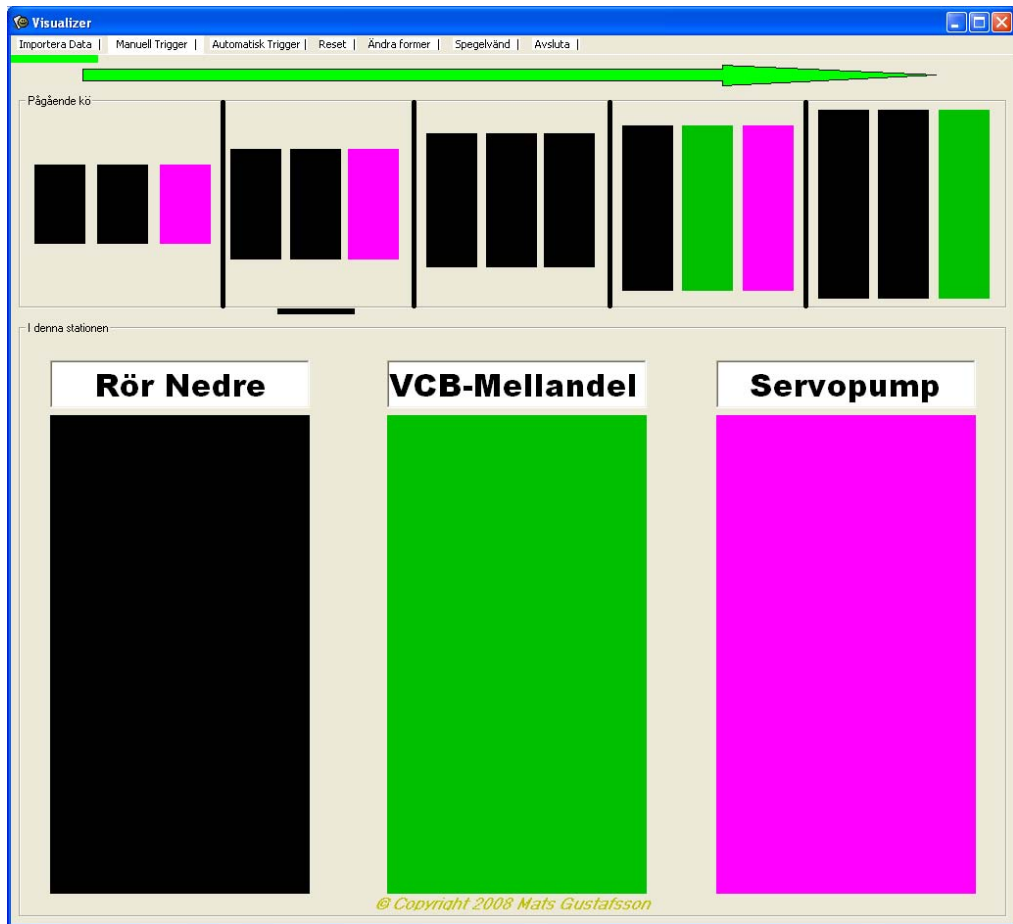


Figure 4.13: Assembly view.

A feature that was appreciated by the personnel during Case study 1 was the possibility to see what engine variant was approaching the assembly station. This feature is handled in the prototype by the field “Pågående kö” (current queue), located in the upper part of the interface (Figure 4.13). This field contains information regarding what type of engine variant approaching the station. In this specific case it is the view seen at station S0800 that is shown, the stations viewed in the approaching field are, from right to left, station S0700 to S0300. The interface is updated each time a carrier is moved to the next assembly station.

If this design was “a real case” this functionality should have been evaluated in the development phase where the humans’ abilities are in focus. The three (coloured) fields however, should be evaluated by the technician in the production phase, where he or she should determine if:

1. More than one variant exists.
2. Number of different variants. This determines the number of different colours.
3. Number of decision points. There are three decision points in the prototype. This is evaluated and defined by using the work method described in Section 4.4.

However, the interface described above only handles decision points. In Figure 4.14, the interface is updated with a process flow description, a view that shows the production status, and a control instruction view that shows how a control process should be performed.

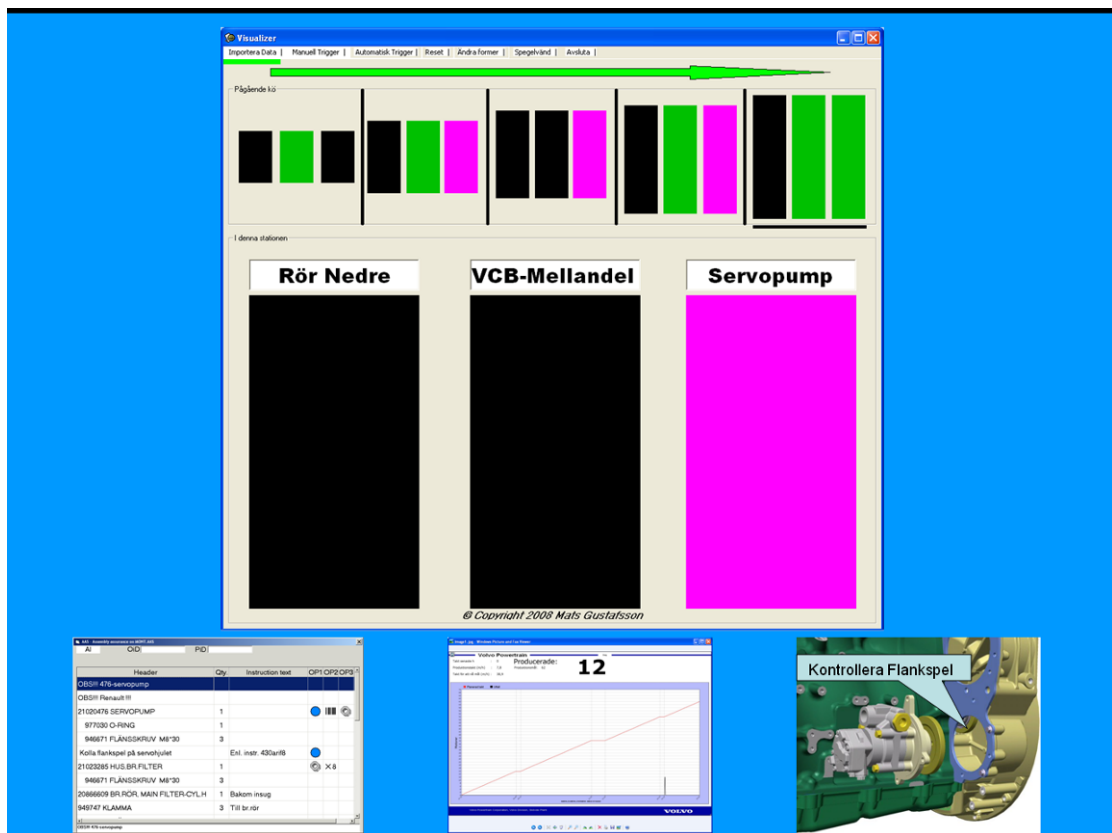


Figure 4.14: Updated interface including for example process support information.

