Quality Assurance in Manual Packaging Case of Thule AB:
A Theoretical Review of Virtual and Augmented Reality Systems as Cognition Supportive Approaches

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SUMMARY

This report is the result of the Master’s thesis work with the specialization of Production Development & Management. The project had been conducted within the collaboration of School of Engineering in Jönköping and Thule AB. The project has the main aim to analyze the root causes of quality problems in the manual packaging operations of Thule AB and offering suitable quality assurance and control approaches.

Majority of the errors made within production environments are mostly caused by human related mistakes. Those mistakes generally damages company prestige among the customers and may lead to high amounts of time and monetary loss as well. So, companies may take the direction of adopting different quality control techniques or implementing the concept of full automation by removing the human parameter from the equation and thus, the errors associated with them.

For the case of Thule AB, where packaging operations are being done by manual workforce, the main problem was incomplete packaging of the products. Questions at issue were related to the root cause of the problem of incompleteness and finding a relevant technology that can ensure the quality of the packaging process for completeness of packages in terms of package components.

Throughout the research two data collections and analyses had been done with a sequential manner. In other words, results of the primary data collection and analysis were the basis for the secondary data collection while explaining the case background, delimitations, problems, and root causes. Therefore, analyses of the data are presented together with each data collection.

With non-systematic interviews, observations sessions had been done during primary data collection and analysis phase, the first result derived was that, the very problem of manual packaging case of Thule AB was not caused by the manufacturing itself but the mental workload of the operators. The motivation of setting the path of cognition support systems was the relationship between the manual packaging case and cognition support systems with the aim of decreasing the perceived mental workload.
As the main content, the study can be considered as a theoretical review of “Virtual and Augmented Reality” based human cognition support approaches through the human cognition theory in context of mental workload and visual search with the main focus of manual assembly operations. Herein the results derived have aspect of presenting “Virtual and Augmented Reality” systems as possible solutions to the case problems. More in detail, advantages, disadvantages and basic cost estimations of those cognition support systems and their components are discussed through the study. The thesis is concluded with presentation of those systems which can be used in order to prevent cognition related problems as the focus of subsequent implementation projects of our study.
KEY WORDS

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Dedicated to Akin and Erdem families…

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Egemen Akin

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1 INTRODUCTION

The background of “Virtual and Augmented Reality Systems” (VAR), as cognition support approaches in production environments, is interrelated with the concepts of manufacturing flexibility, quality management, human factors in manufacturing environments and operators’ mental workload due to the complexity of the work.

In this chapter background and description of the research case are stated after a brief underlying theory presentation about historical development of human-machine collaborated assembly systems including quality, flexibility concerns and manual-automated workforce challenges. Subsequent to the background in this chapter purpose, aims, delimits of the research and outline of the report are presented.

1.1 Background of the Theory

In this section, background description of the research area, which is based on quality assurance, manual and semi-automated assembly processes within the notion of flexibility and human factors is stated.

1.1.1 Quality and Quality Control

As a historical background within the concept of quality control and assurance, up until the “Industrial Revolution”, the products were being manufactured by same person or specific team of people. So the operators were responsible for the quality issues and it was easier to spot a mistake since the production batches were low. With the continuous technology developments and the increasing help of mechanized manufacturing systems, the concept of mass production was introduced. Consequently rapid increase occurred in the amounts of manufactured goods, which changed the concept of quality criteria. Compared to the past, higher amount of people were involved in the production, in which everybody were responsible for a stage of production instead of being responsible of every stage of a product. This resulted with the understanding of inadequacy of current quality assurance methods. Companies started to establish quality departments, which were only responsible for the quality of the output, overseeing the quality of production and fixing the errors. With the introduction of the science and notion of 'industrial engineering', the pioneers of manufacturing came up with different techniques to adapt the changing manufacturing industry. The concept of standardization was introduced to decrease the variation of output by Henry Ford, statistical process control was introduced after the World War by Edwards Deming. After those incidents, concept of quality got more popular and several 'quality management systems' were introduced, several notions approached and quality was introduced as a profession and managerial practice during the second half of
the 20th century.

The concept of quality standards have been getting more and more popular and it had been given much more emphasis than higher production volumes since it is the measure of how well a company produces, therefore concept of quality is highly related with supply-chain relationship and thus affecting the main relations with customer and is one of the main coefficients of success. Nowadays, according to Ortiz (2006) the reason of having product defects is the lack of 5S, inadequate line flow and layout, over-production, insufficient training, inaccurate standards and instructions, and the inability to hold people accountable for continuous mistakes. Most important of it would be as Ortiz (2006) states; wrong manufactured items could cause undue harm to the production environment, it could also potentially damage customer and supply-chain relationships.

1.1.2 Manufacturing Flexibility

Aside from the importance of quality assurance concept on supply chain interrelationships, flexibility is another vital factor which affects competitiveness. In today’s competitive global market, in order to sustain the competitiveness, responsiveness to the ever changing customer demands has to be maintained. (Christopher, 2000) This agile responsiveness is highly related with the concept of flexibility. In order to realize the concept of flexibility companies invest in order to achieve flexible manufacturing systems where the different kinds of demands are aimed to be satisfied. However, it is difficult to automate those kinds of manufacturing systems since they require complex machines, which are capable of processing multiple job types. As mentioned by Heilala and Voho (2001), as an assembly system becomes more ‘manual’, flexibility and the number of variants increases, the batch size and production volumes decrease. In a similar fashion, Zäpfel (1998) emphasizes on the importance of the ability to fulfill individual customer needs in order to obtain competitive advantage which is caused by the increased product variants. Which implies that manual workforce stands as more flexible than full automation since product range and individual customer needs acts has vital importance.

1.1.3 Advantages of Manual Workforce

Even if current technology enables us to automate most of the manufacturing processes, the amounts of industries, which are using manual or semi-automated assembly operations are undeniable. Many industries are still using manual or semi-automated packaging systems for their end products therefore; human factor of the equation still has a role in terms of affecting the efficiency, quality and customer satisfaction. The reason for this issue is caused by the benefits suggested by Michalos, Makris, Papakostas, Mourtzis and Chryssolouris (2010) for human has the abilities such as the flexibility, ability...
of learning, adaptiveness and responsiveness that he possesses. They continue with the description of human operators in manufacturing as the enablers of flexibility. While the automated flows contain complex machines which operates only for specific operations or processes, since human has the ability to learn and implement by itself it is still easier to employ them in a far more flexible sense.

1.1.4 Drawbacks of Manual Workforce

According to Chryssolouris (2006) when it comes to the assembly operations within the automotive industries, increased complexity of operations requires manufacturing decisions need to be considered according to a holistic perspective, which includes cost, time, quality and flexibility. When it comes to manual or semi-automated assembly operations, as the operation complexity increases, the defect or error rate increases due to the human factor. Those human related defects mostly occur because of distraction, learning, cognition difference and poorly designed work descriptions as stated by Stork, Hild, Wiesbeck, Zaeh, Schubö (2009). The authors also state that when confronted by the complex information, people could easily be distracted by environment visually (Stork et al., 2009). Increasing complexity and thus, increasing amount of parts to be assembled leads the companies to have high amounts of defective items and low quality levels. A small defect of a product can lead to severe amounts of losses especially in the automotive industry where, for only one end-product a whole shipment could wait, furthermore; it could lead to accidents in a context that may threaten customers' lives. Thus, automotive companies are also responsible for the errors due to the supplier faults; therefore they are implementing very strict quality measures for their suppliers.

1.1.5 Hybrid Workforce (Human and Machine Collaboration)

As stated by Michalos et al. (2010), when taken separately, each manual or fully automated system have their own aspects. Though, a possible combination of automated and manual work cycles forms hybrid assembly systems that have high potential of satisfying the requirements specified and oriented by the customer. Several technologies has been in development in a human machine collaboration context as hybrid assembly systems and under the concept of cognition theory; such as assistive systems Virtual or Augmented Reality, which are: gather and feed data during the manual operations with the help of sensor technologies like pressure sensors, magnetic field generators, image capturing, camera vision systems.
1.2 Background of the Case

The research is highly related to industrial engineering, operations management and development and quality control areas. The thesis work has been done with the purpose of improvement in quality control and assurance for the manual packaging case in Thule AB, through cognition support techniques and technologies.

Thule AB is a Swedish vehicle solution systems manufacturer, which acts as a major supplier for almost every big automotive manufacturer. The company develops, manufactures and markets vehicle load-carrying systems such as roof racks, rooftop boxes, and sports equipment carriers (bicycles, water and winter sports equipment). To mention customer policies of the company, some contracts enable the customer to reject the whole batch and to request quality control for the whole output, in the case of defective products or missing components in retail product packages. This results with high amount of timely and monetary loss. In addition if the customer rejects the batch it causes a lot of rework and occupied space as well. Some major customers are big retailers who offer a wide range of vehicle accessories for numerous of vehicle brands and models. In a supply chain perspective, even a single defective item may cause high amounts of monetary loss and may even cause safety issues for the end-customer in a possible incident.

As mentioned by Ortiz (2006), rejects can cause line stoppages and may require product rework, which should have been manufactured correctly at the first time. Even if an effective kaizen event could eliminate and minimize costly rework on an assembly line, it is required to imbibe or cultivate the mentality of 'build it right the first time' which would be more effective in the long run. He also states that, the identification of the defective items as early as possible is vital for preventing more manufacturing mistakes from being done (Ortiz, 2006).

Similarly, in manual packing lines of Thule AB, rejects due to the defective products, which did not manufactured correctly at the first time, can cause line stoppages and product reworks. Therefore, it is really important to understand that giving importance to ‘how to facilitate building-right-at-the-first-time’ instead of ‘how to decrease error rates’. Considering the manual packaging case in Thule AB, regardless of the actual manufacturing quality, the rejects are being caused by incomplete packaging in terms of missing package components. Thus, the term of ‘defective product’ stands for the component based package inadequacy, from the perspective of packaging operations. Therefore, besides of implementing quality improvement techniques in the case of inadequate manufacturing, operational improvements are necessary to ensure the completeness of packages.
1.2.1 Current State and Challenges of the Manual Packaging Operations

The case study has been done by focusing on two different manual packaging stations assigned to two distinct product types with different operational characteristics. Even though packaging operations consist from basic reach-grasp-drop tasks of relevant components, they require some physically complicated package component fitting and positioning movements due to the package sizes which were decreased regards to material usage, inventory and transportation concerns, in other words positioning of the components in the boxes are not random and packaging operation should follow a certain sequence in order to fit all necessary components into the boxes.

1.2.1.1 Station 1

As a description for the current state, the first assembly station deals with a product (with the commercial name of “Rapid System 753”), which has the third highest volume among the total production. This product is being sold to the end-customers directly and the product is a universal type, which can fit for every vehicle with the usage of suitable mounting kit. It requires no need of modification of the process due to the variation in the order and thus, there is no setup time or cost incurred. “Rapid System 753” is being assembled and packed in the subjected workstation which consists of one semi-automated assembly and one manual packaging work benches, which are operated by two different workers. Due to the high production volume of “Rapid System 753”, the station functions 2 shifts per day with the overall production rate of 60 complete sets per hour. In other words for the product type of “Rapid System 753” takt time is set to 1 minute.

![Box components of Rapid System 753 as foot covers (A), foot bodies (B) and mounting kit bag content (C).](image)
The whole process covers 10 product parts to be packed where the operator takes the carton and forms into the shape of package with the help of a fixture where he fills in with the plastic foot covers (4 pcs.), feet (4 pcs.), mounting kit bag (including bolts, locks, key, screw driver and plastic caps) and the user manual (Figure 1).

In order to assure quality of manual packaging, task steps are instructed over printed manuals (Appendix 1) indicating number of components to be placed into the boxes and positioning details of the parts restricted by the box dimensions (Figure 2).

Currently in the assembly station of “Rapid System 753” control inspections are being made by picking a random completed box per hour and inspecting for content completeness. Additionally, when a pallet of end products is completed (7x3x12 = 252 boxes) a random box is being selected again among the last layer and inspected for completeness. Therefore it is not possible to mention about 100% quality control in this station.

When it comes to end customer dissatisfaction or claims related with the products, the most frequent problems are missing user manuals, mounting kit bags or missing kit components in the end product packages. Related with this issue Thule AB has a recent 2.2 million SEK investment on fully automated and accurate packaging machinery for pre-packaging of the mounting bags.
However there is still need for a quality control system for assuring box completeness in the manual packaging station.

As another quality control approach unique numbers are being stamped on boxes indicating date and shift of the production. By this tagging it has been aimed to detect, analyze and prevent problematic situations related with assembly, packaging and even production quality.

![Manual Packaging Station 1 (Rapid System 753)](image)

*Figure 4. Layout of manual packaging station 1.*

**1.2.1.2 Station 2**

The second assembly station deals with a product family (in the name of 70010 flow group), which have relatively lower singular product volumes, but the product family cover a significant amount of total production volume as continuous demand is assured over supply contracts. In order to make a sense about the production volume, the station operates 2.5 hours/day with 36 parts/hour production rate on the average. The process consist of relatively more complex set of actions since the worker assembles some parts by himself first and then packages into the final retail box together with other components. Furthermore, this vehicle brand and model specific products is not being
produced for the end-customers but a big automotive accessories and spare parts retailer.