The main issue is that the user should be triggered by an event. This could be the signal to the user that a new variant has arrived at the station, but it could also signal to the user that, for example a change has been made in the assembly process. Figure 4.15 illustrates how a change in a control instruction can be viewed in the prototype interface.

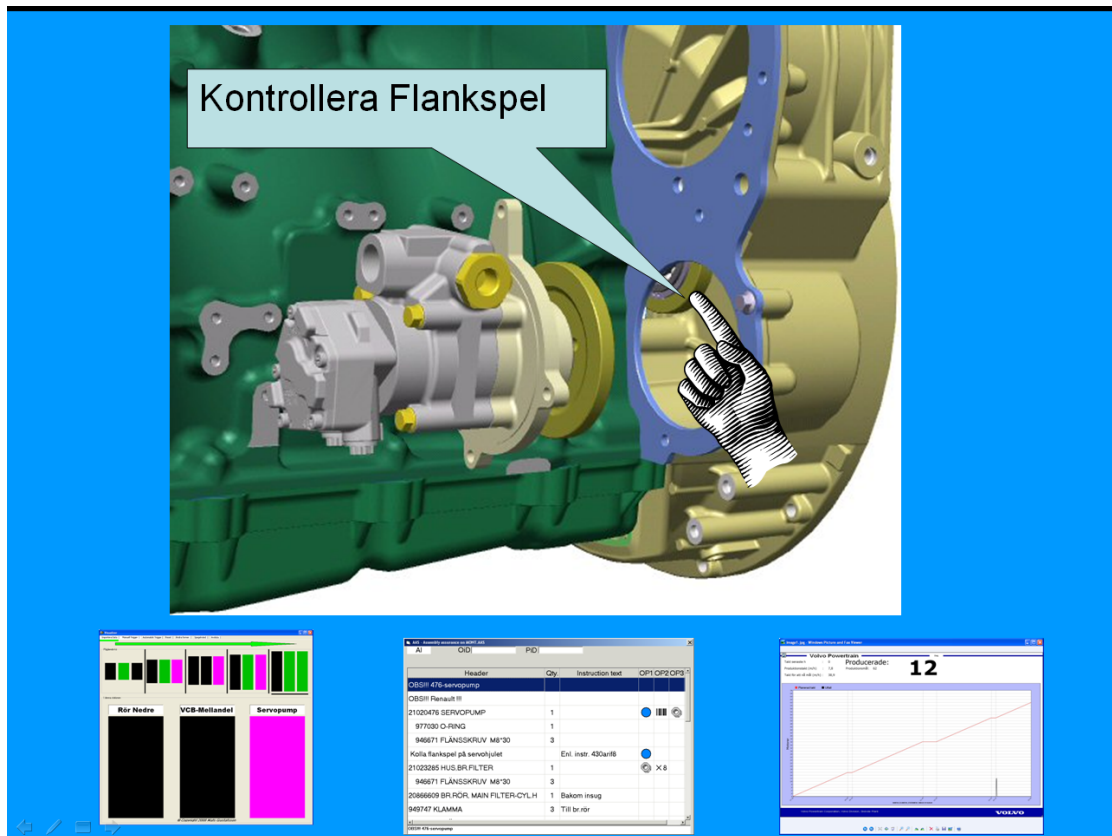


Figure 4.15: Illustration of change control instruction event.

In a real case scenario the updated control instruction is put into focus automatically. It is not possible for the user to continue to assemble the engine until he/she has verified that they have observed and read the new instruction (done by changing the interface back to the assembly view, see Figure 4.14).

4.5 CONCLUSIONS

The conclusion regarding the proposed work method is that it is important to use different ways of working depending on where in the product lifecycle an evaluation is needed. There is more than one reason for this.

- Time: A work process that is too time consuming is not an alternative. Therefore, it is important to have a balance between the output from an analysis, in the form of knowledge, and the time it takes to conduct it.
- Competence: It is not possible to have cognitive specialists working in the later part of the PLC. The cost for this will be too high. However, the need for having a specialist to consult still exists at this stage of the process.

- Simplicity: A work process must be easy enough to use so that a non-specialist can use it.

It is possible put considerable effort into the decision-making process regarding what method is the best to use in the development phase of the product lifecycle. This research never had the aim of evaluating different work methods used in the development phase. However, there is no doubt that an evaluation of information needs in the development phase is a necessity. This will create a demand to find “the best” evaluation method. This demand could trigger a decision-making process regarding what evaluation method should be chosen. As mentioned earlier (see e.g. Section 4.2) CWA has been used during this research on at least one occasion. During its use it has become clear that the method is very time consuming to use, but will return a vast amount of data. Time is relative. In this case the use is too time consuming for the daily work by the production technicians at the assembly plant, but, as an evaluation method in earlier stages of the PLC the method is very interesting. Characteristics of CWA are:

- Easy to use (this can seem as a contradiction to earlier statements made in the thesis), for a person experienced in the use of CWA.
- Documentation is created at the same time as the evaluation of the data is made.
- Assembly process: the documentation can be used as a foundation for the assembly process made in the IS-GPD, before the Release Gate (RG) (Section 4.3 and Figure 4.5). For example the Work Domain Analysis (WDA) (Figure 4.1) and the Control Task Analysis (CoTa) (Figure 4.2) include information that the production technician would need to gather or create before RG. If CWA is used, some of the work has already been done and in an earlier stage of the development process.
- Easy to audit the assembly personnel regarding the assembly process. That is, do they follow the proscribed assembly process or not. This is an important part of the quality work as well as the work regarding productivity.

The conclusion is that at the right time in the product lifecycle CWA is a method that is well suited to providing a project with information regarding information needs in an assembly line.

The derived work method has been applied in the design of the prototype user interface, but has not yet been applied in the daily assembly preparation work at the

reference company. The interface has been presented to and accepted by the assembly personnel, but further testing and implementation has to be performed before an implementation is a fact.

CHAPTER 5

DISCUSSION

This chapter contains the final discussion of this research and summarises some of the findings. It also presents and discusses the findings related to the two hypotheses presented in Chapter 1.

5.1 GENERAL REFLECTIONS

The research shows that just information is not enough to prevent quality problems from occurring and that one of the issues connected to the specific quality problem is attention. The lack of attention at a decision point is a major contributor to the quality problems registered at the reference company. A higher level issue briefly discussed in Section 1.2.1 was that there are potential problems if the personnel use information sources other than the ones that are a part of the general information system. It has been obvious during the work that in some cases the personnel use the product as an information source. This could lead to a quality problem due to the connection between this and the prognostication¹⁸ that the personnel sometime use of what products might arrive next at the assembly station. It is also very difficult to see the difference between parts, and for example in the case of the turbo sometimes only the part number can identify a difference. Although this is connected to the information presentation timing (Section 3.2.4, 3.4 and 4.4.1) it is still interesting and important to understand why a person chose to use one source in preference to another. This issue has not been discussed in depth in the thesis but is still a major issue that should be addressed in further work.

It is important to state that the hypothesis is mainly a result from the research and that the validation of the two and the evaluation method will be addressed in future work.

The following two sections aim to outline what conclusions can be drawn from the research in respect to Hypothesis 1 and 2.

¹⁸ Prognosis: a forecast of the probable development of (something) Hornby, A. S. (1997). Oxford Advanced Learner's Dictionary of Current English. In Crowther, J. (ed.). Oxford: Oxford University Press. In this case is it a forecast regarding what engine is to arrive.

5.2 HYPOTHESIS 1

According to Hypothesis 1 - ‘Information seeking behaviour’

The degree to which Active Information Seeking behaviour is supported/triggered has a large influence on the number of internal rejects.

As noted in Chapter 1, this hypothesis is based on the fact that in most of the cases the assembly personnel have enough information present in their working environment to be able to perform a correct task. Therefore, it is more likely that human behaviour in general, and Information Seeking Behaviour specifically, influence the internal reject rate, and not the amount of data or information.

By presenting information in a way that supports active attention, an Active Information Seeking process can take place that positively affects the internal reject rate (Section 3.2.4). The information seeking behaviour model first presented in Section 1.2.2 and later elaborated in Section 2.5 is by nature connected to Hypothesis 1.

The main issue as mentioned earlier in the thesis is the effect attention has on the information search process. There is no doubt that attention is an important factor in the assembly environment, both case studies have showed this. The interesting work actually starts after the last page of this thesis is written. That is, this thesis presents an explanation model that states that attention is important for the outcome of an assembly task, therefore it is the only natural step to put this explanation model into practice.

5.3 HYPOTHESIS 2

According to Hypothesis 2 – ‘Use of evaluation methods’

The use of an evaluation work method in the design phase of an information flow will affect the internal reject rate in a positive way.

This hypothesis is based on the assumption that the assembly personnel always strive for a performance outcome that lives up to the quality demands and targets. A common opinion among management and technicians is that the amount and the relevance of the data/information present in the assembly environment is enough to perform a correct task. This indicates that there is a deviation between the need and demand connected to a

specific task and the believed need/demand from the designers' point-of-view. The hypothesis states that a method used in the design phase is important and can positively affect the internal reject rate. The conclusion from this research is that evaluation methods are of great importance during a product's entire lifecycle rather than just during the design phase.

A company can only survive if it makes money. Therefore is it very important that every activity tries in some way to lower the cost, short term or long term. A conclusion from this research is that an evaluation method is needed in almost all of the stages in the product life cycle, and as a result money will be saved. One interesting, but missing parameter that all of the evaluation methods studied, briefly or more in depth, is cost. It is not that easy to estimate cost for a solution based on results from the evaluation. The parameter cost and the "equation" $\text{benefit/cost} = \text{savings ratio}$ will be an important part of the decision making process regarding how a user face should be design and used.

CHAPTER 6

CONCLUSIONS AND FURTHER WORK

This chapter presents a brief summary of the research work and the relevance of the results and suggestions in this thesis, and finally, recommendations for further work.

6.1 THESIS SUMMARY

This thesis focuses on the connections between the use of information and quality in a manual assembly context. The main motivation for this research was the desire to understand why the existence of information itself was no guarantee of flawless production. As a consequence of this, the desire was to understand if a way to prevent the occurrence of these quality problems existed and if so, was it possible to incorporate this in the daily work as well as in the development of an information system for industry use. The main objectives were to understand how attention affected the internal reject rate, and to investigate and propose a suitable evaluation method during the design stage of an information system. During the research the knowledge gained regarding attention, evaluation methods and information use have made it clear that attention, active, passive goal-driven, stimulus driven etc. is an extremely important part of the use of an information system. The literature review confirmed the importance of active attention initiated by events in our surroundings as a driver for a successful use of information in an assembly context. This review contributed largely to the design of the case studies performed. During these case studies different information providers were evaluated from a quality as well as a productivity perspective. The results from the studies revealed the importance of the presentation of the information, where the information itself triggers the right search process. The way the information was presented during the studies showed that it is possible to influence quality as well as productivity by addressing the information in the right way and at the right time. Furthermore, the research has shown that it is possible to use information effectively so that unnecessary waiting, due to discreet information flows, is eliminated in the assembly line. It is argued that by using an evaluation method in the design stage of an information system these types of problems could be avoided and eliminated before they occur. The research has brought to light some of the problems connected to existing evaluation methods that focus on cognitive analysis issues. These methods are exceptional regarding the

knowledge output gained from the use of the same. However, it has become clear that these evaluation methods have drawbacks that make it difficult to use by other than experts in cognitive analysis. This influences the use in later parts of the product lifecycle. Therefore, a method is suggested that makes it possible for non-experts to evaluate assembly environments and to find problems related to cognitive issues connected to decision support and process support.

6.2 CONTRIBUTION

The overall research objectives were to:

- Understand how information affects the internal reject rate (Section 1.3.2).
- Understand how the assembly personnel interact with the current information system (Section 1.3.2).
- Investigate and propose evaluation methods suitable for work place design at different phases of the product lifecycle (Section 1.3.2).

These objectives are realised through the following contributions:

- Knowledge gained regarding how attention, human errors and situation awareness influence the assembly worker during the information search process and their assembly tasks, and how this is connected to internal reject rates (Section 2.4).
- A proposed work method that is based on the case studies performed. It also takes into consideration the feedback gained from the interviews and survey that were conducted among the assembly personnel (Section 3.2.4). The method is based on the conclusion that the user needs support regarding the decision point (*decision support*) and assembly process (*process support*).
- A user interface prototype was created with help from the evaluation method. The interface is designed based on three principles: 1. identify decision points, 2. present the information at the right time, 3. connect the information to training. That is, use the same material for viewing the assembly process in the assembly line and to train the personnel (Section 4.4.1).
- Finally, the research has contributed to knowledge regarding the importance of presenting the information at the right time. And this from both a quality perspective as well as from a human workload perspective (Section 3.2).