The manual packaging process in the station, which is assigned to “70010” flow group, involves 10 to 18 product parts and other components to be assembled and packed where the number of parts varies from order to order. In general, packages consist of 4 to 6 feet (assembled from a pad, a body and a plastic cover), a screwdriver, a plastic cover cap and a bracket for each foot, 2 user manuals, mounting kit bag and a piece of protector foam. Even the foot bodies are common, pads and brackets are designed as vehicle specified.

From the point of supply chain contracts, the customer has the right to reject an already produced lot in the case of existence of a defective product in the lot. As a consequence, the customer can request a complete control again which causes the whole production system to stop and the allocation of a significant amount of work force to the control process. Even if this incident does not occur frequently, when it occurs it causes significant monetary costs and rework efforts. As the information we received from Thule AB, the last time this happened it cost 1000 man-force hours and a loss around 200,000 SEK.

Similar with the first station, manual tasks are being guided over written instructions (Appendix 2) indicating sequential assembly and packaging. Also each retail box is being tagged with a unique number but this time with a sticker indicating the order number, which the current product belongs to and the date.

![Diagram of Manual Packaging Station 2](image-url)

*Figure 5. Layout of manual packaging station 2.*
1.3 Purpose and Aims

Two research questions had been constructed through the research, in a sequence, in order to satisfy the aim of suggesting possible quality control and assurance approaches for the manual packaging case of Thule AB. The initial research question had been constructed in order to define main research focus as;

*RQ1: What are the major root-causes of incomplete packaging in terms of missing package components?*

After the primary data collection and analysis had been done, second research question as the main question to be answered was constructed as follows;

*RQ2: Considering the root-causes of the problem, requirements of the company and the limitations of the research; which cognition support technologies or approaches would be suitable to implement in order to ensure quality, in terms of completeness of the end product packages?*

Therefore, this research has the main aim of gathering available sensory, assistive and control technologies within the area of manufacturing. It has the purpose of ensuring the quality by increasing human perception and to reduce the probability of erroneous operations. Additionally, through a holistic underlying theory presentation, the report also aims to accomplish the reader understanding about the human cognition and mental workload related problems in manual operations. Thus, the main objective of this research is to present available cognition support technologies, which facilitate operator cognition and precision in order to increase the reliability of the production of Thule AB.

1.4 Delimitations

Even the research question one regarding to the primary data collection is mentioned among the research aims in order to present a holistic perspective of the research progress, this report does not include the structured explanation of primary data collection and analysis phases together with its results. The reason for this issue is the primary data collection was the pre-study of defining the root cause of the case problems and setting up a focus to the research. Thus, results of the primary data collection are not presented under a specific chapter as ‘results’ or ‘empirical findings’. Instead, those results are mentioned through the ‘primary data collection and analysis’ section in order to create understanding of the research process under the methodology chapter. So that, in relation with the primary data analysis, the research scope has been limited with cognition theory and cognition supportive systems.
While discussing the costs of possible solutions, detailed monetary and financial analyses had not been done. Instead, brief benchmarking and comparison between system components of cognition support systems has been done in order to present the company aspects of possible system components leaving the decision of implementation to Thule AB, as a possible further project of this research.

The cost estimations have been made by the request of Thule AB, in order to give an idea and conceptual information. Besides, the reason of not having detailed cost analysis is related with pricing principles of the VAR system component manufacturers. Most of these manufacturers prefer to give customer and situation specific price quotations according to the different system and component customizations requirements. So that, costs we present are based on a thorough web-catalog search and do not include possible in-house installation, operator training and shipping costs.

Furthermore, this report is not concluded with a suggestion of a possible cognition support system. Instead, it presents possible system solutions discussed according to their aspects. Therefore, the research does not cover implementation as well, since an implementation decision requires detailed feasibility analyses, covering financial analyses, pay-back estimations and depreciation studies.

1.5 Outline

In here, outline of the report is presented as followed below in each chapter in a step wise manner.

Chapter 2 - Research Methodology

In this chapter, chosen research methodology is structured. With the aim of describing underlying logic and philosophical approaches, this section covers methodology approaches, the method, and data collection techniques.

Chapter 3 - Literature Review

In this chapter, theoretical part of the research is presented. With the aim of facilitate a deeper understanding about the human cognition and mental workload related problems in manual operations, the chapter includes the cognition theory the current cognition support technologies based on the Virtual Reality (VR) and Augmented Reality (AR) concepts. In addition, this section covers multiple experimental setups conducted within the theory with the aim of showing proofs to the effectiveness of VR and AR systems.
Chapter 4 – Possible VAR System Solutions for the Thule AB Case

In this chapter, the motivations of concentrating on VAR solutions for cognition assistance are presented as results of our research. Afterwards, input, output and tracking devices are illustrated as system components of cognition support systems. In addition to the illustrated system components, a basic benchmarking is presented in terms of advantages, disadvantages, specs and price.

Chapter 5 – Discussion and Conclusion

In this chapter, the correspondence and correlation of literature with the case has been presented in comparison to the possible setup scenarios. Subsequently, the chapter is concluded with the future research discussion.

Chapter 6 - References

List of references and bibliography are presented in this chapter.

Chapter 7 – Appendix

Exemplary work instructions of the manual packaging stations are presented in the appendix.
2 RESEARCH METHODOLOGY

This chapter describes the chosen research methods and techniques used for conducting the research, with the purpose of creating an understanding of why they are used, how they are used and why they were suitable for this type of research.

This research has been structured as methodology approach, research methods and techniques for data collection. As it is suggested by Yin (2003), a research should be designed in a structure that starts with deciding the research approach, conducting the research for data collection and discussing the research evidences in order to explore the familiarities with the theory and having a result.

According to Marshall and Rossman (1995), a research has the goal of having better understanding of interactions, and having interpretations. When it comes to this research study, it is based on the goal of having a better understanding of human related problems of Thule AB case and techniques for increasing the output quality depending on the root cause of the problems. For this goal, information gathering process consisted literature research for existing technologies based on cognition support systems. This acquaintance is evaluated and discussed considering the manual packaging case, where different cognition support solutions were presented.

2.1 Methodology Approach

In this section several methodology approaches and research traditions are compared in order to stress the similarities between the characteristics of the research study and most commonly used research approaches.

2.1.1 Basic Research and Applied Research

Williamson (2002) defines two research types, mentioned as ‘basic research’ and ‘applied research’. Basic research is explained as a fundamental, theoretical research, which mostly concerns with having novel knowledge that could be applied to specific and practical problems, as broadening the perspective and focusing on theory building. The other type of the research mentioned by Williamson (2002) is defined as applied research, which has the concern of solving specific problems in real life situations.
When it comes to this research study, there exists a problem to solve in a real life situation for the manual packaging case of Thule AB, from where some research questions arise such as:

- **What are the major root-causes of incomplete packaging in terms of missing package components?**
- **Considering the root-causes of the problem, requirements of the company and the limitations of the research; which cognition support technologies or approaches would be suitable to implement in order to ensure quality, in terms of completeness of the end product packages?**

Despite that the research study seems like an applied research, it also has the characteristics of basic research such as being a theoretical research and having the purpose of gathering knowledge about cognitive theories and cognition support systems.

Williamson (2002) mentions that there is no clear distinction between basic and applied research and many of the same techniques are being used for both. The reason for this commonality is because a research could be practical and still generate new theory and contribute to knowledge. For this case manual packaging, the findings of the study has possible cognition support solutions, which might be implemented in short or long term. However, the application decision of those system solutions is up to the company administration since this research does not cover a study of implementation.

### 2.1.2 Deductive and Inductive Reasoning

Before explaining the approach, it is important to understand the underlying reasoning throughout the conduction of the research. Literature suggests that there are two kinds of reasoning styles based on the philosophy used to form the research. The subjected styles are the deductive and the inductive reasoning types. As mentioned by Williamson (2002), deductive reasoning is associated with positivist approach, which is linked to the hypothesis testing approach of a research. On the other hand, inductive reasoning concerns with generating hypotheses from particular instance and concludes as general principals, after the analysis of the data collected (Williamson, 2002).

This research study was conducted under the deductive reasoning logic. The literature review has been conducted through the general principals of cognition theory and within the different cognition support system solutions. The benefits and challenges were discussed, considering manual packaging case of Thule AB. So the main logic and philosophy of this research study is based on the deductive reasoning since the arguments were degraded from general principles down to a particular manual packaging system.
2.1.3 Positivist and Interpretive Approaches

After the underlying logic is formed, an approach based on that reasoning style should have been taken. Based on the literature, there are mainly two distinct research approaches listed as positivist and interpretive approaches.

The positivist approach is mostly based on quantitative data and experimental designs, where the surveys that are being used have the concern of having results with replications for consistency and stability (Kuhn, 1970; Powell, 1997).

On the other hand, interpretive approach concerns with the qualitative methods of research and is generally being used within case studies and historical research. As Williamson (2002) mentions, interpretive researchers conduct their literature researches in order to have the knowledge and understanding of their topic, and then they develop their theory and research questions.

Based on the literature, this research study is designed as a qualitative research study, which had the purpose of creating knowledge and understanding of the cognition theory and cognition support system solutions within the literature.
2.2 Research Method

In this section, several research types are discussed in order to show the similarities of the research study characteristics between various research types subjected in the literature and to define the research method. The research methods such as case study, action research and R&D characteristics are discussed in order to define the research study more clearly.

2.2.1 Exploratory Research

The selection of research type is based on the categorization of typical research questions as, who, what, where, how and why as mentioned by Hedrick, Bickman and Rog (1993). This research focuses mainly on 'what' questions as it has the purpose of acquiring knowledge and understanding. Therefore, based on the literature, this research shows similarity with exploratory research characteristics. As also mentioned by Yin (2003), most of the 'what' question are used for conducting exploratory studies.

In this research, exploratory research study has been conducted within a manual packaging case with the aim of investigating the root cause of the quality problems empirically and presenting appropriate quality control and assurance solutions related to this root cause.

2.2.2 Case Study, Action Research and R&D Characteristics

Similar to the fact that this research has exploratory characteristics, Shanks, Rouse and Arnott (1993) denotes that, an exploratory research generally use qualitative research methods such as case studies. Williamson (2002) states that, a case study is most often primarily concerned with qualitative data and data collection techniques such as interviews and observations, which are mostly used to acquire knowledge and understanding of a subject. In this aspect, this research study involves case study characteristics since it has the aim of having an understanding of cognition theory and presenting cognition support techniques.

On the other hand, as Benbasat, Goldstein and Mead (1987) has mentioned, an action research is different from a case study since it involves the researcher to take an active role in the experiment instead of merely observing it by collaborating with the participants in order to help understanding and solving problems. This study involved the researchers to participate the manual packaging process in order to gain understanding about the root cause of problems and to define the limitations. Thus, the research has also the characteristics of action research as well.
Moreover, this research study also shows similarities with system development approach to some extent. As it is suggested by Williamson (2002), systems development approach falls under development with exploration. Related with this concept, the research study characteristic can be classified as 'research and development' since there exists a manual packaging case and the quality of that process is required to be improved by some technologies discussed by the researchers.

2.3 Data Collection and Analysis

Throughout the research two data collections and analyses had been done with a sequential manner. In other words, results of the primary data collection and analysis were the basis for the secondary data collection while explaining the case background, delimitations, problems, and root causes. Therefore, analyses of the data are presented together with each data collection.

2.3.1 Primary Data Collection and Analysis

The data collected through the primary data collection were used to understand the root causes of the problems while defining the background of the case. Also primary data collection has the aim of setting a focus for the research with the construction of main research question.

As Williamson (2002) has mentioned semi-formal interview has questions but it also allows the researcher to be flexible in order to ask the questions that follows the line of thought of respondent. For primary data collection, combination of informal and unstructured interviewing has been conducted which involved exploratory interviews in order to acquire required information about the case and an understanding of root cause of the problems in the manual packaging case. The main purposes of those interviews were to gain a contextual understanding of the case and reflect upon the causes of problems encountered.

Furthermore, observations were used in order to understand the manual packaging process and see problems encountered throughout the process. According to Williamson (2002) observation is a useful technique for understanding people's behaviors and what is going on in a setting. According to Martin and Bateson (as cited in Williamson, 2002) there are four observation styles such as ad libitum, focal, scan and behavior.
Ad libitum (at one’s pleasure), involves non-systematic ways of observation which is useful when researchers are new to the situation they are in.

Focal observation style involves recording the participants' behavior over a specific period of time,

Scanning involves a quick scanning of a group of participants in regular intervals,

Behavioral observations are used when it comes to scan a particular behavior and recording data based on it.

In this research study, ad libitum type of observation was used in order to get information about manual packaging process, to understand the operation steps of the current manual packaging and to examine the presence or absence of certain activities related to the cognition of participants.

For the analysis of the primary data, basic brainstorming sessions and unstructured discussions were done together with the company officials. More in detail, the first research question was answered as a result of these brainstorming sessions while indicating the human cognition related problems as the root causes and the main research focus was set as cognition support systems.

2.3.2 Secondary Data Collection and Analysis

Secondary data collection was conducted from the books, research articles and journals then the data acquired were presented as the results of the literature review. After that, results of the literature review were discussed in terms of their advantages and disadvantages in relation with cognition support system alternatives for the manual packaging case of Thule AB.

According to Reed (as cited in Williamson, 2002), secondary data consists of conferences, proceedings, journals and books where the other researchers present the results of their research based on their primary data or sources. Secondary data collection is generally useful in inductive methods, since the researcher gathers information from the previous studies and generalizes in a standardized way and expands in broader terms as Sharp, Peters and Howard (2002) suggested. On the other hand, in this research secondary data within the literature review like books, journals, articles etc. were used in order to deduce information down to a specific case.

It is important to mention that, this thesis is mostly based on literature review studies since the aim is to create holistic understanding of cognition theory and to present cognition support system solutions for manual packaging case of Thule AB. When it comes to the literature review studies, Fink (1998) suggests that literature review study is filtered through two eligibility criteria which are defined as practical criteria and quality criteria. Practicality is related with the
usability of literature in language and quality is the adherence of the methods to the studies that science relies on. In this study, the practicality of the information was important since the aim was to deduce the gathered information as cognition support solutions to Thule AB, where a process of implementation might be decided in the future.

In spite of the fact that qualitative data collection methods are mostly used in inductive methods and working as a bottom-up and theory generating culture, this research has the characteristic of interpreting and giving meaning to the general theories and technological approaches in order to obtain similarity with the manual packaging case of Thule AB. Therefore, the data gathered through the literature review has been deduced down and compared with the Thule AB case.

However, based on those deductive results, inductive predictions could also be made in a broader sense of quality control approach in manual packaging systems within industries.

2.4 Validity & Reliability

Even if the purpose, methodological approach and data collection techniques of the qualitative and quantitative research are different, every research needs to be decreed and exhibited as credible. Golafshani (2003) mentions that, in a qualitative research the researcher is the tool considering the credibility in the qualitative research depends on the ability and effort of the researcher. Unlike in quantitative studies, qualitative studies do not use the terms validity and reliability separately. Instead, the terminologies are used differently as credibility, transferability and trustworthiness.

On the other hand, some researchers argue that reliability is an irrelevant concept in the context of the qualitative research studies and thus, the term validity is not applicable through the qualitative research. Therefore, most of the researchers created and adopted their own terms that seem more appropriate to them. The concepts of reliability and validity are still on debate about the qualitative research studies between the research methodologists. The notion of ‘reliability’ within the context of qualitative research has the purpose of the generating understanding (Golafshani, 2003).

Johnson (cited in Golafshani, 2003) also mentions that, the aim of the qualitative research studies is to generate deeper understanding. Hence, the notion of constructivism may satisfy those aims since it suggests the possibility of existence of different constructions of reality. Therefore, it is necessary to use multiple tools of data collection in order to facilitate the reliability and validity of a qualitative research. Patton (2002) and Golafshani (2003) suggested the use of triangulation for having more reliable, valid and diverse
construction of the realities by using multiple methods such as observation, interviews.

In this research study, in order to acquire valid and reliable diverse constructed realities and satisfy different aims of the study, triangulation is used throughout the study. For instance, for acquiring knowledge and defining the current case we have used informal interviews. On the other hand, to understand and define the problem observations were used. Differently, for satisfying the research questions and reaching the aim of the study, literature reviews were done.
3 LITERATURE REVIEW

In order to consolidate the readers’ understanding about “Virtual and Augmented Reality” systems as cognition supportive approaches, this chapter starts with a human cognition theory review with the exploratory focus of manual assembly operations. Subsequently, description of “Virtual and Augmented Reality” systems, system components, hardware and software are presented through the relevant literature. Later on, in order to make conceivable potential assessments of the suggested approaches, four experimental setups had been done by different researchers with the aim of potential validation are presented. Chapter 3 finishes with the future directions of Virtual and Augmented Reality Systems review.

3.1 Cognition Theory in Context of Manual Assembly

Human workers are the most prominent workforce with the capability of increasing applicability and flexibility of assembly operations. However, due to flexibility related high production costs, potential usage area of manual workforce is mostly restricted with prototype building or highly customized limited and valuable product assemblies. In this respect Stoessel, Wiesbeck, Stork, Zaeh and Schuboe (2008) identify the source of manual workforce oriented flexibility with cognitive capabilities of human workers.

3.1.1 Human Information Processing and Mental Workload

In order to predict worker task performance during manual assembly operations, it is essential to understand underlying processes of cognition (Zaeh, Wiesbeck, Stork & Schubö, 2009). With this aspect, Stoessel et al. (2008) come up with a simplified framework in order to explain information processing during manual assembly operations.

This framework offers the division of the whole assembly cycle into sequential processes. In context of this framework, an exemplary manual assembly process, as itself, can be divided into two subtasks: commissioning and joining. Both subtasks consist of cognitive functions, explaining processing sequence; starting with recognition of the environmental stimuli by human senses, then processing of these stimuli information through some cognitive stages and finally action execution as response generation. As it can be seen in Figure 7, perception consists of stimulus preprocessing, feature extraction and stimulus identification while action consists of motor programming, action execution and motor adjustment mental processing sub-stages. Stoessel et al. (2008) also state that such framework is appropriate in terms of explaining reasons and initiators of human errors during manual assembly operations since human information processing resources are finite.
According to Wickens’ (2002) model with four dimensions, subjected mental resources can be described as perceptual processing (visual-auditory), processing codes (spatial-verbal), processing stages (perceptional-central, processing-responding) and response modalities (manual-verbal). Via this framework it is possible to make predictions about multiple task performance. For instance, if a manual assembly operation is supposed be handled in a chorus by two tasks while concerning the same response modalities higher level of mental workload can be mentioned. Therefore, it is necessary to distribute and allocate limited mental resources of humans to relevant tasks while considering interactions between task features and cognitive processes. Plus, contingency of unsatisfactory performance results in the case of inappropriate allocation of these resources, which can be needed by multiple tasks, in context of multiple task performing and mental workload (Stoessel et al., 2008; Stork & Schubö, 2010b; Zaeh et al. 2009).

![Figure 7. Processing stages and resources in manual assembly tasks for the commissioning and joining phase. (Stork & Schubö, 2010b, pp. 322)](image)

### 3.1.2 Selective Attention and Visual Search

Stoessel et al. (2008, pp. 246) define attention as: “The authority deciding which items (features, objects etc.) will be processed at all, and which information is passed over to the next processing stage”. A significant portion of assembly tasks are done over perception of instructions and information through selective visual attention. During manual assembly operations workers are supposed to work with more than one source of information at the same time such as assembly instruction indicating task sequences, task relevant parts and locations etc. Since human mental resources are limited, as mentioned in the previous section, and number of elements can be processed at the same time is finite; workers are supposed to select the right information at the right time by shifting their selective attention to the relevant source (Stork & Schubö, 2010b).
With respect to psychological theory of information processing and mental resources, selective attention should be allocated to relevant location of information and parts in order to facilitate working process of manual assembly (Stork et al., 2009). In addition to this, task of shifting selective attention to the relevant assembly part or source of information among the other irrelevant ones can be mentioned as visual search process. Challenging issues can occur during visual search if similarity increases between target of attention and distracters which cause to time consuming shifts. That is to say; analogy of distracters with the target in the vicinity can obstruct target pop out (Stork et al., 2009; Stork, Stössel & Schubö, 2008).

Stork and Schubö (2010a) mention about an outstanding experimental psychological paradigm while referring to Posner, Snyder and Davidson (1980), in the name of “spatial cueing”, in order to clarify visual attention guidance. It is the case that selective attention can be guided via top-down or bottom-up control mechanisms using variety of spatial cues with the purpose of enabling proper and effective visual search. Endogenous or knowledge-driven cues direct attention to the relevant location by using top-down voluntarily elucidation process. On the other hand bottom-up, exogenous, or stimulus-driven cues, as prominent perceptual events, directs the visual attention reflexively. Symbols expressing the location and direction of the target location, like an arrow, are most commonly used endogenous or central cues. In order to shift attention as a reflexive response to peripheral salient (exogenous) cues such as size, color, orientation or temporary luminance can be mentioned (Stork et al., 2009; Stork & Schubö, 2010a; Stork & Schubö 2010b; Theeuwes, 1994).

Benchmarking of endogenous and exogenous spatial cues in context of their effect on assembly performance can be discussed via fundamental research results. Stork et al. (2008) mention about spatial exogenous cues’ capability of increasing worker performance; by speeding attention shifts together with reduced eye movements and reaction times. With reference to “Findability” concept, defined by Morville and Callender (2010), (as cited in Stork & Schubö, 2010b), instruction and information presentation in manual assembly should be enhanced in a way that making visual search more efficient. Hereof, salient spatial elements can improve visual search efficiency and performance since they pop out among other distracters in the working environment (Stork & Schubö, 2010a). Popping out ability of peripheral salient cues also lead to faster attention shifts comparing to endogenous (central) cues since, via endogenous cueing require some additional time in order to construe the symbol triggering top-bottom interpretation process (Stork & Schubö, 2010b).
3.1.3 Task Complexity and Performance

As a contexture difficult to determine and measure, complexity of a task is shaped by miscellaneous factors. Various number of performance determinants are present in order to assess the complexity of a task concerning mental resources and workload (Stork & Schubö, 2010b).

Referring to the previous sections, during manual assembly, worker has to partition his/her attention among the instructive data, work in progress and the working environment. In this sense Stoessel et al. (2008) put emphasis on importance of proper attention distribution, combination of attention and perceptual strategies about which information source to be attended, what amount of information to be extracted among the source; and their effect on human task performance.

Although it is hard to define and measure parameters of task complexity related with performance, since they are interrelated among certain subtasks which manipulate each other, there are some basic objective task parameters as mentioned by Stork et al. (2008). Distance and size of the target part, total time for grasping movement, movement speed, grasping accuracy, hand selection, peak velocity and latency of hand onset, completion time, number of sub steps needed, dwell time of each instruction and step and also error rates are more commonly mentioned basic objective task parameters can be used during task complexity/difficulty and human performance evaluation (Stork et al. 2008; Stork & Schubö, 2010b).

Besides of those basic quantitative parameters, performance measurements can be done over visual search analyze in context of efficiency of selective attention shifts and cognition processes. In common manner visual search performance is measured by analyzing time required to find a relevant part or source. Referring to Just and Carpenter’s (1976) psychological research about cognitive processes, visual search performance in manual assembly can be measured by tracking the eye movements of the operator. Eye movement parameters like fixation count, duration and eye movement patterns can be beneficial in order to investigate the information processing intensity. More in detail while higher degree of fixation counts inefficiency of visual search process, eye movement trajectories can be used during exploration of visual search strategies and effect of distracters in assembly boundaries (Stork et al., 2009; Stork & Schubö, 2010a). Besides of that Stork and Schubö (2010b) underline the possible usage area of eye movement tracking as future event prediction. Since eye movements can point out the observer’s expectations pertaining to future, prediction of future errors due to the workers future intentions is possible.
In order to get adapted to the task between attention shifts, significant amount of time is required throughout a cognitive process. Therefore shift switches should be abridged to possible minimum by adequate instruction sequences in order to sustain an efficient manual assembly flow (Stoessel et al., 2008). Also prevention from unnecessary attention shifts or efficiency improvement of visual search can assure a smoother workflow. As it is mentioned in advance, spatial exogenous cues are commonly discussed with their advantage of leading to faster attention shifts especially compared to endogenous cues (Stork & Schubö, 2010a).

3.2 Virtual and Augmented Reality Technologies for Cognition Support

In order to sustain a high degree of flexibility, as promised by usage of manual workforce in assembly operations, integration of guidance systems with human workers have to be done with the considerations of cost and operation efficiency. At this point necessity of situation adaptive intelligent system interfaces arises. In context of such assistive systems, right amount of information should be presented to the worker at the right time and place in order to adequately support workers’ cognitive processes together with the assembly (Stoessel et al., 2008).

At this point, Virtual and Augmented Reality Systems, as cognitive technical systems equipped with artificial sensors and actuators, are appropriate applications of interactive and intelligent assistance interfaces (Stoessel et al., 2008; Wallhoff et al., 2007).

3.2.1 What is Virtual Reality Technology?

“Virtual” as a word, became popular during early 1990’s and has been used in numerous of application areas. For instance, in technical and engineering terminology, virtual factory, virtual engineering, and virtual machines are commonly used concepts. However the roots of the virtual reality researches go back to 1960’s, from that date to today, meaning and definition of virtual reality has been changed and became a bit unclear due to the mentioned popular mystifying but widely used terms and concepts. At this point, it is necessary to clarify definition of virtual reality in order to mention the possible usage areas during manual assembly operations. The word “reality” can be explained as the external environment’s cognized and experienced status by human senses. By dictionary definition “virtual” as a commonly used adjective means that “having all of the properties of x while not necessarily being x”, in other words “In effect or essence, if not in fact or reality; imitated, simulated, substantial”. Therefore Virtual Reality (VR) is replication or supersede of the real time objects or instances, which can be accepted as true or real by human senses even they are not exist in the real spatial environment.
VR technology uses digital computing environments in order to create simulation of the real world objects which can be accepted as real by human brain, senses and cognition system. More in detail, VR technology works through a human-machine interface in order to pair human brain and sensory functions and create a feeling like moving around in the created replication environment as we do in real world (Lu, Shpitalni & Gadh, 1999).