6.3 CONSIDERATIONS FOR FURTHER WORK

This research ranged over an area including cognitive science, ergonomics, psychology, human behaviour, engineering and in some sense computer science. The scope for further work is wide, but it should focus on a more integrated perspective within the field of Human Factors. During this research some avenues for further research and future development were identified. It is recommended that new studies and future development are addressed to:

- The connection between information systems and training needs. Case study 2 showed that there could be a connection in how the information is presented and the learning curve. This might not come as a surprise, but it is important that if this is the case, it should be taken into consideration during the design of an information system.
- Put the explanation model into practice, i.e. to test and evaluate user interfaces for decision support, for example pick-lights, voice picking, kitting, sequencing etc. to determine when to use a particular interface.
- Test and evaluate process information user interfaces. During this research the need for an effective way to provide process information was identified. A system with connections to training was evaluated and the conclusions were that this system and the information provided from the system could be used as a process information provider within the assembly line.
- Information sources. Why do the assembly personnel use information sources that are not part of the information system, in this case the product? And is that a quality risk? Is it possible to use this as an information source and thereby incorporate the product in the information system?
- Feedback to product design. The need for information and instructions in an assembly plant must always be seen as a waste, and it is a cost to provide it, not a saving. With this as a fundamental way of looking at information, it is of great importance that the work does not end with the design of an information system. The important work with eliminating this need starts and it should start with immediate feedback to the production designers that are responsible. This requires a work process that continues to evaluate and give continuous feedback to product design so that the process of eliminating information needs can start. The work with this process will start in the near future at the reference company.

- Framework for user interface design connected to *decision support* and *process support* needs. Different needs should create different demands on user interface design, presentation of information and on what information the assembler needs. It is therefore important to investigate further in detail how information should be presented and what type of information the assembler needs to handle situations connected to decision support and process support.

6.4 CONCLUSIONS

This research was initiated and motivated by industry demands regarding the need for information and its influence on quality as well as on humans, in this case the assembly personnel. It has been shown that:

- There is a strong connection between attention and the internal reject rates, where a system which demands an active attention mode is more vulnerable to quality and productivity issues.
- An information system must provide information such that the user understands that there are changes in their work task. A trigger that changes the attention mode should be present. If the trigger is absent or neglected there is an increased risk of quality problems.
- An information system (as presented in Section 3.2) where the focus for the presented information is on decision support can affect the internal reject rates in a positive way.
- The timing of presentation of information to the user is of importance in determining how the assembler acts within the assembly process. This directly affects the risks to quality in the assembly context.
- The way in which information is structured and viewed has a large influence on productivity.
- A connection has been established between productivity and the number of variants. This is not a consequence of product complexity, but instead is a consequence of the information seeking process.
- Design flows can be found by using an evaluation method during the design of an information system.

- An evaluation work process that is too time consuming or too complex is not an alternative during day to day work. The process for evaluation demands on existing information systems must be manageable by the manufacturing technician.

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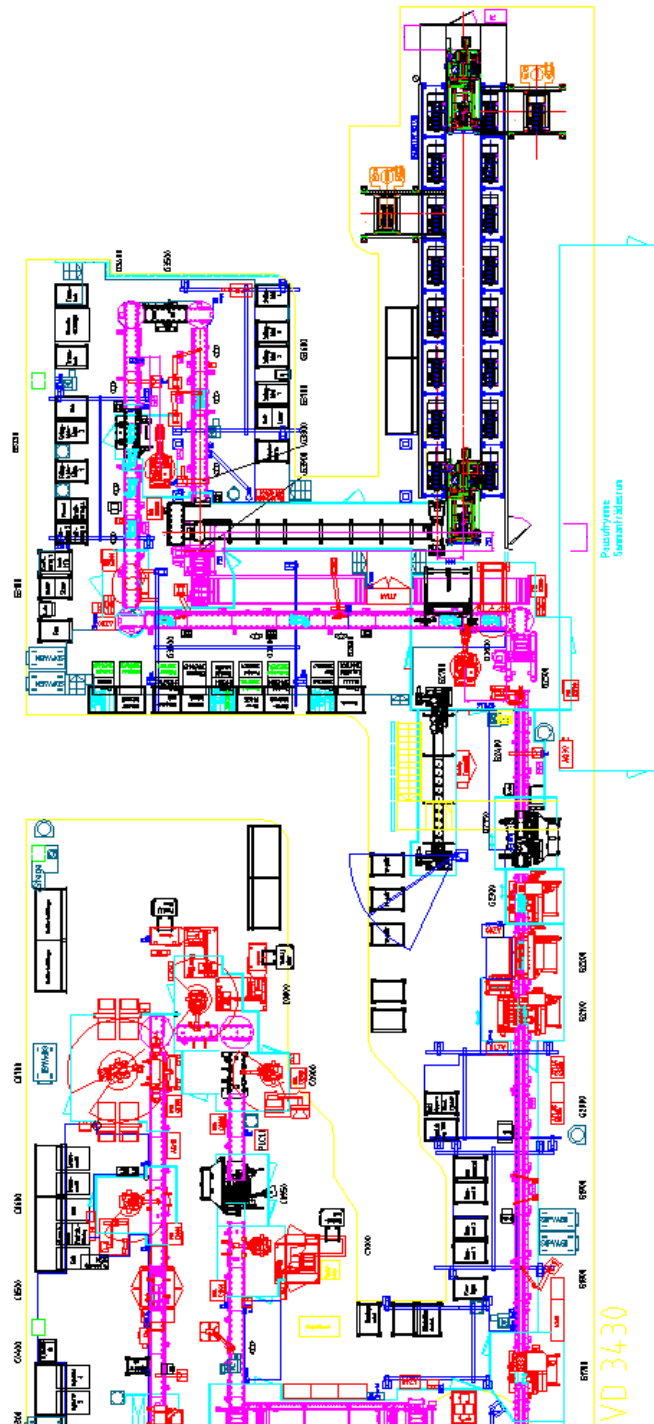
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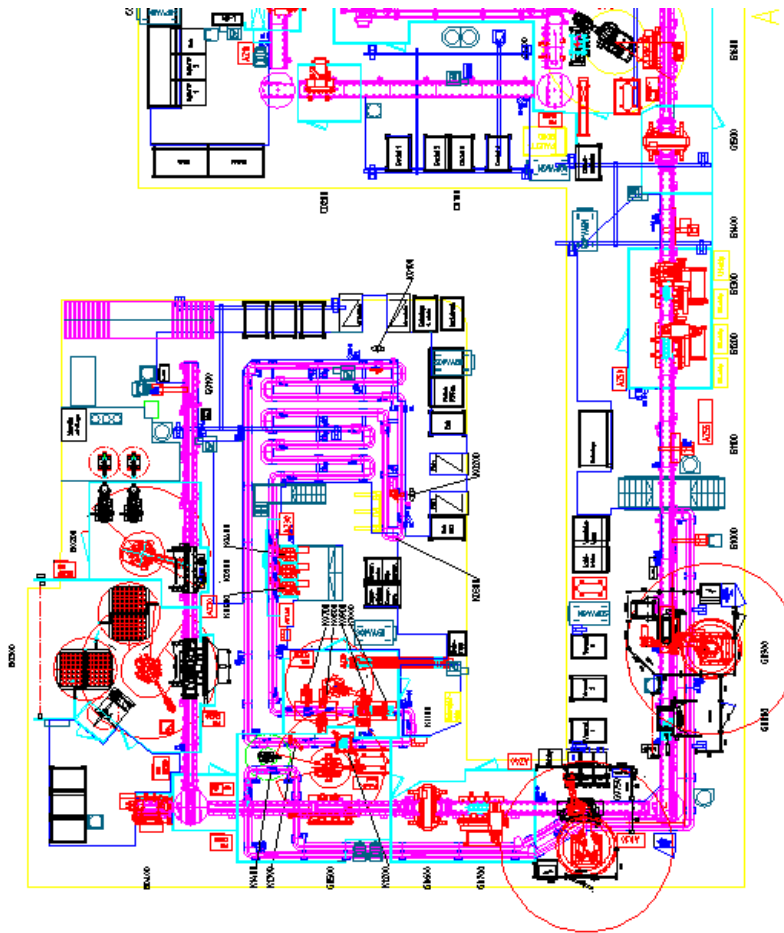
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Appendices