Although VR is a wide ranged concept, possible VR technology applications can be narrowed down related with engineering operations. At this point due to the match and closeness between real world and simulated reality a classification can be made. If the created reality, in the computer environment, is completely separated from real world and the user is wrapped up with absolute virtualization. This is called as “virtual reality”, “virtual environment” or “synthetic environment” (Lu et al., 1999). In the other scenario, if the user does not feel complete existence in the VR and just interact with limited replication of the real environment this is generally addressed as Augmented Reality (AR). (See section 3.2.2).

According to Lu et al. (1999) VR systems can be classified and measured by four key characteristics as immersion, presence, navigation and interaction. In basic explanation, as the user becomes less able to separate the real and replicated environment from each other, the more the computer generated environment becomes immersive. On the other hand, presence is a more subjective feeling of being in VR environment, which requires self-representation of users’ tracked body part (hand, head etc.). ‘Navigation’ is explained as the ability of user to move around for exploring features of virtual environment while ‘interaction’ is described as ability of user to select, move and modify the virtual objects. Among the characteristics introduced by Lu et al. (1999), discrimination of VR systems can be done while evaluating the relation of real-world of users’ and virtual environment (Zachmann, 1998)

- If the virtual environment is a complete representation and projection of the real-world situation or object this is called as “Tele-presence” which can be used in the case of distance between user and actual environment or unlikeliness of physical sizes. As an example to this type of VR applications, atomic scaled representations or remote steering of some vehicles can be given.
- In the case that virtual environment is not a projector of any real-world environment; user interacts with fictional objects differently from previous case. However, virtual environment still matches with real world phenomena’s (physics laws, human perception etc.). These kinds of VR environments can be used with functional simulation, training or ergonomics considerations in context of engineering applications.
- It is also possible that virtual environment feels quite unreal or imaginary with respect to real world. Such VR systems are commonly used for entertainment applications such video games or animations.
Exemplary implications among the types of VR systems can be seen in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>Unreal</th>
<th>Not Existing</th>
<th>Existing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High Immersion</strong></td>
<td>Entertain-ment</td>
<td>Functional simulation</td>
<td>Tele-presence</td>
</tr>
<tr>
<td><strong>In-between</strong></td>
<td>Training</td>
<td>Ergonomic</td>
<td>AR</td>
</tr>
</tbody>
</table>

*Table 1. Types of virtual reality systems (Lu et al., 1999, pp. 475)*

### 3.2.2 What is Augmented Reality Technology?

As a variation of VR, Augmented Reality approaches offer enrichment of the existing environment instead of decoupling it, in other words AR systems are based on unification principal of computed generated virtual environments with real physical world environment while presentation of necessary information when and where it is needed. For presentation of the mentioned necessary information, diagrams, sequential instructions, animations etc. can be used whereas augmenting perception and interaction level of the user (Reinhart & Patron, 2003; Tang, Owen, Biocca & Mou, 2003).

AR systems do not require 3-D representation of the environment and its elements since high level of existence feeling by the user is not essential for these systems. Therefore, differently from VR, AR systems can work through plainer graphics to be presented like wire framed virtualization of the objects rather than realistic models require graphical engines with high frame rates (Lu et al., 1999).

In order to augment real world objects and environments two main categories of visualization can be mentioned among numerous of AR methods (Reinhart & Patron, 2003; Lu et al., 1999).

#### 3.2.2.1 Optical-See-Through Augmentation (OST)

The most well-known application of OST systems are called as head-up-displays (HUD), which are used in military jet fighters. Basically, pilot conducts the fighter jet with the help of the information he/she receives while looking through a semitransparent glass. A projector is placed under the glass, which is also called as “combiner”, to mirror the computer generated graphics to be combined with real world vision. Moreover, beside of fixed OST systems like HUD, displays can be fixed on wearable and portable apparatus like helmets or glasses.
3.2.2.2 Video-see-through Augmentation (VST)

Instead of over layering the real world vision with computer generated graphics like in OST, VST systems works with a mixture of digital images principal. More in detail, digitally captured records of the real world are mixed with virtually augmented elements. On regular basis, a set of video cameras are used for image capturing and a monitor to display the blended stream to be seen by the user.

<table>
<thead>
<tr>
<th>Video-see-through (VST)</th>
<th>Optical-see-through (OST)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Since there is one video streaming it is simplified</td>
<td></td>
</tr>
<tr>
<td>• Resolution of monitor, optic distortion, processing related system delays etc. do not have effect on real world vision.</td>
<td></td>
</tr>
<tr>
<td>• Due to blending of two video images synchronization of two streams is easier and registration problems can be predicted. Also captured video can be used as tracking data.</td>
<td></td>
</tr>
<tr>
<td>• Level of augmentation can be higher</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Advantages of VST and OST systems (adapted from Lu et al., 1999)

As like in OST systems, both fixed and portable VST systems are available among current applications like fixed monitors, data glasses or helmet mounted displays as well.

![Diagram of Video-see-through (VST) and Optical-see-through (OST)](image)

Figure 8. Basic principles of AR (Reinhart & Patron, 2003, pp. 6)

Advantages of these systems among each other are summarized in the Table 2.
3.3 Components of Virtual and Augmented Systems

In this section beyond the background theory of Virtual and Augmented Reality (VAR) systems, components of these systems such as hardware and software will be mentioned.

As a core and main component of VAR systems, a digitally created model of the subjected objects, elements or environment exists to be represented. Due to the application area of VAR systems these digital models can vary from underwater terrain representations to building interiors (Table 3).

<table>
<thead>
<tr>
<th>Architecture / Engineering</th>
<th>Conceptual realistic building interior representation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tele-presence/operations</td>
<td>Digital mock-up of the environment to be explored</td>
</tr>
<tr>
<td>Medical Applications</td>
<td>Representation of the body part subjected to a surgery</td>
</tr>
<tr>
<td>Product Realization</td>
<td>“integrated product model” of the product or process under development</td>
</tr>
</tbody>
</table>

*Table 3. Exemplary digital models of different VAR systems’ (adapted from Lu et al., 1999)*

According to Lu et al. (1999) components of inclusive VAR systems should meet the requirements of creation, storage, exploitation, replication and presentation of the mentioned digital models. Therefore they mention four system levels as:

1. A computer aided design (CAD) environment in order to create and store the required information,
2. An input device to enable user interaction with the VAR model,
3. A dynamic simulation/replication capability in order to examine responses of the model according to different manipulations,
4. A high-fidelity output system empowered with multi-sensory capabilities to give relevant feedbacks due to the manipulations.

While discussing levels of VAR systems Lu et al. (1999) mostly focus on high computational demands of highly interactive, realistic and responsive VR systems. However, the following sections describing these system level related components will be more simplified while reminding AR systems offer less, but still significant, immersive computer generated environments and require less computational capabilities in terms of giving realistic responses such as realistic haptic feedbacks etc.
3.3.1 Computer Aided Design Environment

VAR systems’ information creation, integration, storage and modeling activities handled mostly in CAD environments. CAD applications are widely under usage in different areas, and also VAR based CAD environments are not very apart from these basic applications, in terms of basic functions and working principals. On the other hand, regardless from core functions of CAD environments, VAR digital modeling progresses require higher integration, storage and rendering capabilities than traditional CAD applications. While mentioning rendering capabilities and speed, modeling accuracy inadequacy should be avoided considering VAR realism and interactivity (Lu et al., 1999).

3.3.2 Real-Time Physical Simulation

In the case of VR systems, a created digital model should behave in a similar way, as much as possible, as they do in real physical world with the aim of enabling realistic user feelings. In basic interpretation, physical facts oriented computer simulations should be sustained in order to develop realistic and interactive VAR systems, which are suitable for real-time complex and critical engineering applications.

Apart from realistic behavior of the models, like replicating bouncing reaction due to a dropping action, AR systems should be supported with proper computer simulation, satisfying proper alignment of the objects. More in detail, since AR users can see both real and augmented environment at the same time, exquisite alignment of computer generated elements and real world elements; or proper response generation due to the manipulations has to be done in order to avoid the user from human visual system sensitivity related confusions (Lu et al., 1999).

3.3.3 Natural Input Devices

In order to offer a wide range of interaction opportunities between user and computer generated environment and components, input devices are crucial with the notion of successful VAR applications. Therefore, 3-D, non-obstructive, multi-sensory and accurate input methods have to be associated with the system. Usage of the input devices and methods, which can be used in order to interpret user desires is also a popular technological research area. At this point, voice, body posture, face expression recognition or eye tracking systems are widely mentioned implications which can be used in context of increased interactivity and initiative VAR systems (Lu et al., 1999).
3.3.4 Output Systems with High Reliability

With the same manner of input devices, high fidelity output devices’ usage is crucial for immersive, interactive, multi-sensory, 3-D, real-time and realistic VAR applications. Therefore, output systems should satisfy interactivity requirements through graphical, audio or tactile feedbacks. Displays with high frame per second values and resolutions, 3-D surround audio systems or tactile output devices interact with force, vibration etc. and can be used for increased interactivity manner. Another interactive VAR systems related terminology mentioned, in context of high fidelity output systems, is user-centered. This concept is pointed out as one of the most important necessity of VAR systems in order to sustain desired immersion level and experience. According to this, concept modification of output should be done with tracking the user movements through time (Lu et al., 1999).

3.4 Hardware and Software of Virtual and Augmented Systems

For the purpose of obtaining sufficient immersion and interaction levels in VAR applications, performance and convenience of hardware and software, as components of human-computer interfaces, are inherently critical (Lu et al., 1999). Therefore, possible to use hardware and software should be overviewed among computers, tracking devices, input/output modalities and devices, sensors and software.

3.4.1 Computers

Computers empowering VAR applications can vary from personal computers to technological high end super-computers. Personal computers can be sufficient for supporting VR based video games or basic interactive applications, in terms of processing and multi-media competences. However, due to finite processing, immersion and interaction capabilities of personal computer setups, customized super or high-power workstations are required in order to establish industrial or critical VAR applications (Lu et al., 1999).

From the point of view of VAR applications, small, preferably wearable computers with high-performance and sufficient graphic rendering capabilities are required. At this point Wiedenmaier, Oehme, Schmidt and Luczak (2003) denote that available computer solutions for AR applications do not significantly differ from each other in terms of their core technologies. Also they emphasize the high possibility of supporting AR applications with personal or even relatively smaller wearable computers with variety of figurations in terms of components and operating systems.
3.4.2 Input and Tracking Devices

Sensors and input devices can be mentioned with two main usage areas in VAR applications. From basic functionality point of view, variety of input modalities can be used in order to receive necessary data to be processed and enabling users to navigate and interact in the computer generated reality. A further usage area related with “user-centered” and “initiative system” concepts can be initialized by tracking user and making it possible for real-time output and interaction adjustments regarding to user behavior and actions.

3.4.2.1 Input Devices

As mentioned by Lu et al. (1999), input devices to be used in navigation, manipulation and interaction actions should be capable to receive data in three dimensional Cartesian coordinate systems among six-degrees-of-freedom (6DoF). More in detail, such input devices can detect and measure movements in space (X, Y, Z coordinates) like up/down, forwards/backwards, left/right (translation in three perpendicular axes) and rotations on these axes (pitch, roll and yaw). Herein, numerical keypads, data gloves and 3-D mouse-like devices are the most commonly mentioned basic and relatively affordable solutions.

Beyond the basic methods, more advanced methods and devices are offered and some of these approaches still remain as experimental. For instance, as a useful method, in theory, speech recognition is widely discussed in the literature with the advantages of enabling hands-free operations (Wiedenmaier et al., 2003). On the contrary, as result of recent experimental studies, it is still an inefficient method since the surrounding environment (i.e. noise factor) is influential on the input performance (Reif, Günthner, Schwerdtfeger & Klinker, 2010).

3.4.2.2 Tracking Devices

In context of “user-centered” VAR system frames, ability of the system to track the user, review/update the output and accurately immerse the virtual and real world elements is a crucial challenge (Wiedenmaier et al., 2003). Hereof, tracking technologies are currently used which are functioning with mechanical, magnetic, radio-based, optical, ultrasonic, inertial or acoustic sensory principals. Each one of all possible tracking applications have
advantages and drawbacks mostly based on easiness of implementation and use, cost, sensitivity to surrounding distracters, lateness of measurement and update rate (Lu et al., 1999; Reif et al., 2010).

A reverse robotic arm, using joint angles in order to calculate movement trajectories with reference to a fixed point, can be mentioned as a mechanical tracker. Such a device can have high accuracy and low latency but limited physical area of usage and relatively non-ergonomic usage (Lu et al., 1999).

Utilization of video or infra-red cameras can be noticed as the basic optical tracking devices. Tracking can be done both through fixed markers to user’s hand, head etc. or by using a “Photonic Mixer Device” (PMD) empowered gesture recognition system as suggested by Möller, Kraft, Frey, Albrecht & Lange (2005), (as cited in Wallhoff et al., 2007). PDM sensors offer additional depth for information to be used with skin color recognition, which can make tracking faster, more accurate and reliable (Wallhoff et al., 2007).

Another prospective tracking device implementation can be mentioned in context of ultrasonic sensor technology. These types of systems arise with their advantages of being simple, effective, accurate and affordable. However ultrasonic trackers are capable of functioning in restricted working areas and get easily affected by temperature and line of sight changes against their advantages (Lu et al., 1999).

Electromagnetic tracking systems are the most widely mentioned and used technology in VAR systems (Lu et al., 1999). These type of systems follow the user over a sensor (called as the source) attached a fixed position by detecting the radiated field. Expedient properties of electromagnetic trackers can be mentioned as being ergonomic to use, not restricted with line of sight and having low latency. However, similar to ultrasonic ones, electromagnetic tracking devices can function in restricted working boundaries and big metallic objects in the working area or in the surrounding environment can distort the magnetic field that causes to inaccurate tracking (Lu et al., 1999, Reif et al., 2010).

3.4.3 Output Devices

Output devices are being used for transferring situation adequate information to the user and can vary in three main working principles as visual, audio and haptic (Lu et al., 1999).

3.4.3.1 Visual Output Devices

Visual outputting can be consolidated over fixed or rotatable visual screens as the most empirical solution, though display of the relevant information in a fixed position can hinder VAR interactivity and immersion.
More compatible output modalities with VAR concerns also exists in terms of different applications: 3-D displays, Head Mounted Displays (HMD), virtual tables and panoramic screens; or more experimental and usage area customized solutions as, Binocular Omni-Orientation Monitors (BOOM) and Cave Automatic Virtual Environments (CAVE) (Lu et al., 1999).

In the notion of AR applications HDM’s are typical see-through systems. As it had been mentioned in section 3.2.2, VST and OST type of visual output systems are available. The strength of HMDs is their capability to consolidate high immersion levels (Lu et al., 1999).

Virtual tables generally support the user over an interactive interface by using a projector to display computer generated images on a glass or plastic screen. The advantages of virtual tables are, the capability to broaden 3-D view of the user with the usage of shutter glasses and head trackers, and capability of sharing a common view for multiple users, even if current applications of these systems strictly interact with just one user (Lu et al., 1999).
3.4.3.2 Audio Output Devices

Text-to-speech systems, which generate audio outputs from textual inputs, can be mentioned as well. This VAR output modality can attract the attention of the user to the relevant source or target area even if it is not located in the visual boundaries of the user. On the other hand, surrounding noise, as a distracter, can dramatically affect the VAR interaction performance in the case of audio output implementations (Wallhoff et al., 2007).

3.4.3.3 Haptic Output Devices

Haptic devices generate feedbacks by using force or tactile feedbacks. With the usage of these types of output devices, it is possible to create the feeling of touching, grasping, weight or texture of the virtual objects. Despite the fact that, the importance of haptic output devices are commonly mentioned as their ability to create highly realistic VR environments and interactions; end point of these technologies are not that advanced comparing to the other output modalities (Lu et al, 1999).

3.4.3.4 Software

From a system architecture point of view, software to be used in VAR applications shall be developed and implemented considering both geometric and behavioral characteristics of the objects exist in the real world. In order to sustain functionality of the VAR devices, compatibility of device software and the operating systems with each other shall be considered besides of the rendering, realism and immersion capabilities of virtual reality (Lu et al., 1999).

3.5 Potentials of VAR in Context of Manual Assembly

This section mentions about beneficial potentials of VAR applications, especially AR systems, in manual assembly operations by presenting the experimental setups built in order to find out and prove the effectiveness of these systems within manufacturing industries.

Potential of AR technology for manual assembly is mentioned in the literature by referring to past applications in industrial areas such as architecture, medicine, production or maintenance (Stoessel et al., 2008). For instance, Curtis, Mizell, Gruenbaum & Janin (1998) mention about one of the most successful implementation which has been done by aerospace industry giant Boeing in order to guide cable wiring tasks during aircraft assembly by relevant information projection (as cited in Stork et al., 2008).
Tang et al. (2003) mention that most promising applications within the technology of AR are in increasing in productivity of manufacturing assembly, equipment maintenance and procedural learning. The purposes of those experimental setups with AR systems were to explore the effectiveness of using AR as an instructional environment in computer-aided assembly.

Generally, it had been predicted that AR assistance in an assembly task would increase productivity and reduce the amount of errors due to the instruction and presentation of the task, which is properly registered within the workspace. The cognitive load of translating and interpreting abstracted instructions onto reality would be reduced (Tang et al., 2003). Thus, it had been predicted or hypothesized that AR may have a remarkable impact on manufacturing industries by supporting human manual operations by facilitating the cognition process by easing the complexity. Some examples of the experimental applications within the theory will be presented with their hypotheses, and results in the following sections.

**Hypotheses:**

- By reducing movements of head and eyes and thus increasing ‘eye-on-the-workspace’ time, performance of the user would increase. In addition, time of the information seeking about the instructions would be reduced by presenting relevant information on work pieces in a spatially meaningful way (Tang et al., 2003).
- Synthesized computer graphics are presented and overlaid on the normal view which facilitates the attention on the required operation or item by arrows, tags, object highlighting, animations, etc. Thus, VAR can be used to reduce the cost of attention switching between the environment and task (Stoessel et al., 2008; Wiedenmaier et al., 2003).
- Memory assigned to spatial objects is in the field of neuroscience. So by assigning the spatial information to physical objects and locations, VAR would facilitate the spatial cognition and memory, since managing the spaces has relationship with thought patterns and behaviors (Biocca et al., 2001; Kirsh, 1995).
- AR would be very helpful for difficult and infrequent assembly steps (Wiedenmaier et al., 2003).

As it is mentioned above, some experimental studies, which were conducted within the literature, has been made in order to test the relative effectiveness of AR instructions within assembly tasks.
3.5.1 Experiment 1: Comparative Effectiveness of Augmented Reality in Object Assembly

The first experiment mentioned by Tang et al. (2003) has been conducted within four levels of instructional mediums where the work instructions are overlaid with different techniques (Figure 15). Those are; printed manual (treatment 1), computer assisted instruction (CAI) on a Liquid Crystal Display (LCD) monitor (treatment 2), CAI on a see-through HMD (treatment 3), and spatially registered AR (treatment 4) where the variables was the total time of task completion, error rates and mental workload according to the users perception.

![Figure 15. Experiment 1 setups: (a) Treatment 1, (b) Treatment 2, (c) Treatment 3, (d) Treatment 4 (Tang et al., 2003, pp. 76)](image)

The assembly task consisted of several procedural steps. According to the instruction, the subject were required to acquire a part with a specific color and size from an unsorted part box; and insert the part into the right assembly location with the specific position and orientation.

In treatments 1, 2 and 3, pictorial instructions are images from a static perspective viewpoint; however in treatment 4 the images are spatially registered with the real environment and rendered according to the user’s orientation and position. Furthermore, in order to facilitate the hands free operations, the users had the ability to control the environment by voice commands in treatments 2, 3 and 4. As it was mentioned by Tang et al. (2003), completion time and accuracy together with perceived mental workload were the performance measurements.
Results and Inferences

Effect of Information Overlay on Performance: The statistical results showed that, treatment 4 had the shortest time of task completion where treatment 1 took the highest time among the others (Figure 16). Furthermore, treatment 4 had remarkably lower error rates among all categories. Additionally, treatment 1 had resulted with highest levels of mental workload whereas treatment 4 had the lowest (Tang et al., 2003).

Treatments 3 and 4 were expected to be better than the treatments 1 and 2, in terms of performance. In addition, there is an existence of statistical advantages of performance in treatment 4 compared to treatments 1 and 2. However, there were no significant advantage on time of completion between 2 and 3; and between 1 and 3 in means of accuracy. Thus, treatment 3 did not have the advantage of information overlay as expected (Tang et al., 2003).

What is more, the results indicate that, overlaying the information on the center of the visual area of the user do not facilitate improvement in human performance and sometimes hinders and interferes with the view (Tang et al., 2003).

Effect of Attention Switching on Performance: Tang et al. (2003) continues with the results that, treatment 2, 3 and 4 had a significant difference of completion times compared to treatment 1; however treatment 4, compared to 2 and 3 did not have any significant difference. Thus, it was presumed that the advantage of hands free operation had caused this effect. Furthermore, there was a remarkable improvement in accuracy for treatment 4 compared to the rest.

Furthermore with the registered computer graphics into the real world within the technology of AR, the mental load of attention shifts among the instructions and the work places that operations took place had been eliminated. It was expected to have an improvement in performance as the minimization of attention shifting took place. However, more research had been needed to determine such contributions (Tang et al., 2003).
Effect of Instructional Medium on Mental Workload and Error Rate: The participants had reported that, for the conditions where the AR had been used, the mental workload was lower and less demanding. This result poses as a proof for the researchers that AR reduces the amount of mental manipulation at the object location.

Moreover, the study indicates the users that had been using the AR systems had made fewer mistakes. As inferred by the authors that, this is due to the fact that, by overlaying the instructions to the exact place of the part to be assembled, AR also eliminated reliance on potential errors would have been done as well as the mental workload. (Tang et al., 2003)

In conclusion, this experimental study within the literature had shown evidences supporting the hypotheses that were related to the benefits of AR systems in means of reducing mental workload, perceived complexities and improved task performances.
3.5.2 Experiment 2: Augmented Reality for Assembly (ARsembly) Processes Design and Experimental Evaluation

Another experiment was conducted by Wiedenmaier et al. (2003) within the area of assembly focused AR systems (ARsembly). An automotive door assembly operation had been chosen as a feasible scenario. The assembly task consisted of three main steps as; mounting the window regulator (WR), wiring, and fixing clips for the inner door panel.

The first task was composed of picking up WR, inserting the WR into the door frame, aligning the fixation points of the WR, fastening the WR using the screws and tightening the screws with an electronic screwdriver. The step of wiring involved connecting the car door to the car power supply and three small branches for the car door electric equipment. The clipping task was composed of several types of clips and then locking of them with a tool. Those assembly steps was perceived differently in terms of difficulty among the participants. WR assembly has been selected as having the highest difficulty since it had the various fixation points and branches, whereas the clip mounting process had the easiest perceived difficulties among the others.

As Wiedenmaier et al. (2003) mentions, the independent variable consisted of three factors such as the instructions were overlaid with paper, an AR prototype and an expert tutorial where the expert assembler was able to guide the assembler by giving vocal advices without touching anything.

Results and Inferences

It was found out that, participants of AR system completed their tasks in lesser amounts of time than the participants of paper instruction, which is considered as an advantage. However, AR system did not take less amount of time than the expert tutorial. Apart from the total scenario results, the purpose of selecting different steps for augmentation was to find out the suitable type of assembly tasks for ARsembly since the efficiency of the AR support differed depending on the steps. For instance, ARsembly did not support intuitive assembly, since the operators had to reorient every time they position new clips. At the end the advantage of expert tutorial over two other experimental cases and the advantage of ARsembly over paper instruction were statistically significant.

In conclusion, total assembly completion times were different in each step of assembly. As the task get more difficult the potential for AR applications increase. For instance, wiring task has shown more potential for AR applications than the easier tasks. On the other hand, for the tasks requiring intuition and repetition, AR support did not achieve a significant difference than the paper instructions. Moreover, ARsembly has been proved to be well suited for the task with ambiguous assembly positions and for the cognitive process of finding the place where the part needs to be attached, during the
process of reading, hearing, and comprehending the support media (Wiedenmaier et al., 2003).

### 3.5.3 Experiment 3: An Adaptive Interaction Model

The third experiment had the purpose of developing a virtual workbench adaptation, which satisfies the operators’ ergonomic constraints for effortless manual assembly. The experiment includes the good adjustment of display and tracking technologies with the aim of identifying the cognitive bottlenecks encountered by the operator through the assembly operation (Stoessel et al., 2008).

The performance measurements were based on motion tracking technology that records worker behavior. Measured values such as, time of completion, error rates and error categorization had been the behavioral variables. In addition to those behavioral variables, the system is capable of tracking the eye fixations of the worker, which is a measure of attention allocation (Stoessel et al., 2008).

Three different assembly conditions were created; in condition 1 the instructions were presented on a monitor, which is mounted on a workbench. In condition 2, instructions were projected directly onto the working area, and in condition 3 the worker received additional contact analog information on the parts needed to be assembled in each step (Stoessel et al., 2008).

![Figure 18. Experiment 3 - Schematic depiction of the workbench (Stoessel et al., 2008, pp. 248)](image-url)
Results and Inferences

Results had shown that, the complexity of assembly task had a great impact on the assembly performance where certain steps required longer times while the others required really small amount of times to be completed. In addition, the projection methods for the representation of the assembly instructions were really beneficial for the worker since the assembly instructions were highly complex. Measurements done through the experiment as eye fixation counts, time required to complete tasks, movement onset latencies, grasping times and grasping movement distances indicates the process betterment potential of special exogenous queues in context of cognition assistive systems in manual

Figure 19. Experiment 3-Presentation modes (Stork et al., 2009, pp. 72)

Figure 20. Experiment 3-Completion times per item on the basis of foot pedal presses in three presentation modes with different number of items (left). Fixation counts per item on the basis of eye tracker data in the three presentation modes (right) (Stork et al., 2009, pp. 76)
assembly.