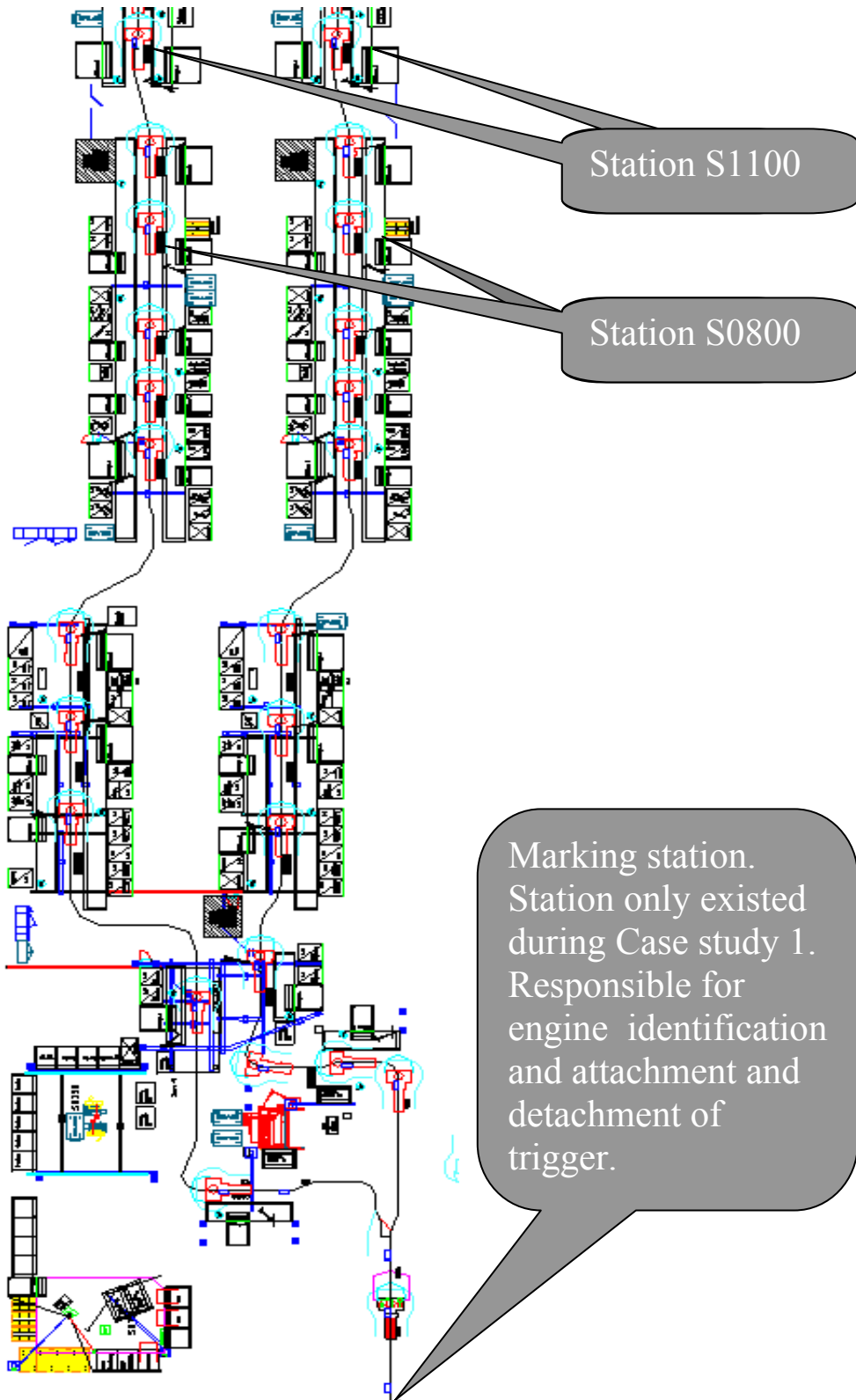
Appendix A: Layout assembly



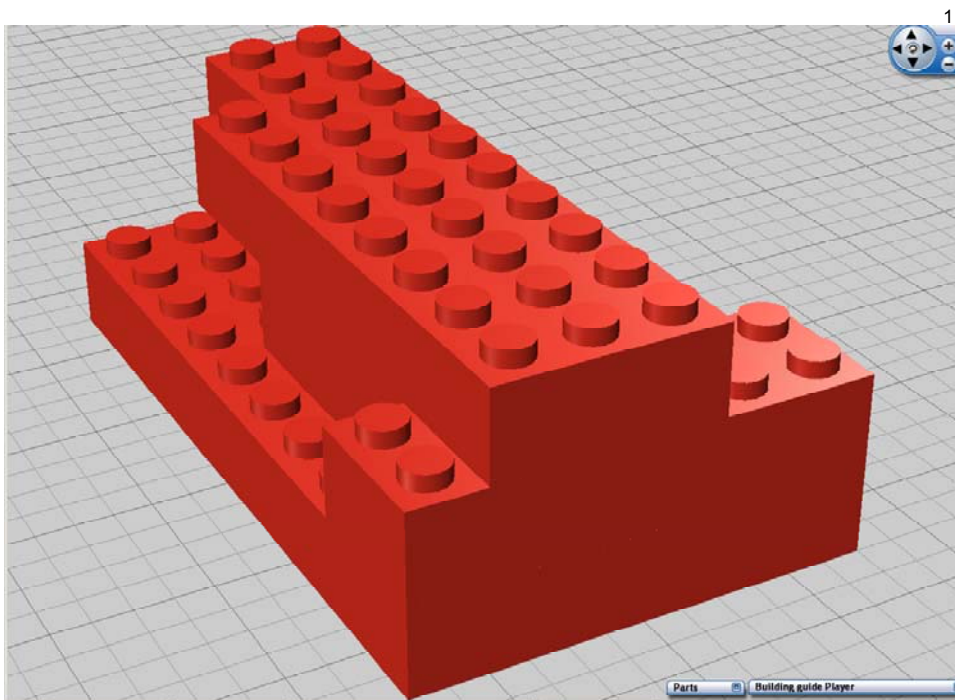
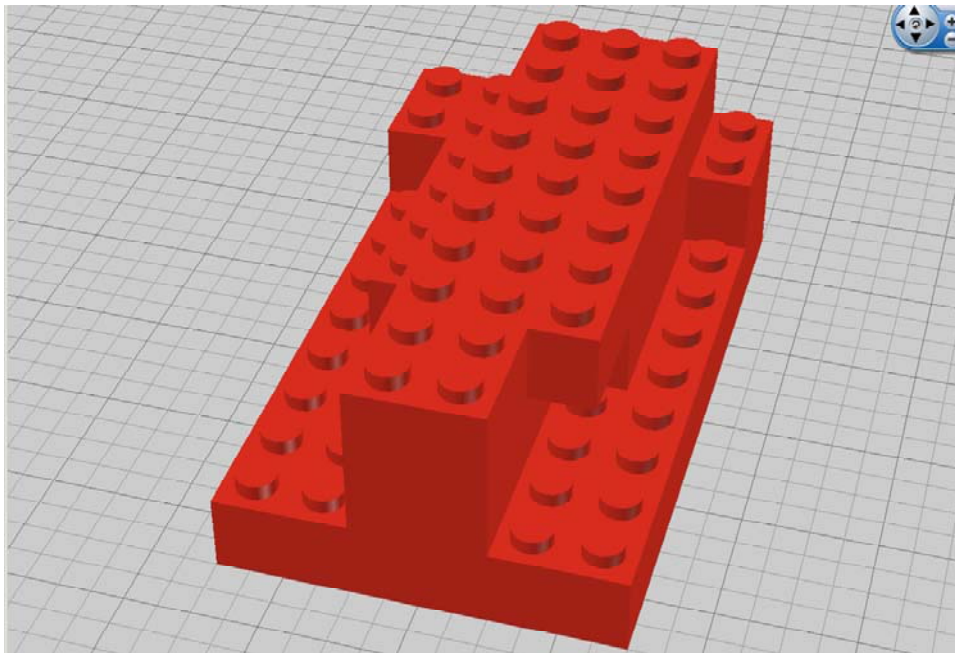
Basic Assembly part 2.



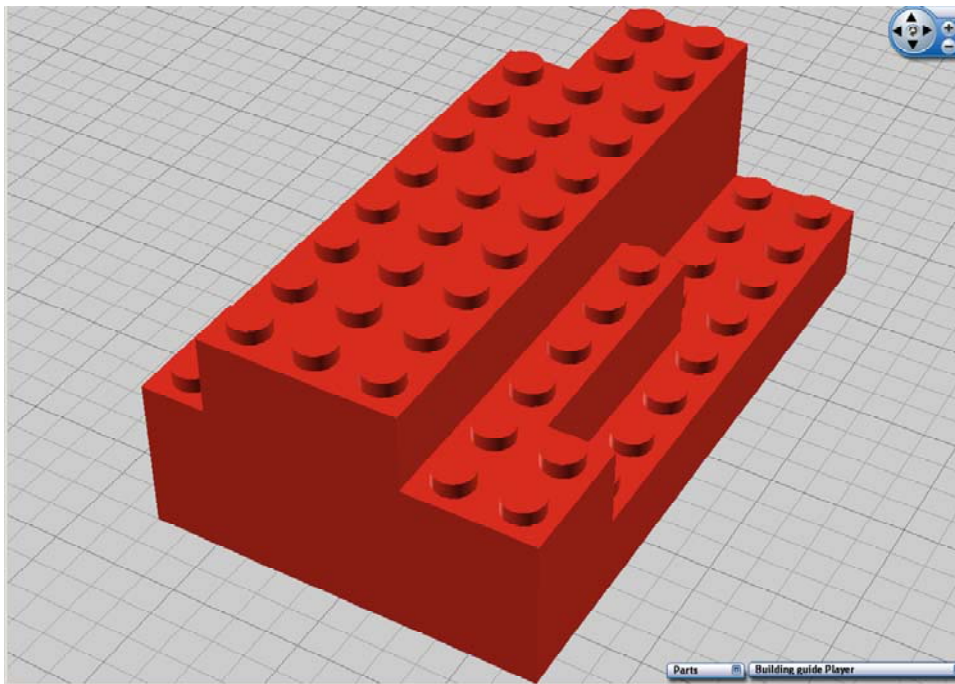
Basic Assembly part 1.