![Figure 21. Experiment 3: Means and standard errors for movement onset latencies and time to grasp (left) and peak velocities and accelerations (right) with different instruction modes (Stork et al., 2008, pp. 169)](image)

The authors suggest that, in order to achieve more efficient manual assembly operations, workers should be supplied with a context-sensitive guidance and assistance. In the cases of highly complex operations such as highly customized product assemblies, productivity would be increased significantly if the operator is supported by an assistive system. Therefore by providing the instructions according to the capabilities of the specific worker or specific situation, assistive system helps to avoid the mistakes (Stoessel et al., 2008).

### 3.5.4 Experiment 4: Evaluation of an Augmented Reality Supported Picking System

In this fourth experimental setup which is the most recent one amongst the others, an AR system, called Pick-by-Vision was introduced. With this system the information visualization would be facilitated by a HMD for order picking process. The results were expected to show that, this Pick-by-Vision system would improve the order picking processes significantly.

Although this experiment is not dealing with the manual assembly context, it has shown remarkable similarities with the concept of quality since order picking and manual assembly operations show similarities in terms of visual search and selective attention. For instance, as Reif et al. (2010) have suggested; the quality of the delivery and thus the relationship between the customers and suppliers, highly depend on the mistakes arising from the manual operations. Furthermore, the aim of the research was to support the workers optimally for the provision and gathering of the required information during their tasks. By the aforementioned facts, this experimental setup has high correlation within the manual assembly context.
The setup consists of a wearable HMD that visualizes all the required data directly in the operator’s field of view. By this way, the operator does not have to move his head. Therefore, it reduces the exposure of unnecessary time losses by looking at somewhere else like data terminals or paper instructions. In addition, the system includes a voice recognition system as a data input, enabling the data input process hands-free and enabling the usage of both hands for the operation.

The Pick-by-Vision system had been compared to a paper instruction in a compartment shelving system of a distribution center. The storage consisted of more than 600 stock locations where 75% of those were filled with goods. The subjects had to finish 14 orders using both paper list of instructions and Pick-by-Vision system where the items were boxed in different sizes and with different weights. Altogether, there were 52 order lines with 119 items.

**Results and Inferences**

During the test, two performance measurements were taken into the consideration such as order picking time and error rates. Where, order picking time of the orders in the storage was important for the throughput time. It is a part of reaction time between the customer order release and the delivery time. Besides, amount of picking errors has a big effect if they are not recognized before the shipping. This can result in high contract penalties and damage on customer relations (Reif et al., 2010). In means of order picking times with Pick-by-Vision system, subjects were about 4% faster than with the paper list as expected. When the picking times by Pick-by-Vision are compared, there is a 19% of difference than the paper list. This difference shows that, the subjects were a lot faster with Pick-by-Vision system than the paper instructions. As mentioned by Reif et al. (2010), the explanation of this fact would be the fact that, the subjects work more confidently with Pick-by-Vision. Furthermore, within the conduction of the test series the error rate in the paper instructions
had been found that, it was seven times higher than in Pick-by-Vision system.

On the other hand, other than the performance measurements, it is vital to consider the psychological factors such as motivation, usability, impression and cognitive load as mentioned by Reif et al. (2010). Those factors were measured with the help of questionnaires, which resulted with that the AR system was very well accepted and the strain was lower than the paper list. The high usability and the low cognitive load lead to the high motivated operations with Pick-by-Vision system with a significant difference. Furthermore, the subjects liked that they could work their hands free and that the information was displayed clear in their field of view. The main advantage of the AR systems was picking the right amount of items, which was the main reason for the low error rates.

In conclusion, the evaluations showed that users were faster and less error prone while using the AR system when compared to the paper instructions. When it comes to the information gathering and processing, with the AR system the user acceptance was high, since the cognitive load perceived by the operators was reduced thus increasing the motivation.

*Figure 23. Experiment 4- Mean values, maximum and minimum of the order picking times with paper list and Pick-by-pick-Vision over all 16 subjects (Reif et al., 2010, pp. 8)*
3.5.5 Future Direction of Manual Assembly Assistive VAR applications

With respect to theory, experimental setups and their results, most promising future direction of the VAR systems in manual assembly operations arises as development of more initiative assistive systems. More than predicting operator errors by appropriate information presentations, integration of more accurate behavioral assessment systems may adapt the assistance in a way that detecting and even predicting possible errors by immediate feedbacks and situation specific corrective actions. Face recognition, eye and movement tracking technologies shall be used together with real time online analysis of movement trajectories in order to extend the assistance among workers with different behaviors and skills (Stoessel et al., 2008).

According to Reif et al. (2010) implementation challenges of such experimental setups in real world production environments mostly interrelated with the current technological level of necessary hardware components such as HMD’s, visual tracking and analyze systems. However, they also state that, due to the continuously increasing interest on VAR technologies, mostly driven by gaming industry, VAR will be a part of the daily life mobile multimedia applications so that, they will be widely used in industrial applications starting from upcoming 2-3 years.
4 POSSIBLE VAR SOLUTIONS FOR THE THULE AB CASE

Here in this chapter, we present the results we achieved throughout two main stages as by referring to the data we have gathered during the company visits, production area observations and literature review:

- Evaluation of cognition support oriented VAR systems, with respect to the case itself, in terms of conformance as a solution approach and answer to the research question 1.
- Presentation of the possible VAR system solutions together with system components as input, output, tracking devices and cognition assistance principles, including advantages, disadvantages as an answer to the research question 2.
- A benchmarking presentation with respect to first two parts of this chapter, including advantage, disadvantage, specification and basic cost comparison of different solutions as VAR system components.

4.1 Why VAR Solutions for Cognition Assistance?

As it is mentioned in the methodology chapter, our research has the characteristics of exploratory research. More in detail, progress of the research has started with an initial go through literature review for possible research areas with respect to the empirical problem definition has been made by the case company. Subsequently to the initial literature overview we evaluated the possible focus areas according to the data collection was made over company visits, unstructured interviews and real-time observations of the manual packaging operations. As a result of this initial evaluation about which research topic to be profoundly analyzed, “Virtual and Augmented Reality systems: as cognition support approaches in production environments” has been chosen for main research scope. Therefore, here we present our analysis and validation of the research scope among the other initial alternative scopes, such as full automation, with respect to the current state analysis of the manual packaging stations and task properties.

According to Michalos et al. (2010), as it was mentioned previously, effectiveness of manual work force is undeniable due to the several reasons. Since human has abilities such as flexibility, ability of learning, adaptiveness and responsiveness that he possesses, full automation solutions would be unnecessary and infeasible in some cases. For instance, automated flows contain complex machines which mostly function only for specific operations. On the other hand; human labor stands as a more flexible workforce with the abilities of learning, implementing and behaving proactively. However, in every system, for the operations involving the human work force, as the
complexity increases, the error rates of the defective items increase due to the human factor. Those operational errors and thus, the defective items mostly occur because of the cognitive differences, distraction, loss of focus and learning problems and poorly designed work instructions. It is also suggested in the literature that when confronted by highly complex information, people could be very easily distracted by the environment visually and lose their focus on the operations which leads to human related errors (Stoessel et al., 2008; Stork & Schubö, 2010b; Zaeh et al. 2009). Affirmatively, through the literature it has been mentioned that, high level of complexity, different kinds of operations and variety, environmental distractions leads companies to encounter high numbers of human related errors and thus lower quality of output.

In automotive industry, as the business area of Thule AB, even small defects can lead severe consequences, where for only one end-product whole shipment could wait furthermore; it could lead accidents in a context that may threaten customers' lives. Thus, automotive companies are also responsible for the errors due to the supplier faults; therefore they are implementing very strict quality measures for their suppliers. So that, during the complex manual jobs, appropriate guidance on the information seeking through the instructions makes it even easier to lose concentration and causes time losses as well as the emerging defects.

As it was mentioned during the current state explanation of the manual packaging stations, problematic operations require some physically complicated fitting and positioning movements of the components to be packed. The reason of this complexity is related with the package sizes which were decreased regarding material usage, inventory and transportation concerns. Additionally, most of the subjected fitting tasks are only possible to be managed by usage of both hands of the worker’s. At this point, even human work force seems like an adequate solution, packaging operations are still needed to be automated or supported. Manual operation assistance systems to be used can also support quality control and assurance due to the problems related with human work force.

Herein, full automation solutions like robot arms has been recognized as inadequate due to the physical complexity of the tasks and high amount of investment costs increase parallel with complexity of the solution. Systems suitable with the subjected packaging operations should be extremely accurate with the help of visual sensory abilities. Also one-by-one component feeding systems are mostly required in order assure that packaging is done correctly. Additionally, on the ground of subjected products’ box component properties as physical shape and workplace storage, a robot arm should be able to grasp the closest component among the others from the storage boxes unless it is supported with a one-by-one feeding system.
Additionally to the full automation alternative, semi-automated work bench solutions consist from a worker assisted by a robot arm which operates relatively less complex tasks had been also considered. However due to the work place conditions in terms of physical boundaries and working security concerns, this solution had been found inefficient as well. Because, the robot arm is should be placed in a secure distance from the worker. Also worker tracing should be used in way that worker is prevented from injuries. With this manner, slower movements of the robot arm controlled with worker tracing sensors can assure safety. However it is still an expensive and inefficient solution considering the current takt times.

Considering the challenges of being expensive to invest, complex to operate and maintain, automation did not appear as a feasible solution due to the case specific disadvantages. Furthermore, the root cause of the problem was deduced as human related errors caused by high mental workload. At that point, VAR based cognition support systems were recognized as the possible solution approach among the other alternatives.

4.2 VAR Implementations as Possible Solutions for the Case

VAR systems, as currently popular and promising assistive approaches in manual assembly operations, were analyzed and evaluated through some experimental setups as it is presented in the previous chapter. To mention about common conclusions of these experiments, VAR systems have facilitated significant improvements on error rates and information or visual component search times. In the case of repetitive tasks, even VAR systems have assisted shorter assembly completion times comparing to the traditional guidance approaches (ex. written instructions), after the initial items were assembled (4 to 6) completion time differences under different conditions became significantly lower due to the learning effect on tasks (Figure 20). In relation with limitations and drawbacks of VAR systems are based on current technology and industrial conditions, VAR systems currently are not able to detect the assembly tasks’ completeness in a corrective manner. For instance, in the case of complex assembly operations, possible VAR solutions only offer guidance of which part to be assembled and where to find it. However, quality control of the tasks’ itself still remains as an important drawback under high production rates, if the parts were assembled in the right way or not. Furthermore extending functionality of VAR systems with proactive manners through face recognition or eye tracking is still an experimental research area.

However, with respect to the task properties of the case’s manual packaging operations. VAR systems are also capable to control task completeness can be implemented. Unlikely from complex assembly tasks, manual packaging operations mostly consist of basic reach-grasp-drop tasks. So that, only by tracing grasping actions and detecting the existence of subjected components in the box, possible VAR systems can be extended with error corrective traits.
Through the review of VAR system’s architecture and tools, it is presented that, which input, interface and output modalities can be used during possible VAR system implementations for manual packaging operations in Thule AB.

VAR system implementations, as appropriate cognition assistance approaches for the case, can be structured through system setups using different hardware in order to be used as input, output and tracking devices.

4.2.1 Input Devices

In VAR systems, hardware is being used with the aim of enabling the user and the system to interact with each other. For the further VAR system suggestions in context of the research case, appropriate input modalities for the case such as foot pedals, knobs and mouse like devices are presented with the advantages and disadvantages among each other.

4.2.1.1 Foot Pedals

Foot pedals can be used as input devices in VAR system implementations like in the experimental setup mentioned by Stoessel et al. (2008). Over the usage of foot pedals command prompts can be given by the worker as “next”, “previous” or “end of the task” within the manual packing operation guides or instructions. As it is supported by various experimental studies, Reif et al. (2010) emphasizes that the input devices should be robust and should not limit the worker’s freedom of movement. Herein, in the experiment done by Stoessel et al. (2008) two foot pedals were used in order to switch between work instructions while enabling the operator to work with both hands (Figure 18). Thus, foot pedals as input devices would be applicable since their cost efficiency (even possible to be built in-house), low complexity for the operator usage and for the hands-free operability. On the other hand as a drawback, this solution is not capable to handle the interaction requirements in 3-D VAR environments.

4.2.1.2 3-D Knobs and Mouse like Devices

Compared to foot pedals, knobs and mouse-like devices offer higher navigation and interaction freedom in VAR environments, especially for the operations requiring multi-dimensional movements. On the contrary, knobs and mouse-like devices can limit down the operator with one hand usage, to perform the manual tasks. Therefore, the operations which require frequent usage of hands can cause time losses and operator performance reduction.
4.2.2 Output Devices

In order to instruct or guide the user through the VAR systems properly, various devices could be used as output devices. Those devices, present the augmented information to the system user according to the data interpreted by the input devices. In the case of manual packaging, output devices such as screens, HMDs, virtual tables and projectors are presented with their advantages and disadvantages among each other.

4.2.2.1 Screens and Monitors

The work instructions are presented to the operator through the screens, where the operator has to attend in order to receive the correct information about the assembly task. Compared to the other output devices screens, like LCDs, are cheaper to invest. Furthermore, low complexity of such output devices cause almost no time loss during the learning process since they are user friendly and are easier to learn. Furthermore, some displays and screens can be used as both input and output devices, for example touch screens.