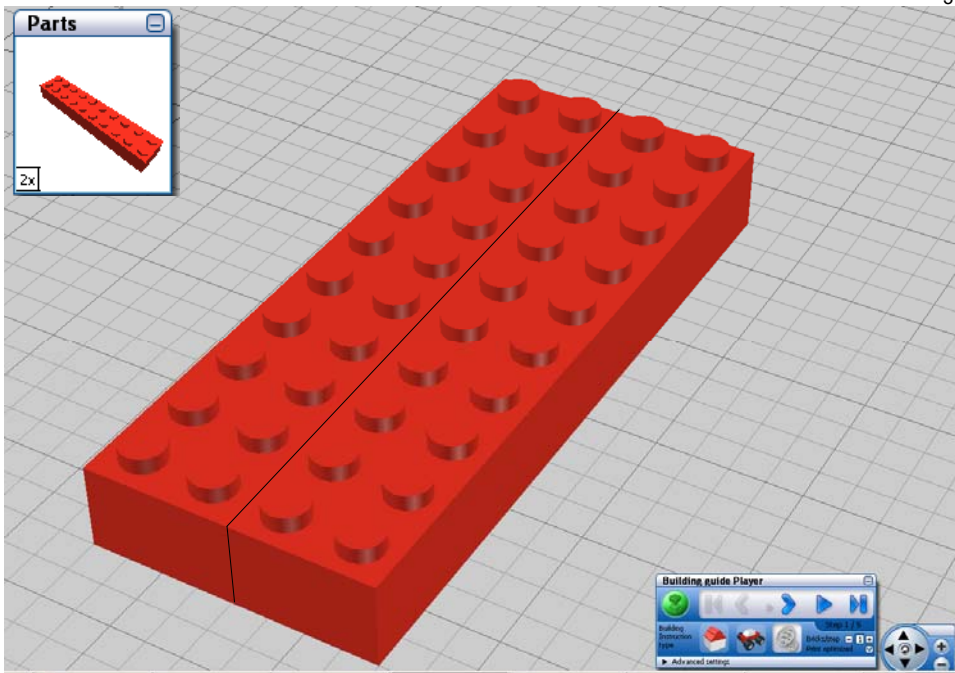
Appendix B: Case study 2 - Instructions



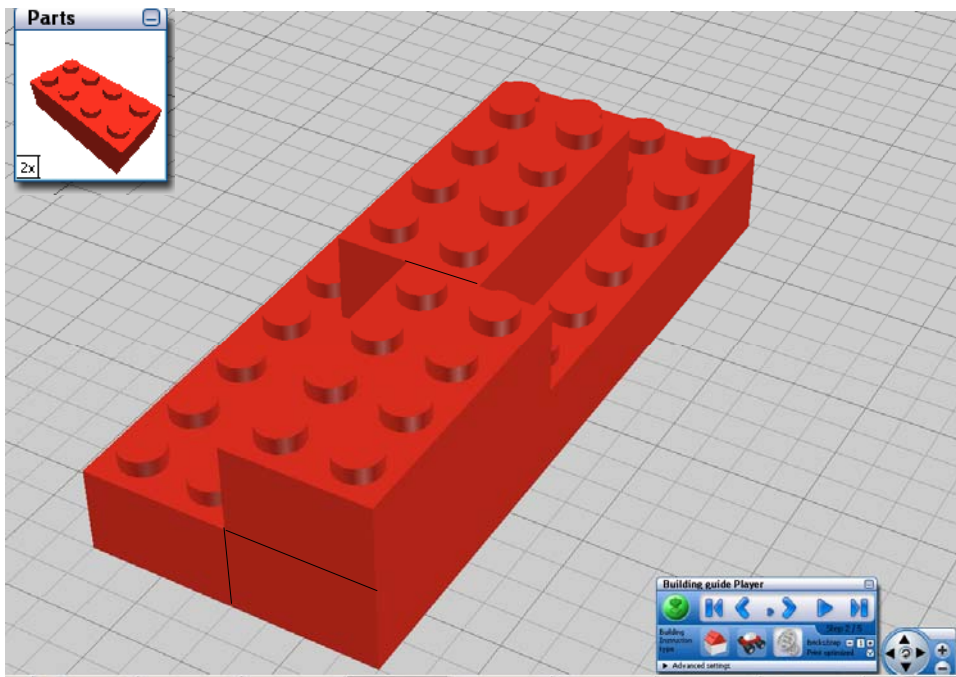
2



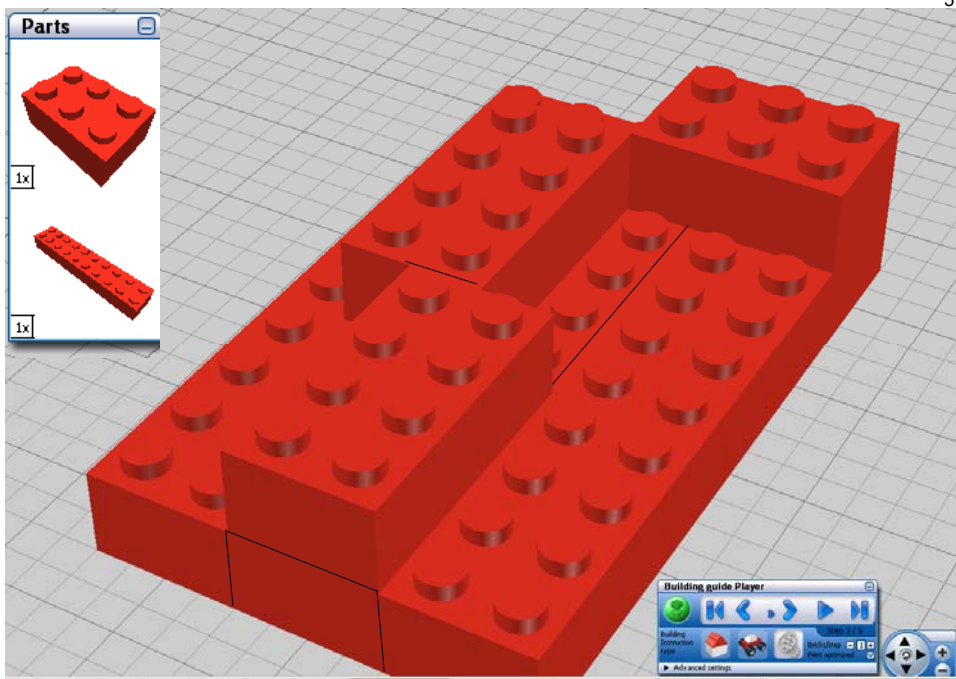
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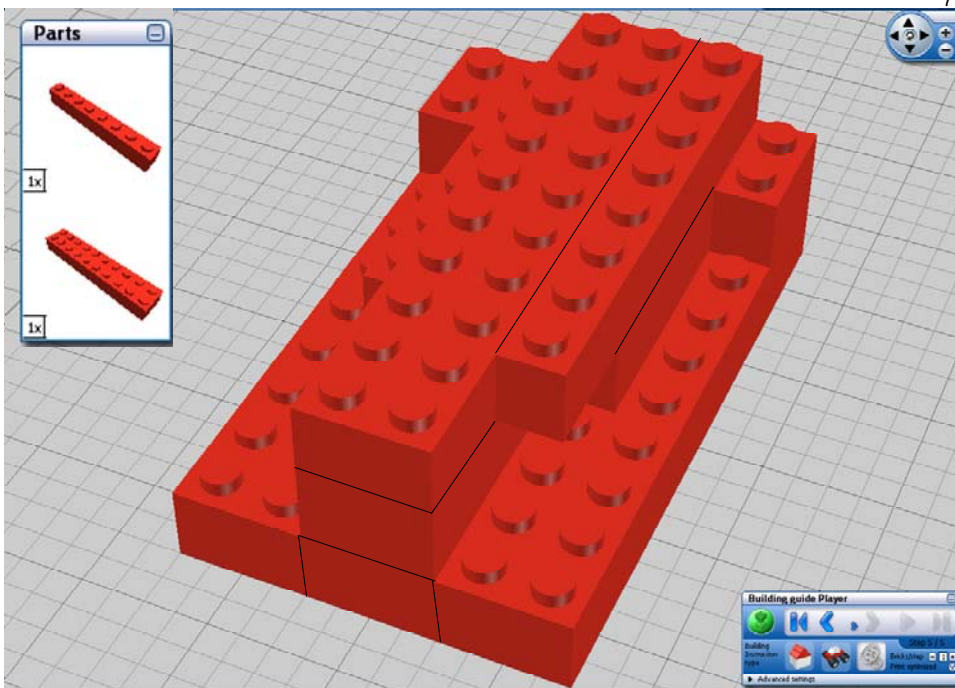
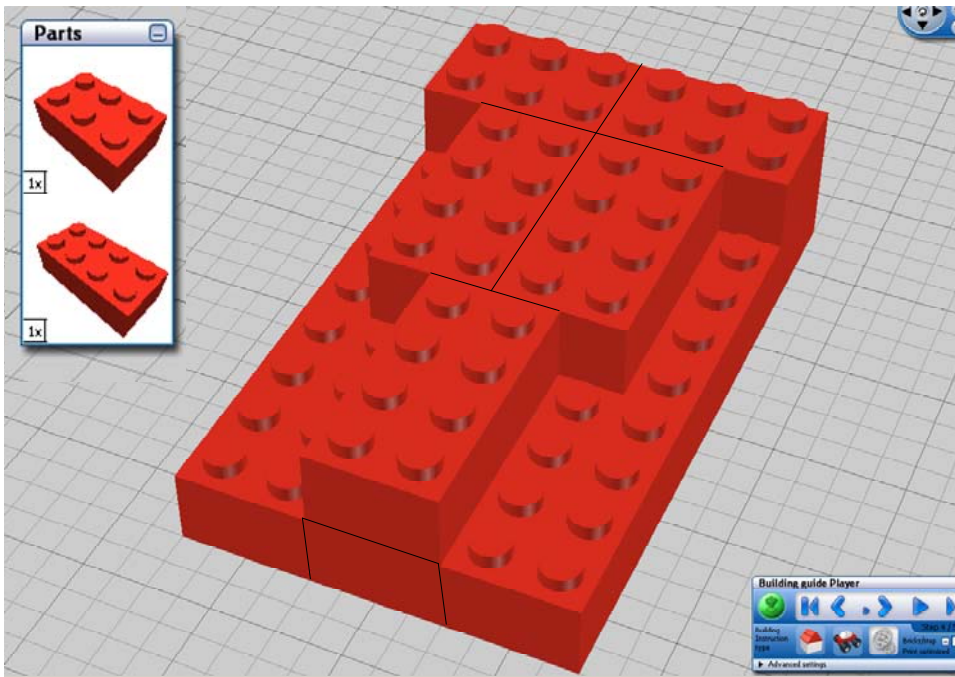
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5