By the usage of screens the information is presented in a fixed position. Between each task, operator needs to shift his/her attention to the screen from the task in order to gather the required information about the assembly process. In the case of frequent attention shifts between the workbench and the screen; increased time losses and mental workload can increase the probability of having defective products (Stork & Schubö, 2010b). As mentioned by Tang et al. (2003), in terms of performance, LCD screens can lead to significantly lower performance, related with attention shift frequency compared to other output modalities such as HMDs.

4.2.2.2 Head Mounted Displays (HMDs)

Head mounted displays are used in order to visualize all the required information directly on the user's field of view. By this way HMDs may decrease the time losses caused by attention shifts between the instructions and the tasks. HMDs, as look-through devices, let the operator to be able to work by not moving his head through information gathering and task performing activities.

HMDs are proved to be useful in terms of increasing the operator performance by decreasing head and eye movements and increasing the amount of time spent without getting distracted. As also mentioned by Tang et al. (2003), HMDs reduce the time spent on visual information searching, by presenting the required information within the visual sight of the operator. By this way, time losses caused by attention switching between the task and the instructions are decreased. Thus, cognitive workload caused by frequent attention shifts is relieved.
According to the results of the experimental setup done by Reif et al. (2010), the subjects of the experiment were faster and have made fewer amounts of errors while using a HMD. Considering this finding, HMDs has advantage of speeding up the information provision and the training curve since the information is displayed directly in the operator's field of view. HMDs also enable the operators to work with both hands decreasing the perceived cognitive load. Furthermore, the user acceptances to feel comfortable to use HMDs were turned out to be high according to the research (Reif et al., 2010).

On the other hand, most of HMDs limit the field of view increasing the risk of accidents. In addition, HMDs come with the requirement that the operator has to wear it over a shift of 8 hours. Thus, HMDs needs to be light and ergonomically designed with the capability of having battery operation more than 8 hours. Moreover, information presentation for each repetition of frequent tasks on the visual sight of the operator can be over-monotonous and annoying for the operator as well.

### 4.2.2.3 Virtual Work Benches

Virtual work-benches use highlighting principles in order to guide the operator visually. By projecting the augmented reality on the work place itself, this method aims to decrease attention shifts between the work instruction and the task. As it was mentioned by Tang et al. (2003) relating the spatial information to physical objects, the cognition could be increased. Virtual work benches use spatial cueing principles (Posner, 1980) in order to guide the operator through the operation by using exogenous or endogenous cues (Stork et al., 2009; Stork & Schubö, 2010a; Stork & Schubö 2010b; Theeuwes, 1994).

The experimental setup mentioned by Stork et al. (2009), has shown that the lowest completion time among others was with the contact analog highlighting technique as projection and screen displaying (Figure 19). Also in the presentation modes of projection and contact analog highlighting, as virtual table based output modalities, number of eye fixation counts per assembled part were lower (Stork et al., 2009). Therefore, the number of attention shifts was lower in virtual work-bench scenarios than the LCD screen output modality.

On the other hand, this technique has also some disadvantages which have to be considered. It is vital to present the instructional information at the right time and place since wrong timing of highlighting may lead the risk of attention capturing and product defects. In addition, lighting conditions are really important within the production environment and the implementation of the virtual work-bench may sometimes be infeasible since the technique needs gloomy production environment in order to capture the attention by beam projectors or illuminated tables.
4.2.3 Tracking Devices

From the perspective of high fidelity output systems, the terminology of “user-centered” was mentioned by Lu et al. (1999), with the necessity of output modifications through the data gathered by user tracking. For instance, empowering VAR systems with tracking devices can ensure user centered modifications of the outputs. For instance, usage of HMDs empowered with tracking technologies can extend the user-centered output modifications of a VAR system. In the experimental setup was implemented by Reif et al. (2010), with a tracking system, 3D information has been displayed in the correct spatial position over an HMD due to the subject’s sight of view. The method used by Reif et al. (2010) in the name of “Attention Tunneling”.

![Attention Tunneling](image)

Figure 24. "Attention Tunneling" approach integrated with a HMD (Reif et al., 2009, pp.10)

Furthermore various tracking devices empowered with different sensory principles can be subjected, for quality control and assurance approaches in manual packaging operations. As in the approach used by Bannat et al. (2008) some tracking devices are suitable to track worker hand for to know what parts have been taken out of which box or location on the workbench (Figure 25).

![Hand Tracking](image)

Figure 25. Optical hand tracking with the usage of color based image segmentation for detecting human skin color (Bannat et al., 2008, pp. 4)
As it was mentioned before, manual packaging steps of the case, consist of basic reach-grasp-drop tasks. By tracing grasping actions and detecting existence of the components in the box; possible VAR systems can be extended with error corrective traits.

4.2.3.1 Electromagnetic Tracking Devices

Electromagnetism is the most widely used principle on the basis of target component and operator tracking systems (Lu et al., 1999). Basic working principle of electromagnetic tracking devices is based on usage of mobile sensors to feed backing their spatial position within the electromagnetic field is created by a source and a tracking unit. Although electromagnetic tracking systems are emphasized with their wide application areas, due to the environmental restrictive factors related with their functionality, working area conditions should be analyzed before implementation decisions. For example, metal objects as magnetic field distracters and physical dimensions of the working area are the main problems of electromagnetic trackers. Additionally, tracking device limitations and capabilities should be realized in order to choose the suitable solution. In other words, functionality of electromagnetic tracking devices is based on:

- Supported degrees of freedom for tracking (3 or 6 DoF).
- Supported number of sensors.
- Update rate of the sensors in units of Hz.
- Static position and orientation accuracy.
- Latency of position tracking.
- Tracking range of the markers from the magnetic source.
- Operating system

Therefore, effect of these components on the electromagnetic fields should be analyzed carefully in order to select suitable device considering the accuracy and magnetic source capacity. Besides, for not being affected by line of sight and temperature conditions, electromagnetic tracking systems can be advantageous over some other systems like ultrasonic ones. With a device has enough electromagnetic range tracking can be done even the magnetic source is not in the direct line of sight of the sensors.
4.2.3.2 Inertial Tracking Devices

On the basis of mechanical approaches, another type of tracking systems can be mentioned as inertial tracking devices. Basically inertial trackers rely on the usage of mini gyroscopes within the sensors to measure orientation changes. Inertial tracking devices stand to be fast, accurate and relatively more affordable, because they do not need a separate source. However due to their simple mechanism their functional range is limited with the length of the cable which connects the sensor to computational unit (control box or computer).

4.2.3.3 Optic Tracking Devices

Optic tracking devices can function both over high definition video or infra-red cameras. Tracking over high definition video capturing requires fast and complex image processing software algorithms and hardware running on computers with high calculation capacities; such as “Photonic Mixer Device” as mentioned by Wallhoff et al. (2007). Herein, infra-red cameras stand as more affordable tracking solutions for the operations do not include complex movements. Basic working principle of infra-red tracking devices is based on usage of infra-red reflective passive or active markers to be detected by an infra-red camera. Additionally infra-red cameras can both execute as beaming and transmitting actions depending on the type of markers are used (active or passive). Also illumination conditions do not affect tracking performance of infra-red optic trackers. Conversely, infra-red optical tracking systems’ functionality can be restricted due to the line of sight.
4.2.3.4 Data Gloves

Even data gloves are used as input devices on the basis of main usage principles; we considered them as possible to be supported with sensory devices and used in tracking systems (Lu et al., 1999). Various sensor technologies are used in order to capture physical data of hand movements like bending of fingers, grasping etc. As to enable detection of grasping or bending actions, pressure sensitive sensors can be integrated in data glove applications. Besides of gesture based motions, by the attachment of magnetic or inertial sensors to the glove, location of the hand as spatial coordinates can be tracked. To mention about users’ freedom of movement within the environment of tracking, it is possible to use data gloves in VAR applications as they transmit data through both wireless technologies (Bluetooth, etc.) and cables.
4.3 Benchmarking of Different VAR System Components as Solutions.

Here we present the results of our basic web based price estimation research among different VAR system components as possible cognition support solutions related with the case problem. Web sites of the VAR system manufacturers that we gathered the specification and price information of the alternative system components can be found under list of the references.
### Quality Assurance in Manual Packaging Flow Case of Thule AB: A Theoretical Review of Virtual and Augmented Reality Systems as Cognition Supportive Approaches

#### Table 4. Benchmarking of possible VAR system components (1)

<table>
<thead>
<tr>
<th>FUNCTIONALITY</th>
<th>TYPE</th>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
<th>PRODUCT</th>
<th>PRODUCER</th>
<th>SPECS</th>
<th>PRICE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INPUT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foot pedals</td>
<td>- Hands-free operation - Cheap to invest</td>
<td>- Limited interaction</td>
<td>USB Foot Switch Triple</td>
<td>Sythe</td>
<td>- Weight: 900g - Dimensions: 130 x 360 x 37mm - Cable Length: 180cm - Switch Life: 1 Million Times - Windows 2000 / XP / VISTA / 7</td>
<td>$ 53.00</td>
<td></td>
</tr>
<tr>
<td>3D Knobs /Mouses</td>
<td>- 3 or 6 DoF navigation - Wide compatibility with different systems and applications</td>
<td>- Limitation due to use of the hands</td>
<td>SpaceNavigator</td>
<td>3Dconnexion</td>
<td>- 6DoF technology - Two Standard 3D Mouse Keys (Fit / Menu) - Dimensions: 78mm x 78mm x 53mm - Weight: 479g</td>
<td>$ 99.00</td>
<td></td>
</tr>
<tr>
<td><strong>OUTPUT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Screens</td>
<td>- Cheap to invest - Wide range of choices - Possibility to use as an input device with touch sensitivity</td>
<td>- Information presentation in a fixed position</td>
<td>12.1&quot; LCD Kiosk Touchmonitor</td>
<td>EloTouchSystems Inc.</td>
<td>- 800 x 600 resolution at 75 Hz - Perform the following mouse functions: Left-Click, Double-Click, Drag-and-Drop, and Right-Click - Multiple mounting options - VGA video port for Monitor - Windows XP / Vista / 7, Mac OS X, or Linux Kernel 2.6</td>
<td>$ 679.00</td>
<td></td>
</tr>
</tbody>
</table>
### Table 5. Benchmarking of possible VAR system components (2)

<table>
<thead>
<tr>
<th>FUNCTIONALITY</th>
<th>TYPE</th>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
<th>PRODUCT</th>
<th>PRODUCER</th>
<th>SPECS</th>
<th>PRICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Presentation of the required information within the visual sight of the operator - Support for high level of user-centered systems - Support for operator mobility</td>
<td>VR Pro AR</td>
<td>- Camera: 1x Color, SVGA, USB 2.0 - Convergence: Manually adjustable - Focus: Manually adjustable - Resolution: VGA (640x480) or SVGA (800x600) - Field of View: 35 Degrees Diagonal - Color Depth: 24 Bit Input - IPD Adjustments: None Required - Audio: Full Stereo - Weight: 141g</td>
<td>Virtual Realities Inc.</td>
<td>$599.00</td>
<td>$1299.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Camera: 2x Color, SVGA, USB 2.0 - Convergence: Manually adjustable - Focus: Manually adjustable - Full SVGA stereovision: (800x600) OLEDs - Field of View: 40 Degrees Diagonal - Image Size: 105° at 12° - Color Depth: 24 Bit Input - High contrast: 200:1 ratio - Full color: 16.7 million pixels - Weight: 226g - Built-in stereo microphone - Head tracking device with 6DoF</td>
<td>Z600 Pro AR</td>
<td>Virtual Realities Inc.</td>
<td>$1799.00</td>
<td>$2595.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- SVGA OLED panel (1.44 Million pixels) - 800 by 600 resolution in true color - 40° field of view - Display: 85g</td>
<td>VR1 Monocular</td>
<td>Virtual Realities Inc.</td>
<td>$1699.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Resolution: 1920x1080 pixels per eye - Field of View (diagonal): 60 degrees - Total HFOV: 48° - Vertical FOV: 40° - Input Signal: Dual VGA, DVI, Composite, S-Video - NTSC/PAL - Modes: 2D and 3D Stereoscopic - Overlap: 100% - See-thru Transmission: 40% - Eye Relief: 35AM - Weight: 226g</td>
<td>VR Pro WUXGA (Optical-See-Through)</td>
<td>Virtual Realities Inc.</td>
<td>$11,500.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Resolution: 800 x 600 pixels - Field of view (FOV): 40° x 30° - Image distance (adjustable): 30 cm to 3 m - Image format: 4:3 or 16:9 - Optical module size (L x H x W): 45 x 19.8 x 16 mm - Wireless Data Transfer: optional - Types of data displayed: Text, images &amp; video clip - Colour depth: 24-bit - Micro-camera: Yes</td>
<td>Pro Mobile Display (Optical-See-Through)</td>
<td>LASTER Technologies</td>
<td>$11,000.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 6. Benchmarking of possible VAR system components (3)

<table>
<thead>
<tr>
<th>TRACKING</th>
<th>FUNCTIONALITY</th>
<th>TYPE</th>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
<th>PRODUCT</th>
<th>PRODUCER</th>
<th>SPECS</th>
<th>PRICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnetic Tracking Devices</td>
<td>- No requirement of direct line-of-sight for tracking - Availability of wireless systems</td>
<td>- Distraction effect of metal objects on the magnetic field</td>
<td>Patriot Wireless</td>
<td>Polhemus</td>
<td>- Degrees-of-Freedom: 6DOF - Number of Sensors: Wireless Markers 1-4 - Update Rate: 50Hz per Marker - Latency: 20ms - Resolution Position at 30cm range: 0.0015in, 0.0038cm - Resolution Orientation: 0.003° - Interface: RS-232 or USB - Both Included - Host OS compatibility: GUI/SDK 2000/XP</td>
<td>$ 2250.00 (system without markers and receptors)</td>
<td>$ 2498.00 (one marker)</td>
<td>$ 1100.00 (one receptor)</td>
</tr>
<tr>
<td>Inertial Tracking Devices</td>
<td>- Fast, accurate and affordable solutions - Availability of wireless systems</td>
<td>- Limited range in the case of data transmission through cable connections - Price gap between regular and wireless systems</td>
<td>VirtualCube</td>
<td>Virtual Realities Inc.</td>
<td>- Degrees-of-Freedom: 3-DOF - Update Rate: 125Hz - Host OS compatibility: Windows XP / Vista / 7 - Dimensions (W/H/D): 30mm/13mm/30mm</td>
<td>$ 499.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Optical Tracking Devices</td>
<td>- Robust to the metal objects - Impregnable to the illumination conditions</td>
<td>- Requirement of direct line-of-sight for tracking</td>
<td>TrackPack2</td>
<td>Advanced Realtime Tracking GmbH</td>
<td>- Frame rates up to 60Hz - Delay &lt; 20ms - Up to 4 &quot;6DOF&quot; targets tracked simultaneously - Maximum tracking distance 2.5 m (for 12mm markers) - Working in the NIR range at 850nm - Noiseless tracking cameras (no fan)</td>
<td>€ 15,100.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data Gloves with pressure sensors</td>
<td>- Possibility to use for both input and tracking - Multi-sensory integration possibility - Availability of wireless systems</td>
<td>- Possibility of limiting operators’ hand sensitivity and movement capability due to the material and glove structure</td>
<td>Data Glove 5 Ultra</td>
<td>Fifth Dimension Technologies</td>
<td>- Bend Sensing Method: Fully enclosed fiber optic bend sensors - Number of Sensors: (one per finger) and the orientation (pitch and roll) of the user’s hand - Resolution: 8-bits (256 positions/finger) - Output Interface: USB 1.1 - Minimum 75Hz sampling rate - Integrated pitch and roll sensor - Glove fitting: RH &amp; LH versions; “One size fits many” - Calibration Routine: Open &amp; close hand: each user</td>
<td>$ 895.00</td>
<td>$ 1495.00 (Wireless)</td>
<td></td>
</tr>
</tbody>
</table>
5 DISCUSSION & CONCLUSION

5.1 Discussion

Before starting to discuss the validity and reliability of our research, it is better to remind that there were some restrictions throughout the research progress. As our research does not include implementation of the possible approaches; further analysis should be done before implementation decisions. With this research our aim was to offer possible quality assurance and control solutions for the manual packaging operations with respect to the relevant literature. Besides of the solution approaches we also tried to provide a holistic understanding about human information processing, mental workload in context of cognition theory and their consequences on quality of manual operations.

As we mentioned before, we have established a primary analysis among possible research scopes before starting to the actual research. Automation of the manual packaging operations and manual work force assistance were two main possible focus areas. To make an initial assessment of the candidate technologies, manual packaging operations and case specific conditions have been considered. To remind the research questions:

*RQ1:* What are the major root-causes of incomplete packaging in terms of missing package components?

*RQ2:* Considering the root-causes of the problem, requirements of the company and the limitations of the research; which cognition support technologies or approaches would be suitable to implement in order to ensure quality, in terms of completeness of the end product packages?

As one of the delimitations of the study and the result of the primary data collection and analysis, the root cause of the incomplete packaging in terms of missing package components was deduced as being human related errors caused by high mental workload. Herein, Virtual and Augmented Reality oriented cognition support systems can facilitate the establishment of built-right-in-the-first-time approach as a solution to the root cause of incomplete packaging. Those possible VAR implementations should facilitate cognition with visual and auditory tools while preventing the focus loss which might be caused by unnecessary and excessive amount of information. Advantages of the manual assembly operations over the automation alternatives, was the support for our conclusion. Affirmatively, such system, which facilitates the cognition support, can be beneficial for decreasing the probability of errors made, as well as decreasing the takt time of the operations by this way.
Supportively, the results of the experimental VAR setups, which are mentioned in the literature, has the property of consolidating the answers given to the subjected research questions. So we esteem that, the research questions has been answered adequately and conveniently.

During the further studies subsequent to this research as implementation projects or researches, the possible VAR solutions that might consist of system components with input, output and tracking functionalities, should be analyzed and evaluated with respect to case specific conditions.

In context of our case, manual packaging specified prospective VAR assistive systems do not require high level of immersion and interaction capabilities. Hence, relatively simpler input devices like foot pedals or buttons would satisfy the interaction requirements of navigating between working instructions. On the other hand, more advanced input devices with higher navigation capabilities can be implemented as well. For instance, the VAR applications that are specific for the manual packaging case will not be requiring input devices with 6DoF navigation capabilities. However, such input devices are able to function in variety of systems with high level of interaction capabilities, may be beneficial considering the future VAR system application areas such as product design and realization. Data gloves as another input device option can be also chosen to be used in VAR applications. The advantage of data glove usage can be related with their capability of integration with tracking system.

Appropriate output devices should be used, depending on the decision of how interactive and immersive will the VAR based cognition support system be. As we mentioned before, capabilities and compatibilities of output devices with other system components are critical to consolidate user-centered interaction structure of the VAR system planned to be implemented. Also, effects of output modalities on the operator performance should be examined with respect to the product and task properties. For instance, reminding the result that, information presentation for each repetition of frequent tasks on the visual sight of the operator can be over-monotonous and annoying for the operator. In addition, usage of HMDs can be inappropriate in the “Station 1” due to the high rate and takt of the product “Rapid System 753”. However for the case of “Station 2”, a HMD output modality can return high performance and lower error rates considering the frequent product changes in the manual packaging operations. Also wearing a HMD for 8 hours in a day while working with a relatively high tempo can disturb the operator.

Another consideration on output devices should be made related with their effect on operators’ freedom of movement. More in detail, for the operations that require mobility of the worker, a fixed output device, like a LCD, can limit the worker performance by causing frequent attention shifts between tasks.
Electromagnetic, inertial and infra-red optical tracking devices are prospective to be used both for increased user centered VAR and error detective/corrective assistance systems. In the case of manual packaging operations in Thule AB, since some of the package components are metal, their distraction on electromagnetic fields should be realized in relation with functionality of electromagnetic tracking devices. Another consideration should be made about electromagnetic tracking devices about the usage of wireless and traditional sensors. Since manual packaging operations require worker mobility due to the component locations around the workbenches, wireless solutions can be a better solution. However, it should also be considered that wireless solutions are significantly more expensive than the regular devices using sensors connected to the tracking unit with cables.

As we mentioned, another tracking solution possibility is infra-red cameras as optic trackers. In the case of manual packaging stations in Thule AB, due to the component storage locations, the line-of-sight of infra-red cameras can be obstructed by the operator himself while making necessary movements in order to reach to the target location. Hence, reorganization of the workbenches or usage of necessary amount of infra-red cameras enough to cover the whole operation area should be considered while implementing infra-red tracking systems (Figure 4 & Figure 5).

With the aim of quality control in the manual assembly stations, another approach can be used as the usage of pressure sensory devices. For instance, both for facilitating tracking and quality control of the packaging operations, multi-sensory data gloves can be used. For the functionality of grasping and dropping detection, as the parts of quality assurance and control, pressure or bending sensitive sensors can be applicable. However for setting the reference grasping and dropping gestures for each component can be challenging due to the physical force usage by different workers. Therefore, through a more basic usage of pressure sensitive sensor, scale like devices for measuring the box weight after each reach-grasp-drop task can be integrated with other tracking devices. As additional information, we have observed that scale-like weight measuring devices are currently in use within other semi-automated packaging flow lines of Thule AB, which are not in the focus of our case, for quality assurance and control. Therefore, implementation and experience of usage about scale-like devices as quality control tools can be mentioned as an advantage from the point of Thule AB.

To mention how to control packaging quality during manual operations, fixed sensors or markers near the hands of the worker can be used in order to detect if the worker reached to the target location of component in the workbench or not. Also only one component should be grasped by one hand at a time. Even this limitation can reduce task completion time; it may assure an accurate tracking as well. The reason for us to suggest such a limitation is that, the operators can grasp more than one component by one hand at a time. In this
case, detection of the grasping movements and quality control of the packaging operations would require highly accurate hardware and complex software algorithms which are too expensive to invest and operate.

Similar to the principles have been mentioned by Bannat et al. (2008) (Figure 25), some basic pseudo-codes can be structured in order to explain the usage of different sensory devices in order to track the operator and control the quality. As a basic control mechanism of the tasks are completed or not, here we present a tracking pseudo-code for an exemplary manual packaging operation, subject to the following assumptions.

Assuming that there are three types of components to be packed, “A”, “B”, “C” and “D” tags indicate spatial centers of mass of fixed storage boxes and the packaging fixture. Hands of the operator are tracked over the points of “L” and “R” (Figure 28). As setting the functional parameters of the system as:

\[ T_i : \text{Packaging task of component } "i" \]
\[ D_i : \text{Maximum allowed distance of the worker's hand from the fixed position } "i" \] for grasping or dropping detection.
\[ F_i : \text{Spatial fixed point of the } "i" \text{ as the components or packaging box} \]
\[ H_i : \text{Current location of the operator's hand} \]
\[ |PQ| : \text{Cartesian distance between the points } P \text{ and } Q \text{ with the coordinates of } (X_p,Y_p,Z_p) \text{ and } (X_Q,Y_Q,Z_Q) \]

For the case of component A as first component to be packed:

Begin

Present the packaging instruction of \( T_A \)

wait until \( |H_L F_A| \leq D_A \) or \( |H_R F_A| \leq D_A \)

if \( |H_L F_A| \leq D_A \)

wait until \( |H_L F_D| \leq D_D \)

return information of task is completed

move to next task

End

else

wait until \( |H_R F_D| \leq D_D \)

return information of task is completed

move to next task

End
As we emphasized before sensitive scale like devices can be integrated with other tracking devices. By this multi-sensory approach both user tracking and quality control activities can be covered in a more accurate and reliable way. In this case, the control mechanism we mentioned above can be extended on the multi-sensory basis by adding box weight measurement activities for each task control loop.

When it comes to the discussion of the validity and reliability of the research itself, we deem that, considering the case delimitations and requirements, more extensive and inductive research could be done covering the product, production and production environment factors. As it was mentioned before, the underlying reasoning of the research is based on deduction, since deductive answers were given for a single case based on the general theory. However, considering this fact, the findings of the research study may indicate the validity for the similar cases within industry. Furthermore, the research represents characteristics of generalizability and reliability to some extent, since different constructions of diverse realities are possible due to the practice of triangulation techniques during the data collection process. By this means, we esteem that this research study is reliable and valid.

Figure 28. Exemplary schematic description of a manual packaging work bench.
5.2 Conclusion

By this research we aim to present a feasible solution approach for quality problems related with manual packaging operations in Thule AB as the case company. Considering the task properties, production environment conditions and company’s investment policies, VAR based cognition support systems can be used in order to assure and control the quality throughout the manual packaging operations with acceptable investment costs compared to other technology alternatives. Additionally by presenting a holistic underlying theory of human cognition, information processing and mental workload, an understanding on root causes of the problems are aimed to be consolidated.

VAR technology in the manner of cognition support concluded for being suitable to implement in order to ensure quality, in terms of completeness of the end product packages. Additionally, experimental research results that we have mentioned; support our conclusion of possibilities on improving operator performance and decreasing the overall error rates in manual packaging operations with VAR system implementations. However, before the actual ramp up of possible VAR based cognition support systems, it is suggested to have a detailed analysis about tasks, products and production environment, preferably supported with pilot studies.

With the increasing demand on VAR systems triggered by continuously developing technologies in gaming industry, it is inevitable to presume that such systems will take more and more part in industries and even in our daily lives. Considering this trend, with the help of the experience and know-how gained from possible application and usage of the VAR systems, further VAR applications can be implemented within more complex organizational operations like product design-development-realization and maintenance.

Besides of the case related results, this research can also lead the alternative VAR development studies by indicating a new research area as manual packaging operations.
6  LIST OF REFERENCES


Quality Assurance in Manual Packaging Flow Case of Thule AB: 
A Theoretical Review of Virtual and Augmented Reality Systems as Cognition Supportive Approaches


7 Appendix

7.1 Appendix 1 – Packaging Instructions of Station 1 (Rapid System 753)
7.2 Appendix 2 – A Packaging Instruction of Station 2 (Flow group 70010)