6



Appendix C: Questionnaire survey (translated from Swedish)

Survey case study regarding information handling

Place:	Final Assembly, Volvo Powertrain, Skövde
Date:	2007-08-23
Study performed by:	Gunnar Bäckstrand

Please be as accurate as possible when you fill in the form. The purpose with the survey is to get an accurate picture of your work situation, from an information handling point-of-view.

Part 1 Background data

1.1 Year of birth

1	9		
---	---	--	--

1.2 Female Male

1.3 I have worked at the company for:

0-1 year

1-2 years

2-5 years

5-10 years

More than 10 years

1.4 I have worked in the assembly plant for:

0-1 year

1-2 years

2-5 years

5-10 years

More than 10 years

1.5 I work mainly:

- Day
- Evening
- Night
- Weekends
- Other How: _____
-

1.6 My main assignment is:

- Assembly
- Quality
- Management
- Other _____
-

1.7 I have worked on station S0800 during the case study:

- Yes
- No
-

1.8 I have worked on station S1100 during the case study:

- Yes
- No

If “No” in question 1.7 and 1.8, continue to question 2.8

Part 2 Information

2.1 Do you believe that the colour coding used on station S0800 and S1100 influenced the quality in a positive way?

- To a very high degree
- To a rather high degree
- In some way
- In a rather insignificant way
- Not at all
- Negatively
-

2.2 Did you feel secure with the colour coding that was used in station 800 and 1100?

- Yes
- No
- Sometimes
When? _____
Why? _____
- Sometimes not
When? _____
Why? _____
-

2.3 Is it your opinion that the information you received via colour coding was the information you needed to perform a correct assembly task?

- Yes
- No
- Sometimes
When? _____
- Sometimes not
Why? _____
-

2.4 Using colour coding on station S0800 and S1100 worked very well.

-
- Agree Entirely Neither or Disagree Entirely
-

2.5 It was faster to use colour coding when I assembled.

Agree Entirely Neither or Disagree Entirely

2.6 Colour coding made it easier for me to better keep track of what to assembly in the next engine.

Agree Entirely Neither or Disagree Entirely

2.7 By using colour coding it was possible to take away some of “blue buttons” without influencing the quality negatively.

Agree Entirely Neither or Disagree Entirely

2.8 Which information source would you say is the most important when it comes to viewing information regarding what to assemble in a specific workstation?

- My colleagues
 - Computer screen on carrier
 - The part to assemble
 - The engine
 - Paper instructions
 - Other sources
 - Which? _____
-

Which information source would you say should be the most important when it comes to viewing information regarding what to assembly in a specific workstation?

- My colleagues
 - Computer screen on carrier
 - The part to assemble
 - The engine
 - Paper instructions
 - Other sources
 - Which? _____
-

2.10 According to you WHEN do you need the information? Rank them, where 1 is the most important.

- When the carrier has stopped on a station
- Before the carrier has stopped on a station
- When it is time to assemble the part on the engine
-

2.11 Do you believe that information can affect productivity?

- Yes, a lot
- Yes, some
- No
- Don't know
-

2.12 I believe that the information I receive can affect the quality

- Positively
- Negatively
- Not at all
-

2.13 I believe that too much information can affect the quality

- Positively
- Negatively
- Not at all
-

2.14 Can the information you have access to, via IT-systems and instructions, influence the quality?

- Yes
- No
- Don't know
-

- 2.15 The information you have access to is a:
- Support
 - An obstacle
 - Annoying
 - A prerequisite for a successful assembly
-

- 2.16 Is it your opinion that the information is accessible when you most need it?
- Often
 - Sometimes
 - Seldom
-

- 2.17 Is it easy to find the information when you need it?
- Often
 - Sometimes
 - Seldom
-

- 2.18 Is it easy to see the information present on the computer screens?
- Yes
 - No
- Why?: _____
-

- 2.19 Is it your opinion that for example "20824541 SERVOPUMP" is enough information for you to quickly find the part in the material racks?
- Yes
 - No
 - Sometimes
- When? _____
- Sometimes not
- When? _____
-

2.20 You are working at station S0800 and are to assembly a part (for example the servo pump), where do you look for/find information regarding the part your are about to assembly?

- Get info from team leader
- Engine
- Computer screen
- From colleague
- Other
When? _____

2.21 Is there a quality risk with "prework"?

- Yes
- No
- Sometimes
When? _____

2.22 The best way to get information is via the text on a computer screen.

-
- Agree Entirely Neither or Disagree Entirely

2.23 Which of the following statements, according to your opinion, is correct.

- "Colour coding is easier to understand than text on a computer screen"
- "20824541 SERVOPUMP is easier to understand then colour coding"
- "Colour coding does not make my job easier"
- " Colour coding make my job easier"
- "None of the above"

2.24 If I had access to colour coding on the station where I work it would go faster to assemble.

-
- Agree Entirely Neither or Disagree Entirely

2.25 I believe that colour coding could be used in more stations.

-
- Agree Entirely Neither or Disagree Entirely
-

2.26 Some statements regarding your work.

	Totally True	Partly True	Partly False	Totally False	Don't know
The assembly goes faster when I "prework"	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
"Prewrite" does not affect quality	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
The risk to assemble wrong part increases with "prework"	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
I look at the approaching engine and thereby see what I should assemble	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
With right information at the right time could "prework" make my work easier	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

2.27 The information I receive during the assembly contributes to the feeling of control regarding my work situation.

Agree Entirely
 Neither or
Disagree Entirely

2.28 When the carrier arrives at the workstation I always look at the computer screen first to see what to assemble.

Agree Entirely
 Neither or
Disagree Entirely

Other remarks: