CHALMERS
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Digital information presentation in a complex production environment

An investigation into reducing operators cognitive workload

Master's thesis in Production Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2020

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Cover: A rendered workstation layout equipped with the developed information presentation concepts.

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Abstract

A production environment defined by low volumes and high product variance in an industry that is characterized by immense quality requirements confronts assembly operators with high complexity in their daily work tasks. Therefore, operators must be supported by information presentation of high quality to effectively handle the complexity.

In this thesis the perceived cognitive workload of operators in the complex production environment evident in the space manufacturing industry was evaluated. Based on this assessment two solution concepts for presenting work instructions were developed that contain several improvements reducing an operator's cognitive workload in the assembly present at the case company. These concepts feature different implementation horizons, where one of the concepts lies within the reach of short-term implementation, while the other one presents an outlook on how information could be presented in the future. These concepts were evaluated by a focus group consisting of both researchers on the area of information handling and industry practitioners.

It could be concluded that a fundamental challenge an operator faces within this environment is the handling and processing of large amounts of information, which acts as a source for several information presentation issues affecting cognitive workload. Furthermore, it was found that the application of an approach considering the active cognitive processes of an information receiver may improve the effectiveness of the information presentation within this environment. The evaluation of the developed information presentation concluded that the developed concepts show potential to reduce the cognitive workload of the user. Furthermore, it was concluded that operator involvement will be necessary to ensure true usability of the instructions, therefore operator validation is recommended for further research.

Keywords: Cognitive workload, Information presentation, Work instruction, Information quality, New space, Space industry, Final assembly

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1 Introduction

The introduction presents the background of the research topic and the purpose of this thesis as well as a description of the case company and its production.

1.1 Background

A segment within the electronics manufacturing services sector is the high-mix low-volume manufacturing of electronic components and circuit boards. The production environment within this sector is characterized by fluctuating product demands, long lead times, high product variance combined with a diverse set of required operations and quality assurance procedures [1]. An industry within this segment is the manufacturing of space applications which is defined by high levels of expertise and considerable investments in research and development in order to provide the customers with specialized solutions of immensely high quality. The space manufacturing market is currently proceeding towards a more commercialized space sector commonly referred to as "New Space" with new actors demanding products in higher volumes at a lower cost with shorter lead times creating a more competitive landscape [2]. Consequently, various adaptation efforts must be made by component manufacturers that wish to compete effectively on this developing market [3].

The production within this industry can be defined as complex assembly since customer specific products are assembled that are inherently complex both in terms of product and manufacturing process [4]. This complexity may be handled by employing a suitable level of cognitive automation that supports operators in decision-making processes to counteract the negative influences on an operators cognitive workload imposed by high product variance [5]. An increasing degree of cognitive automation can assist in reducing an operators workload by improving the quality of the instructions making complex information appear to be more simple [6].

This thesis is part of a collaborative research project, “Framtidens rymdfabrik II[1]”, between RUAG Space and Chalmers with the goal of decreasing the gap between the current production and the production that is needed to support the future industry through a series of improvement efforts on the manufacturing side. The project is composed of a series of study areas that in various ways will contribute to a more capable production. This thesis is part of the cognitive automation area with the goal of improving the production through changes in the flow of information.

[1] `https://research.chalmers.se/project/9321`

1.2 Purpose and research questions

The purpose of this thesis is to develop a concept for presenting work instructions using an operator-centred approach that will enhance operators ability to assemble greater volumes of high quality products by decreasing their cognitive workload in a complex final assembly environment. Based on this purpose two different research questions can be posed:

Research question 1

The purpose of research question 1 is to understand how operators could be supported with improved information presentation in the future by investigating how the current information presentation influences an operators cognitive workload.

- How is an operators cognitive workload influenced by the current information presentation in the complex production environment?

Research question 2

The purpose of research question 2 is to develop and evaluate two solution concepts for presenting information within the new space manufacturing industry.

- How can information be presented in the future in order to decrease an operators cognitive workload within a complex production environment?

1.3 Delimitations

The thesis exclusively investigated the information presentation from the perspective of the receiver as it would have been too comprehensive to thoroughly examine the perspective of the instruction preparer during the limited time available for the project. For the same reason, the concepts developed in this work were limited to solely feature a mechanical assembly operation.

The conducted work was focused on lowering the cognitive workload by improving the cognitive support received through the existing information carriers in the form of computer monitors. Hence no investigation was taken into assessing physical automation or the physical workstation where the tasks are performed. Furthermore, the work did not involve the optimisation of work processes that are performed within production as the information presentation was the focus of the study. Altering the physical circumstances or procedures of the task would have rendered comparisons with the current information presentation difficult. Physical testing of the developed concepts with operators would have been beneficial for the underlying work, however, circumstances beyond the control of this thesis made it impossible to obtain valid results within the production environment.

1.4 Case company

The case company RUAG Space is a supplier of products used within both the public and commercial space industry and has its foothold primarily as a manufacturer for the european space market. RUAG Space is part of the swiss-based technology group RUAG Holding specialized in aerospace and defense technology development. RUAG Space employs 1300 employees located on sites across 6 countries in Europe and the United States [7].

The nordic subsidiary RUAG Space AB has its headquarters in Gothenburg where the product group of reliable electronics in the categories of microwave, digital and antenna products are produced. The manufacturing process that the company applies can be described as engineer to order where the full chain of product development, production and final product usage testing is performed for most of the projects. The project oriented production that the company applies is defined by high product variance and low volumes of products with exceptionally high quality, resulting in long lead times and high complexity in the manufacturing process [8], [3]. Currently the produced volumes can vary from a few units to hundreds of units, with the transition into new space manufacturing the product volumes are estimated to increase by approximately 400% at RUAG [9].

The manufacturing processes within the production system such as mechanical assembly, soldering and gluing of mostly small and fragile components are performed in large extents manually in carefully controlled procedures and environments. The operators performing these procedures undertake rigorous training enabling them to gradually perform more unique and complex tasks in order to manage the challenges of the production system [3]. The production at the company is characterized by a fluctuating product demand following the customer projects. These fluctuations result in a production system that may be under high pressure during certain projects while underutilized during other projects which poses the need for temporary consultants to uphold the flexibility required to handle the alternating workload. The operator workforce currently consists of approximately 62 people out of which 34 are assembly operators, 10 operators inspect the assembled products, 15 operators performs final testing of the inspected products and 3 operators are working with material supply and inspection. The work is conducted within a clean room where the cleanliness is highly controlled by surveilling the amount of particles in the air to protect the components. Furthermore, all products are to be handled with great care to protect them from electrostatic discharge and damage caused by impurities.

2

Theoretical framework

This chapter presents relevant research within the field of cognitive ergonomics, information quality and information presentation applied within this thesis.

2.1 Cognitive ergonomics

The field of cognitive ergonomics aims towards studying and designing solutions regarding how well they suit interactions with the cognitive limitations present in the mind of a user. These cognitive limitations can be described by the theory of cognition where information processing is divided into different cognitive processes. The support of cognitive processes within the design phase will assist in reducing the mental workload of a user. The knowledge about human performance at different task levels increases the awareness of what to support, while the implementation decides whether users will trust the solution and use it.

2.1.1 Cognition

A human information processing model as can be seen in figure 2.1 is presented by Wickens et al., it describes the information flow at hand while performing tasks from sensory processing of data to execution of a response [10]. The senses provide sensory input which during less than a second is stored in the STSS (Short Term Sensory Store) before being perceived and associated with meaning. The meaning is derived from past experience stored in the long-term memory. Information is then either processed triggering an immediate response such as slowing down the car when approaching a stop sign or triggering the work memory consciously thinking about the perceived input such as scanning for potential police cars which are examples provided by Wickens et al [10]. The process of cognition is initiated through active thinking and interaction with the work memory. The feedback loop presents the changed sensory input as an answer to the chosen response. Attention connects to all inputs as it redirects mental capacity to all steps.

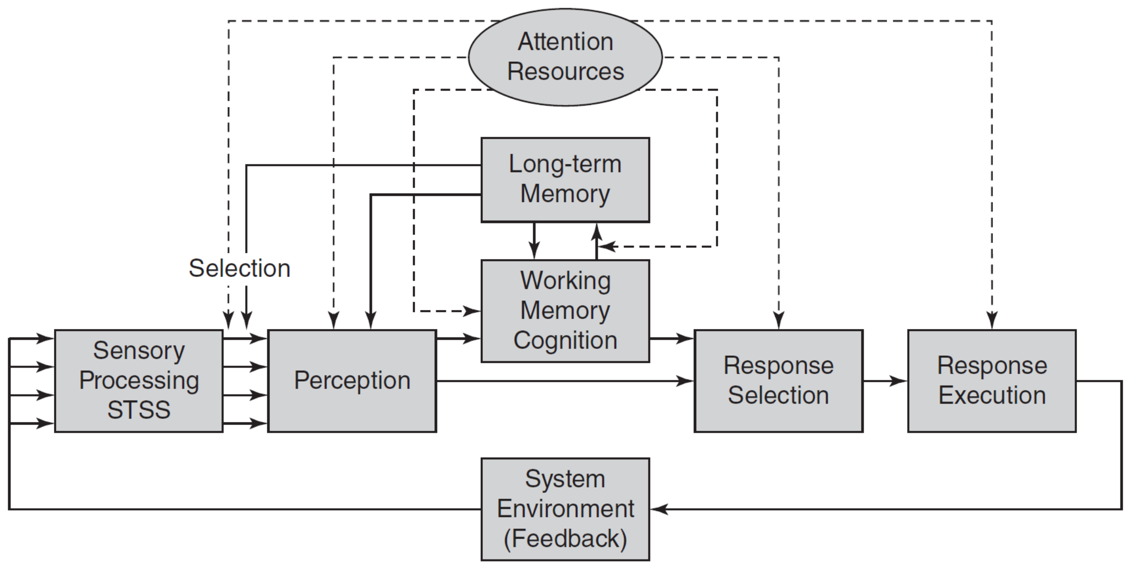


Figure 2.1: A model for human information processing, from Wickens et al. [10]

The processing of information described in figure 2.1 can be categorized as four cognitive processes named perception, memory, attention and mental model [11].

Perception

Perception refers to the act of associating a sensory input or signal with meaning, this relation is heavily reliant on the use of past experience and knowledge as for example the association of yellow light with caution [10]. These associations speed up the computation time required to make sense of a signal, but also make humans vulnerable to optical illusions as shapes and signals can be misjudged through overestimating or underestimating quantities compared to their true value.

Memory

Memory can be divided into two different storage systems namely working memory and long-term memory [10]. The working memory is a temporary and attention-demanding storage that holds information before it is encoded into long-term memory. It can be referred to as a workbench where mental representations are evaluated, transformed and compared. The working memory capacity is classically described as the rule of 7 with storage of 7 ± 2 objects, while newer research argues that the actual capacity is lower containing 5 ± 2 objects [10]. These objects are described as memory chunks which are grouped elements that are tied together by associations in the long-term memory. The long-term memory refers to either procedural or declarative memory [10]. Procedural memory is implicit and refers to information that has been stored through an active learning process. Declarative memory is divided into the general knowledge of concepts and experienced situations.

Attention

Attention can be described as a filter that identifies which kind of all the perceived signals to be selected for further processing and which to block out [10]. It also acts as an indicator for redirecting attentional resources to other required processes such as perception when for example driving a car during a foggy night. The amount of attentional resource capacity is limited, which can create difficulties multitasking when a single task most of the attention.

Mental model

Mental models are described as long-term memory structures that contain information about system functionality and provide a human with the ability to predict future system states [10]. Accurate portrayal of processes for example will allow operators to mentally simulate potential failure modes of a system. Mental models can either be generated automatically or through deliberate formal training. A signal can often trigger multiple different mental models, humans then compare and choose the most appropriate one for the situation. An expert for example often possesses more accurate and refined models than novices increasing their ability to alternate between them when faced with problem-solving.

2.1.2 Mental workload

Mental workload can be described as the memory related effects that a user experiences while processing information, this can be explained as part of the cognitive load theory which divides experienced cognitive load into two separate domains namely extraneous and intrinsic load [12]. The experienced extraneous cognitive load can be controlled by an instruction designer as it refers to the actual information presentation received by the user, which can be minimized by presenting information more simply through for example pictures. This can be supported by a case study that concluded that a more extensive use of pictures can reduce perceived cognitive workload [13]. The experienced intrinsic cognitive load refers to the induced intellectual complexity of the information itself which depends on how much individual elements interact with each other. Pollock et al. provide an example for intrinsic load where a learner can learn the individual behavior of components in an electrical circuit, but the behavior of the circuit itself cannot be learned without knowledge about the components and their interaction with each other [12]. The amount of intrinsic load is therefore often regarded as fixed with multiple elements present in the working memory. Therefore, in cases of high intrinsic load being present the amount of unnecessary induced extrinsic load should be minimized.

An operators cognitive workload can be influenced by the presence of information overload within the system when too much information is presented, the presence of several different work tasks within a work environment cannot automatically be classified as mentally demanding but can act as a source of complexity and therefore may require more information support [14]. The operator wellbeing and performance can be affected by not being involved in design processes, but also the non-consideration of active cognitive processes in the instruction design process can cause unnecessary cognitive workload to appear [15]. Furthermore, an operators mental workload and health can be influenced by perceived boredom induced through monotonous work tasks that cause mental weariness, the amount of stimulation and motivation received through the work and workplace stressors generated by for example high demands and bad communication [11].

2.1.3 Human behavior

The theory regarding human behavior describes the learning process of users from being novice to becoming experts. The knowledge about human performance provides a guideline for how different levels of experience and task complexity should be supported to minimize errors. The design of a support should aim to build the users trust in order to be perceived as useful and be accepted.

Performance

The human performance model SRK (Skills, Rules and Knowledge) that was developed by Rasmussen divides human performance during tasks into three different levels namely skill-, rule- and knowledge-based behavior [16]. Skill-based behavior refers to activities where highly automatic and integrated patterns are used that do not require any kind of active or conscious control such as for example the by-heart learned procedure of riding a bike. Rule-based behavior refers to familiar activities where stored rules are activated by following presented procedures that are linked to already present mental models such as for example following a cook book recipe. Knowledge-based behavior describes activities which are unfamiliar and previously unencountered, where stored knowledge has to be retrieved from memory to be combined with unguided troubleshooting in a scenario such as for example the identification of an engine discord.

The SRK model is according to Berlin et al. applicable to describe the learning process of humans from being a novice to becoming an expert [11]. All humans when faced with new tasks that were previously unknown to them start as novices in carrying out these tasks and are highly dependent on instructions that convey detailed information about the required procedure, before acquiring routines tasks therefore often are performed on a rule- and knowledge-based level [11]. The continuous completion of tasks leads towards a gradual development of skills that makes humans less dependent of instructions as procedures have been internalized within the long-term memory making someone an expert. Experts in general mainly rely on skill- and rule-based knowledge [11].

An adaptation based on the SRK model is presented by Mattsson et al. which combine Rasmussens work with two other models developing a model for describing intuition within complex assembly [17]. The model aids the process of identifying and characterising cognitive processes within assembly tasks, where subtasks are categorized as intuition level 1 referring to skill-based behavior and level 2 referring to rule-based behavior.

Trigger

The different types of behaviors described within the SRK model are activated using different types of behavioral triggers such as signals, signs and symbols indicated in figure 2.2 [16]. The figure shows three different representations of the same flowmeter control panel where all different types of behaviors are requested. The signal *"set point" arrow* indicates that pressure always should be kept at a set point, making deviations easy to monitor. The sign provides procedural information about actions to be taken in different scenarios. The symbol indicates the need to perform unguided trouble-shooting for the experienced deviation.

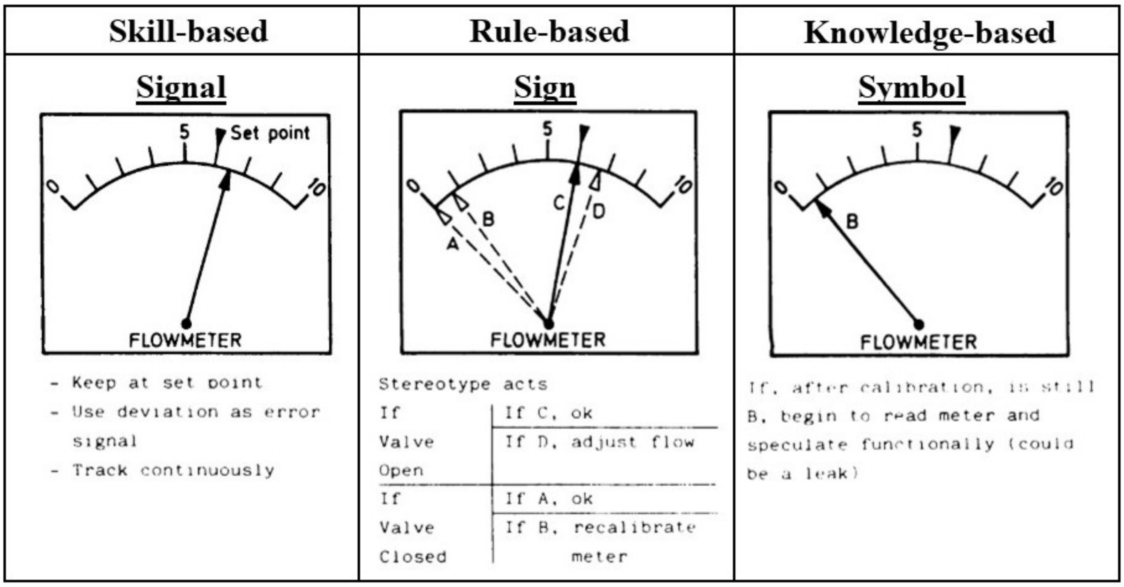


Figure 2.2: The three behavioral triggers, adapted from Rasmussen [16].

Error modes

The SRK framework was extended by another dimension by Reason who associated the skill-, rule- and knowledge-based behavior with behavioral error types namely mistakes, lapses and slips [10]. Mistakes occur in both the rule- and knowledge-based dimension where the wrong action or intention is triggered for the situation. Rule-based mistakes are carried out with strong confidence as the operator believes that the right rule has been activated, while knowledge-based mistakes can be associated to working memory overload and a failure to correctly assess the situation. Lapses relate to a failure in memory storage where no task is carried out meaning that an operator has forgotten to accomplish it such as for example missing to perform a task in a procedural sequence. A slip occurs when the right action has been triggered, but carried out in a wrong way caused by lack of attention or deviation from routine.

Trust & Acceptance of Automation

Operators' trust in automation as described by Lee & See is important as a system which is not trusted is unlikely to be used [18]. The level of trust compared to the automation capability can either result in distrust where automation is not used or overtrust where automation is misused when not calibrated correctly. Trust is often created through observations where operators over time get used to a system and are able to build greater trust. Lee & See present certain guidelines that should be used to increase trust while designing systems for reliance [18].

- **Education:** Operators should be prepared in advance with training to understand the intended use and expected behavior of the system combined with the purpose of why automation has been applied. Operators should be told how the system relates to their personal performance goals and how they are supposed to interact with the system. Emphasis should be directed towards operators understanding the true capability of the automation [18].

- **System design:** Operations and algorithms should be simplified in order to increase operator awareness of automation need. The system should take into account the cultural and individual difference of operators as these factors might influence reliance while aiming for an appropriate level of trust not trying to exceed to greater levels [18].

- **Visual interface:** The system interface should relay the process of the automation and thereby communicate intermediate status updates. The interface should contain a well-structured layout with an appropriate amount of information content as a system is often judged by its interface rather than the true capabilities available within [18].

The acceptance of users for technology can be measured using TAM (technology acceptance model) that aims towards tracing the impacts of external factors on operator belief, attitude and intention [19]. There are two beliefs that are especially important for technology acceptance such as the *perceived usefulness* which includes the feeling that the system will improve the job performance within the organization and *perceived ease of use* that comprises the feeling of how easy the operator perceives the system is to use.

2.2 Information quality

The concept of information quality can generally be defined as an information characteristic describing the degree of which the information is fit for the intended purpose. Several different frameworks to define and evaluate the quality have been proposed with the intention of creating effective information usage through higher quality. Haug proposes a framework describing work instruction quality as a series of intrinsic and extrinsic dimensions that affects the information quality of the instructional resources [20].

2.2.1 Intrinsic information quality

Intrinsic information quality of work instructions is described with five different informational dimensions that affects the relationship between the instructions needed and the instructions received by a user [20]. The intrinsic information quality can thereby be evaluated by identifying the five different types of imbalances in the connections between the entities seen in figure 2.3. The five intrinsic quality dimensions causing these imbalances, and finally a balanced instruction, are defined as:

- **Deficient instructions** are defined as quality issues caused by the lack of the required information needed to perform a certain task. Instructions can only be categorized as deficient if the instructions are incomplete as a cause of the absence of instructional elements [20].

- **Ambiguous instructions** are information quality issues that emerge when the information within the instruction can be interpreted in several ways, leading to different outcomes. Ambiguous instructions can be defined as a type of incomplete instruction along with *deficient instructions* since the lack of information causes ambiguity [20].

- **Unneeded instructions** are characterized as instructions given to the operator that are composed of information that provides no valuable knowledge about the task at hand. This occurs either in cases where the information lacks relevancy or in situations where the operator is already aware of the given information [20].

- **Incorrect instructions** is a type of information quality problem describing instructions that contain information that can be classified as factually incorrect. Incorrect information is referred to as misinformation which by definition cannot be considered a type of information [20].

- **Repetitive instructions** is a quality issue that arises when the required instructions are repeated to the operator too frequently without a clear reason. This issue should not be confused with the concept of redundant instructions, as redundancy can be beneficial in aiding recollection of crucial information in certain situations [20].

- **Fitting instructions** are defined as instructions that are complete and correct without any of the previously described information quality issues, making them fit the information quality needs that the task demands [20].

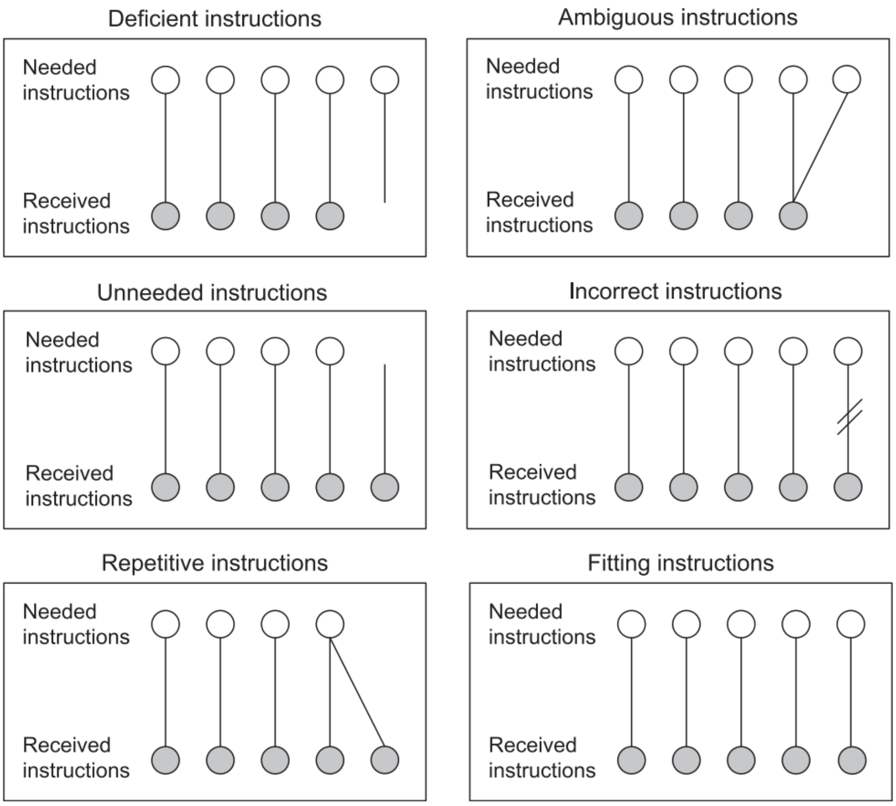


Figure 2.3: Intrinsic information quality relationships, from Haug [20].

2.2.2 Extrinsic information quality

The framework proposed by Haug, seen in figure 2.4, also considers dimensions that are of an extrinsic nature meaning that they are dependent on the characteristics of the environment the instructions are being used within. The dimensions rely on intricate and subjective aspects such as user perception, organizational culture and communication which makes them more difficult to evaluate than the intrinsic dimensions. Haug proposes that the extrinsic dimensions can be categorized into the four different categories described below [20].

- **Representational problems** are defined as information quality issues caused by unfitting presentation of the instructions to the user which may occur if instructions are inconcise in describing procedures, inconsistent in the use of information or if information is repetitive without a purpose [20].

- **Unmatched information** are quality issues that emerge when the information content is inadequately adapted to the user or task that the instruction is describing which may occur either if the information is too complex to comprehend, too vast to memorize or delivered in an untimely manner [20].

- **Questionable information** are quality problems that arise when the user has a negative perception about the information source or the content of the information. This may occur either if the user does not trust the information to be correct or if the reputation of the instruction is unfavorable [20].

- **Inaccessible information** are defined as quality issues caused by barriers that hinders the user from accessing the information. These barriers may either be blocking the access to parts of information completely due to security aspects or hinder the user by making the information difficult to obtain [20].

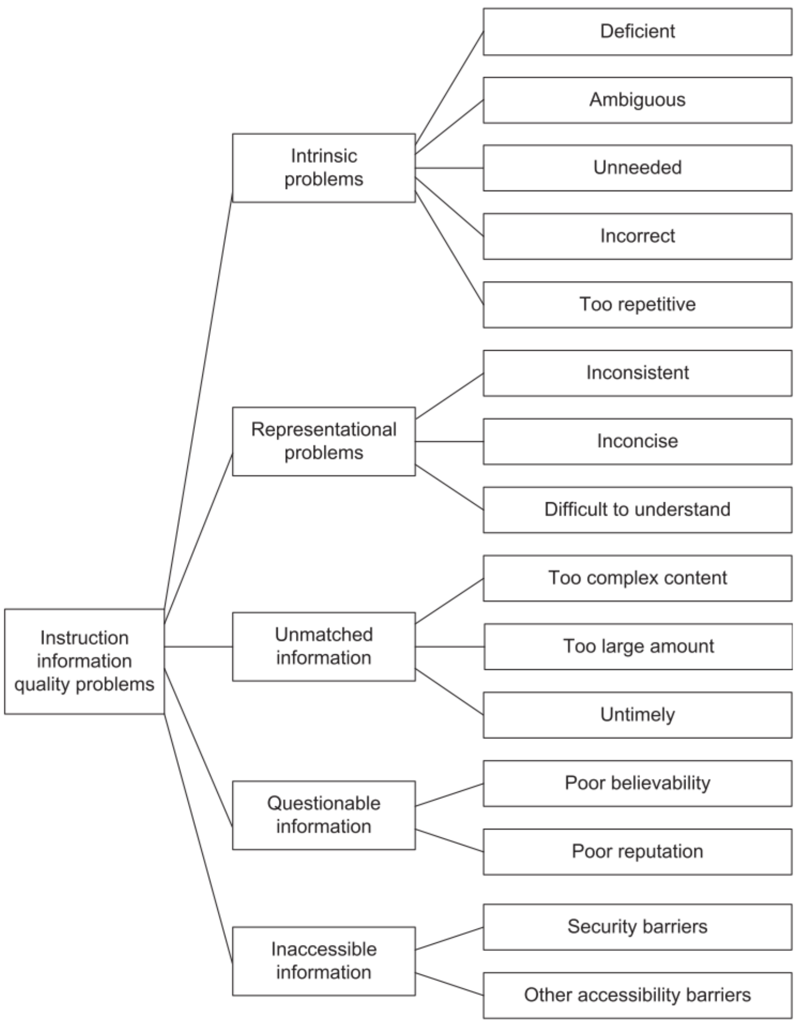


Figure 2.4: Instruction information quality framework proposed by Haug [20].

2.2.3 Information quality attributes

Kehoe et al. proposes a view in which information can be considered to only have a single characteristic defined as its quality which can be evaluated and put in relation to its benefits. The quality of the information is of high importance to its utilization since information without quality will provide no support to the receiver. The characteristic of information quality is composed of six different attributes, as described below, to consider in the evaluation of the overall information quality [21].

1. **Relevance**
   The attribute of relevancy refers to the information contents ability of being connected to the topic it means to describe. The information provided must be relevant in order to benefit the receiver in completing their tasks [21]. Information that is relevant will provide the receiver with support in their actions and aid decision-making.

2. **Timeliness**
   The quality attribute of timeliness describes the extent to which the information content can be presented to the receiver at the correct times [21]. The information must be timely so that the receiver can utilize information relevant to the task being performed at the time.

3. **Accuracy**
   The quality attribute of accuracy is defined as the extent of which the information content provided to the receiver is factually correct and precise in its descriptions [21]. The information must be accurate and precise so that the receiver can perform the tasks correctly and make informed decisions with precision.

4. **Accessibility**
   The quality attribute of accessibility describes how available the information is to the receiver at the time of need [21]. The information must be accessible since its contents otherwise cannot be utilized effectively by the receiver.

5. **Comprehensiveness**
   The quality attribute of comprehensiveness is defined as the extent of which the information content is concise and complete without redundant information [21]. The information must be comprehensive to ensure that the receiver can perform tasks and make decisions adequately informed without being distracted by unnecessary amounts of information.

6. **Format**
   The quality attribute of format refers to the ability of the information presentation to convey the content of the information to the receiver [21]. The information must be formatted so that it can be perceived by the receiver to provide value in performing tasks or decision-making.

2.3 Information presentation

The concept of presenting information to the receiver involves a plethora of different aspects to consider as information can be presented in a variety of different ways with different purposes. The *instruction design principles* presented by Osvalder et al. provide a foundation for the design of instructions as they relate the cognitive processes of the receiver to tangible principles of visual information presentation. The summation of several case studies within the field of *procedural assembly instructions* provide a set of guidelines to be used while designing work instructions.

2.3.1 Instruction design principles

Osvalder et al. have proposed a set of thirteen design principles that should be kept in mind in order to design effective information presentation on visual displays. These principles are divided into four different categories according to the cognitive process they are intended to support. Principle 1 to 3 supports attention, 4 to 8 aids perception, 9 to 11 supports memory functions while 12 and 13 assists the operators mental model [22].

Attention

The principles supporting attention are aimed towards reducing the number of distractions a receiver is subjected to in the interaction with the information as well as increasing the inherent ability of the information to sustain the focus of the receiver. Osvalder et al. emphasizes that information must be easily found in order to be used and effectively support the human limitation of attention. This may be achieved by placing information that must be interacted with frequently in the location that is the easiest to find while minimizing the effort required to interact with the carrier of the information [22].

The author also implies that the comprehension of several information sources in a design can divide the attention of the information receiver. Related information should therefore be formatted so that the connection between them is coherent while also striving towards minimizing the connections that must be considered across information sources. This may be achieved by utilizing color coding, groupings or patterns so that the user easily can understand how the information is related [22]. However, the use of complementing information sources may also increase the ability of the information to sustain the attention of the receiver. Attention can be supported by utilizing more than a single channel in the presentation of information. For example, visual information that is enforced by auditory information will more effectively maintain the attention of the receiver [22].

Perception

The collection of principles to be considered in the effort of aiding the perception of the information are directed towards increasing the visual quality of the information so that it may be seen clearly as well as reinforcing the coherence of the information so that the receiver can interpret the content being observed with less effort. The visual quality should be supported by designing information presentation channels that are easily assimilated by the senses. This puts demands on visual design factors such as contrast, illumination and viewing angle which are all contributing factors to designing information that easily can be perceived [22].

The interpretation of information is highly dependent on the receivers previous knowledge and experience. The perception should therefore be supported by clearly signaling information that may conflict with the receiver's expectation. Information that describes an unusual process could therefore for example be highlighted in a bright color to bring awareness to that information [22]. A source of misinterpretation and difficulty in the comprehension of information are visual similarities between objects containing different information content. In order to support perception, objects of varying meaning must be clearly differentiated by reducing similarities and reinforcing differences [22]. However, the information conveyed to a receiver will always be susceptible to some degree of interpretation. Osvalder et al. proposes that the use of redundancy where combining multiple ways of presenting the same information simultaneously will decrease amount of interpretations possible [22].

Memory

The principles supporting the memory functions are aimed towards reducing the number of entities occupying the short-term memory and minimizing situations where a receiver actively must search within the long-term memory. The short-term memory of a receiver can easily be overloaded by having to memorize information previously given. Information therefore needs to be adapted to fit with the tasks performed in the real world by presenting the complete information needed in that task while not encumbering the receiver with untimely information.

The short-term memory may also be occupied if the receiver is unaware of the future state of the operation being performed. The prediction of the future state of a system requires that the information receiver considers a series of factors based on previous events which thereby occupies the short-term memory. In order to support the memory and thereby enabling an operator to be proactive and focus their limited memory resources on the task at hand, the system should present the anticipated future system status [22]. As for the long-term memory, the receiver should not be subjected to vastly different presentations of information. A receiver will unconsciously apply previously learned procedures of apprehending information even if the previous application of the information was vastly different. Therefore, in order to support these learned behaviors' information should be consistently presented across the complete system [22].

Mental model

The principles supporting mental model are aimed towards simplifying the understanding of the information by presenting information material that is consistent with the receivers mental conception of the system described. This conception is based on the real environment that the information aims to describe. Therefore, information presented should represent the reality as accurately as the system allows. This will aid the comprehension of information since the mental model of the receiver and the information presented will be aligned and consequently provide a combined interpretation of the information [22]. The information should also represent the receivers mental model regarding how moving elements of a system would behave in reality. Therefore, it is important to consider how the receiver expects dynamic objects to behave within the presentation in order to not conflict with the mental model [22].

2.3.2 Procedural assembly instructions

A procedural document such as for example an assembly instruction contains all the procedures that are necessary to complete a task provided in a consequential order. The main use of procedural documents can be divided into either linear or case-by-case use, where the user either conducts the documentation in advance for complete guidance or targeted use for a specific problem [23]. A study by Agrawala et al. mentions two important features, *planning* and *presentation*, that should be taken into account while designing step-by-step instructions [24]. The study reveals a framework of design principles that was obtained during experiments assembling a TV stand. Heiser et al. later advanced these design principles for the design of work instructions and assembly procedures for creating effective, visually comprehensible, and accessible instructions for furniture assembly [25]. Ganier presents characteristics that should be followed while designing procedural instructions to lessen the cognitive workload of operators describing the effects on both novice and expert users [23]. A study by Söderberg et al. presents a set of guidelines for developing simple instructions which are partially based on the above mentioned studies in an assembly environment including *structure*, *layout* and *pictures and text* [26]. An abstract of the suggested principles in these case studies can be seen below.

Step-by-step instruction

Instructions are preferably communicated through a series of diagrams that feature a pleasant hierarchy instead of displaying the complete assembly on a single diagram [24]. The assembly structure should be carried out on a planned procedure which could be obtained by performing an HTA analysis [26]. The addition of an important sub-part should always be communicated through a single diagram, while the assembly of multiple less significant parts can be presented in the same diagram [24]. Repetitive detailed presentation of an assembly step should be avoided to reduce the creation of unnecessary long and tiresome instructions [24]. Text should be segmented in the form of lists for easier comprehension as the time required to localize the information is reduced while enabling an easier transfer of perceived information to the physical product [23].

Diagram type

Action diagrams that show the gradual progress of an assembly are often preferable over the use of structural diagrams that show the finished assembly when different types of fastening tasks are in place [24].

Orientation

The orientation of a displayed object should maximize the amount of visible important features to improve recognition and minimize the risk for potential misalignment [24]. The viewpoint and format should be as consistent as possible throughout the assembly, if change to another viewpoint is required it should be easy to understand how the transition is performed [25]. It is also important that the shown orientation should be physically realizable for an operator [25].

Visibility

All newly added parts to an assembly should be visible in an assembly step, while an exception can be made for structures that feature a clear and obvious symmetry where only one side can be shown [24]. All the previously attached parts do not have to be visible, but it must be clear how and where the new assembly is supposed to be placed [24], [25].

Elements

Motion, direction and interaction of parts should be clearly indicated by using semiotic and diagrammatic elements such as arrows and guidelines [25]. The use of different sizes and colors for text fonts has the ability to highlight it from the rest of the available information providing the opportunity for easier localization of information [23]. Pictures should be used to a great extent with the provision of reoccurring visualizations of the finished product, if the instruction layout itself is limited separate presenters could be used [26]. It is important to clearly highlight differences visually between similar objects to avoid confusion and misassembly [26].

Organization

A procedural document should both feature the learning process of new operators by conveying the basic procedures following a chronological and linear approach, while the information presentation also should facilitate a secondary level of expert users that consume information in a nonlinear manner requiring a modular organization into functions and categories [23]. The headings of tasks and subtasks should use clear, concise and direct language and thereby transmit the information about what to do [23]. The order of words used should strictly follow the execution order of the task as for example *"do this, then that"* instead of *"do this after you have done that"*, while generally conveying a clear and explicit order [23], [25].

Mixed format

Instructions should combine the use of both pictures and text, while the focus for designers should be directed towards designing the picture and then adding the text to support operators to develop a quick mental model based on the picture, but guided by the use of complementary text [23]. The pictures and text that are used should only contain the information that is necessary in order to perform the task [26].

3
Methodology

This chapter states the employed research approach within this thesis and explains how it has been performed by presenting applied research methods.

3.1 Research approach

A mixed-methods research approach was used in this study with a simultaneous research design involving the use of both quantitative and qualitative data [27]. This approach was chosen as by complementing both these data types more thorough findings providing a more adequate portrayal of the study can be achieved including other perspectives and less research-induced bias [27]. Methodological triangulation as often employed by mixed method researchers was used within this thesis as all the employed methods such as interviews, observations, questionnaire and focus group allowed the research to be viewed from a variety of stances to provide a more nuanced picture [27].

The thesis work has broadly been based on the flow shown in figure 3.1 with some process steps being revisited at several occurrences. Initially the problem under review was stated and followed up by an analysis of the initial state at the case company. The development of both concepts was performed in parallel following an iterative process after completing the instruction system design phase. A focus group was conducted to review and evaluate the developed concepts and thereby conclude the findings of this work.

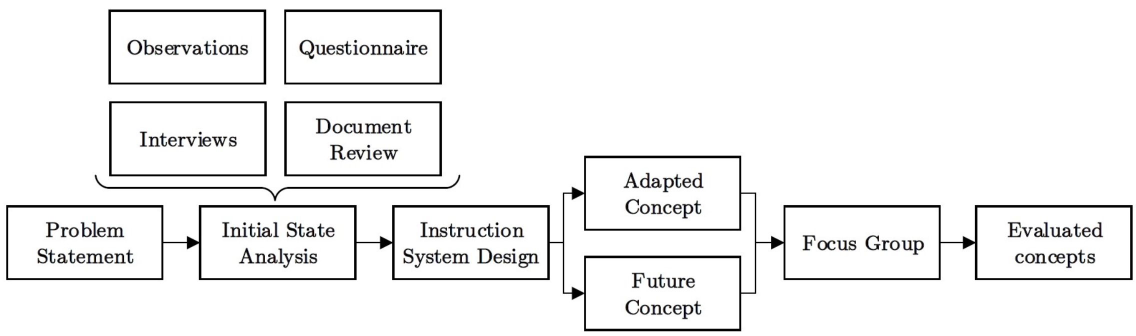


Figure 3.1: The thesis workflow leading up to the findings of this thesis.

3.2 Data collection

The initial data collection phase within this thesis was performed through conducting shop floor observations at the case company that were accompanied by unstructured interviews with supporting functions. The obtained feedback was then used to develop an operator questionnaire that assessed both work environment and information handling. Furthermore, a document review featuring work instructions for several products was conducted.

3.2.1 Observations

Observations were conducted throughout the course of the thesis. The general advantage of the method includes that large volumes of data on a wide selection of categories can be obtained from a system in its true operational setting. However, the method is time-consuming to perform and the data may have certain biases since humans generally are prone to changing behavior when observed [28]. The observation sessions were prepared by establishing an observation plan containing specific areas of observation along with the goal for the session. The observed data was collected by noting observation results, which after the session were summarized. The observations were combined with informal unstructured interviews on a conversational level where the operators would for example explain procedures and highlight issues with the information presentation.

The observations performed over the course of the project could generally be classified into two different categories, guided and unguided production walks. The purpose of these observations was to understand how the general production environment along with its main functions worked and how information presentation was implemented within this environment. In total three guided walks together with three separate shop floor functions being an operator, a production engineer and a project manager were conducted. These walks provided insights from different perspectives on the shop floor operations combined with perceived challenges in information handling. The guided walks were complemented by several unguided walks where workstations could be observed more thoroughly, especially regarding material and tool handling, which was beneficial for the concept development.

3.2.2 Interviews

Unstructured interviews with relevant key persons in the case company were held with the aim of gaining insights about the information handling at the case company. The interviewees were selected either because of their knowledge regarding shop floor operations or the information system. The interviewed functions included production personnel, product unit managers, IT department and production engineering. The advantage of this type of interview is its flexibility in being able to explore several aspects under review, but the lack of structure poses the risk that important aspects are not being discussed [28]. The method was chosen as it provided the opportunity to conduct an open conversation in a less formal style with a duration of approximately 10-15 minutes per interview.

3.2.3 Questionnaire

A questionnaire, as can be seen in appendix A, was administered to the shop floor operators with the aim to solidify answers previously obtained through unstructured interviews by a larger population of operators. The main purpose was to identify trends in operator perception of their workplace and tasks to be used as a follow-up for operator interviews, while the secondary purpose was to enhance the understanding of problems and ways of working. The method was chosen as it enabled operators to anonymously transmit their opinion while acting as a quantitative complement to the other data collection methods.

The questionnaire was distributed to all shop floor operators, including both final assembly and inspection, that were present during two consecutive days within the production units of microwave and digital when the questionnaire was administered. Out of 18 operators present a total of 13 answered questionnaires could be collected. The questionnaire was handed out to operators in paper while they were working in order to encourage and simplify participation. All participants were ensured of complete anonymity of their answers and informed about the purpose of this study. The questionnaire was composed in swedish language as the main language of all operators was swedish. Two question categories were used, *rating scales* and *open-end questions*, to both obtain quantitative and qualitative data, both of these question types aimed towards obtaining subjective data regarding operators opinions [28]. The rating scale was composed of 5 levels (1-5) following the principle of "strongly disagree" to "strongly agree" as well as different statements at the extremes. Operators were encouraged to skip any questions which they did not want to answer or deemed irrelevant.

The content of the questionnaire was divided into six different sections with 32 questions in total excluding the initial demographic data where 26 questions were assigned rating scales and 6 questions were open-end. The first section *work environment* contained questions relating to perceived complexity of the product, stress levels and required learning curve to understand how the work environment influences operators. The second section *work instruction* aimed towards understanding how well the operators are supported in their daily tasks by their work instructions with questions regarding the perceived ease of use to perform operations, satisfaction level with instructions and the need for complementary information.

The third section *work station layout* aimed to understand how operators are working at their stations and to assess individual preferences with questions regarding listening to music, use of tools and work station. The fourth section *information system* aimed towards understanding how well operators are supported by the implemented information system and their perception about the quantity of information carriers by asking questions about the perceived ease of use of the system and interaction with quality documents. The fifth section *future outlook* aimed to assess operators opinions on change of work instructions and work station layout in the future by asking about their level of influence of change while also gaining input from operators regarding desired information support.

3.2.4 Document review

A document review for a selection of documents used by operators were performed. In total 9 different assembly procedures for three different products, as seen in figure 3.2, that are representative for the production environment were selected, combined with all the referenced documentation within these documents such as quality and project documents. The products *S1 TCU Top Assy* and *KRX1 Top Assy* were established to be representative for manual assembly in a previous master thesis [8], while the product *SCOUT PCU Assy* was reported to be a representative for future production by the company supervisor of this thesis.

The information content was assessed by evaluating the visual representation in terms of assembly pictures, the observed clarity of the information and the interlinking of information between the documents. This was performed by reviewing each of the assembly procedures and understanding how the information presentation is meant to support the operator within a selection of the final assembly operations. The reference of information was then followed to the appended documents to understand how the different sources contribute to the information requirement of the operator. This review resulted in an understanding of the general structure of the appended documents and the purpose of their linkage. Furthermore, the information presentation for the product *SCOUT PCU Assy* within the case company information system was observed. This involved the investigation of how documents are linked to operations accompanied by the presentation of the materials used within the assembly. This provided an understanding of the amount of functionality for presenting information in the case company information system that is used.

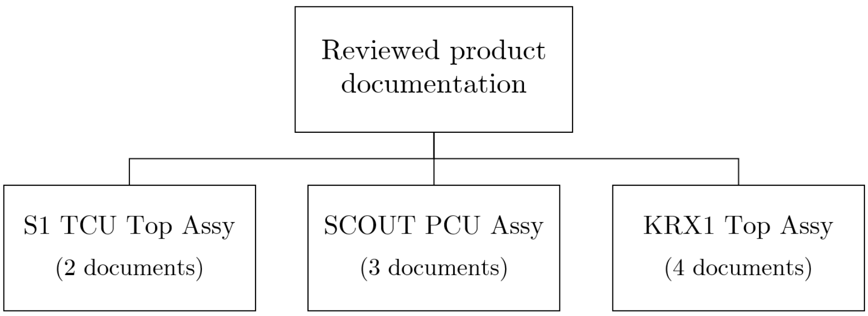


Figure 3.2: The product documentation reviewed during the document review.

3.3 Operation selection

A fitting operation to be used to apply the found theoretical information presentation principles needed to be selected. This selection was initiated by establishing a set of criteria that must be met in order to ensure that the creation of the instruction concepts is practically feasible and that the resulting findings are applicable for other operations within the production. A total of three criteria was used during the selection process as listed below.

1. **Relevancy**
   The criteria of relevancy evaluates if the chosen sequence of tasks are representative of the type of tasks generally performed within the production. It was of great importance that this criteria was met since the purpose was to develop fundamental principles for alternative ways of presenting information rather than a specialized approach fitting a rarely performed operation.

2. **Feasibility**
   The feasibility criteria aimed to evaluate whether it was practically feasible to improve the information presentation for the operation and product. This was determined by evaluating if the operation was meaningful to improve and whether the operation was fitting for validation purposes. This also included the practical prerequisites such as material availability and possibility to perform the operations during potential testing.

3. **Complexity**
   The complexity criteria evaluated whether the chosen operation required a significant level of expertise that would require vast knowledge about the process to understand. It was important to ensure that all dimensions of the task could be learned so that accurate instructional material could be created.

A product with the potential to satisfy the relevancy criteria could be identified in collaboration with the case company. The product belonged to a previously completed project that would return to the production in a foreseeable future, while sharing similarities with several other products of the same product type. It was determined to adapt the operation structure by merging several shorter operations and thereby creating a more diverse operation to better meet the feasibility criteria. The chosen operations could all be categorized as mechanical assembly which fitted the complexity requirements well.

The mechanical assembly consisted of a total of 6 different parts as illustrated in figure 3.3. First, the circuit boards marked A and B had to be carefully aligned on top of each other so that the two contacts on the underside could be connected by applying manual force to the boards. This is followed by fastening the boards together with 36 small screws along with accompanying cup springs, marked C and D respectively. Finally, two labels marked E and F in figure 3.3 are applied to the product and fixture.

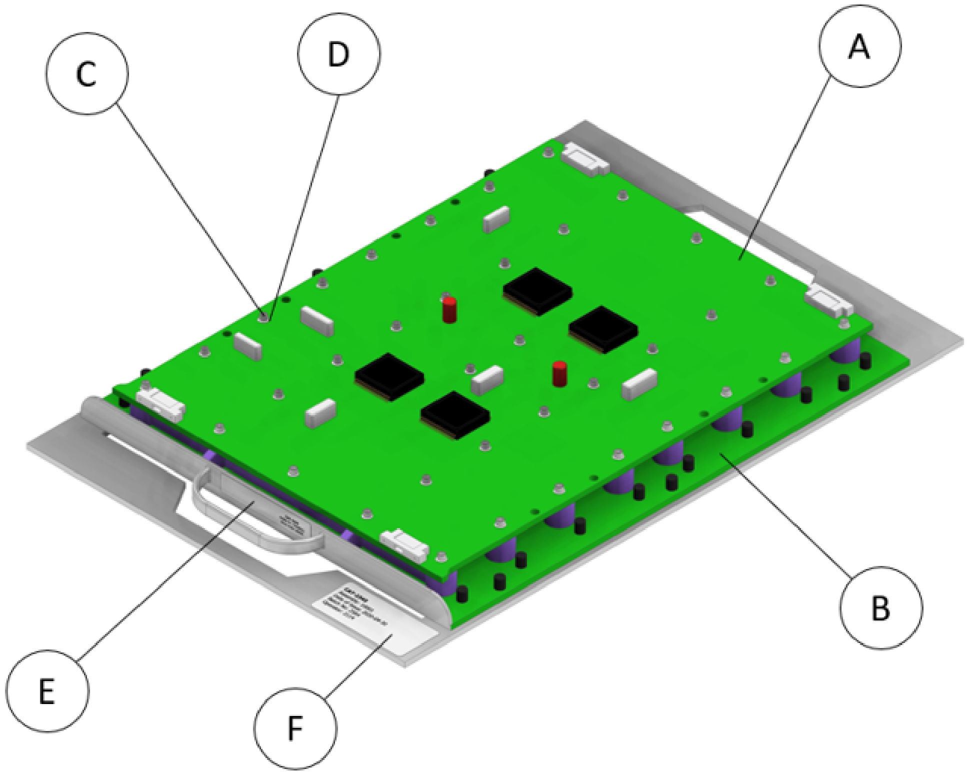


Figure 3.3: A rendered representation of the selected product to be examined.

3.4 Instruction design

The DFIP (Design principles For Information Presesentation) methodology that originated from the work by Söderberg et al. [26] and then later was developed and set into context by Mattsson et al. [5] was chosen during the work instruction development phase by adapting and applying useful principles to develop a work instruction layout for the selected operation. The method has been evaluated and expanded upon several times and now consists of the second iteration DFIP II [29], [15]. DFIP II is conducted through the use of six consecutive steps where each step seeks to evaluate a new dimension of the operation, workplace and operator needs. The output generates a new conceptual work instruction for the operation that facilitates all the determined factors with the aim to reduce assembly complexity. The method creators stress that each used step should be closely evaluated in cooperation with operators in the workplace. In this thesis the feedback that had been retrieved in the initial data gathering was combined with the results from a previously conducted CXI-analysis [30] and used as a substitute for direct operator input. This led towards every step being interpreted and redefined to be applicable with the limited amount of data input provided. Below all the steps in the DFIP methodology stated, conveying the performed actions.

Step 1

The first step of DFIP *"choose a work task in the workplace"* aims to divide the operation into smaller subtasks using the widespread human factor method Hierarchical Task Analysis [5]. The method is used to gain detailed insights into different operations by breaking down the operation and condensing the information required to perform each task [28]. The hierarchical task tree developed in this thesis can be defined as a simplified version of an HTA following the main principles. All the information in terms of quality documents, assembly procedures and procedural documents that is required for performing the selected operation was collected. The necessary parts specific for this mechanical assembly was then extracted. It was decided that all the tasks should be grouped under five main subtasks, as seen in figure 3.4, that are required to complete the operation. These main subtasks were then further divided into smaller tasks as can be seen in appendix C.

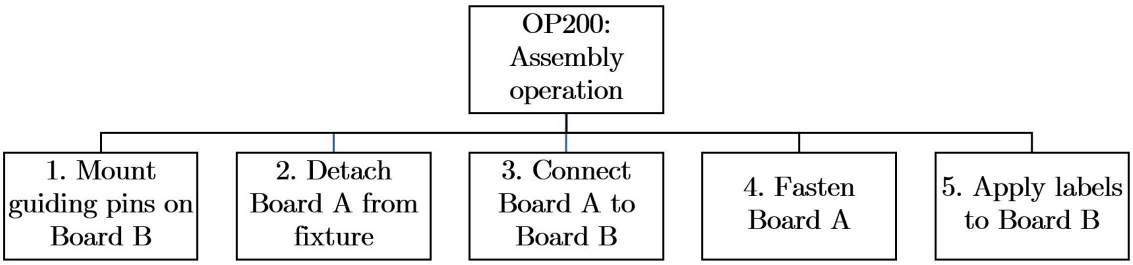


Figure 3.4: The division of tasks for the selected operation.

Step 2

The second step of DFIP *"identify and support active cognitive processes in each subtask"* aims to classify and support the cognitive processes that occur in the operation [5]. This step was used to determine the information that an operator requires to perform an operation by assessing each subtask as either containing intuitive level 1, intuitive level 2 or resonating cognitive processes [16], [17]. The classification of tasks can be seen in the HTA in appendix C. Based on this classification necessary trigger types such as signals and symbols initiating the correct cognitive process of the subtask were evaluated [16] and then established as can be seen in table 3.1. The required information content was then assessed based on the level of intuition as higher levels require more details and alternative trigger types.

Table 3.1: An extract of the triggers and required information for two subtasks.

Subtask	**Intuitive level 2**	**Intuitive level 1**
	2.4.3 Identify fastener position	**2.4.5 Fasten screw**
Trigger	Marked screw position on drawing	Signal to fasten screw
Required information	- Screw position on assembly - Order of insertion	- Required tool - Orientation of parts

Step 3

The third step of DFIP *"analyse tasks based on how the operator perceives the work environment"* aims to investigate problems, general opinions and production-related factors within the work environment that influence work instructions [5]. Therefore, operator feedback gathered regarding these issues and identified reasons for these statements was used to derive factors and properties that should be considered within the improvement of the work instructions. The statements were grouped into three categories namely *work environment, information quality* and *information content*, as seen in table 3.2. Step 3 provided the instruction creation process with the view of the information receiver which directed the development towards solving identified issues imposed by the production environment and current instructions.

Table 3.2: An extract of feedback and factors that influence work instructions.

Category	**Feedback**	**Factors to consider**
Work environment	Operators believe that it takes novices a long time to learn their tasks.	Instructions should be simple and comprehensive to ensure a novice operator quickly can perform non-complicated tasks.
Information quality	Information is not timely and located where needed.	Information should be provided to the operator in a timely manner while also being accessible and easy to find.
Instruction content	Operators believe that more visual information would be beneficial.	Instructions should be based on visual information where possible and complemented with text where needed.

Step 4

The fourth step of DFIP *"analyse tasks depending on cognitive limitations"* aims to investigate which mental limitations are present within a task and how they can be supported [5]. The required information for each subtask provided from step 2 was transformed and described as mental limitations within all the four cognitive process domains *perception, memory, attention and mental model.* A selection of these cognitive processes may need to be supported in different situations depending on the characteristic of the task being performed.

Perception has to be supported in situations when the operator must distinguish between similar objects, required information in illustrations has to be identified or when information from illustrations must be converted to reality.

Memory has to be supported when the operator needs to store temporary information in the working memory like for example remembering article numbers following the rule of 7 and when mental models about how to use things are stored in the long-term memory. *Attention* has to be supported when the operator experiences the risk of loosing focus during a task which can be triggered through performing monotonous work, inducing boredom such as fastening a large amount of screws or if information is received from a set of different sources dividing the attention. *Mental models* have to be supported when an operator needs to identify objects based on the instruction description such as choosing the correct tool and to ensure that the correct mental model is triggered performing the correct behavior.

For each of the identified cognitive limitations, ideas for supporting them were evaluated creating more concrete principles of how the information should be conveyed using visuals or text. An extract from this process can be seen in table 3.3. Step 4 thereby provided the instruction creation process with the insight about influences on the cognitive workload in each subtask and how these can be reduced through support.

Table 3.3: An extract of the cognitive limitations and support analysis.

Subtask	**Cognitive limitations to support**		**Suggested support**
2.4.3 Identify fastener positions	Perception	Identify fastener positions on the assembly.	Visual highlighting of fastener positions on the assembly.
	Memory	Short-term memory used by the positions of the fasteners.	Visual representation of the fastener positions on the assembly.
	Attention	Keeping track of the amount of inserted fasteners.	Visual confirmation of the amount of fasteners inserted.
	Mental model	Order of insertion of the fasteners into the assembly.	Visual reminder regarding the order of insertion.

Step 5

The fifth step of DFIP *"analyse tasks depending on individual differences and needs"* aims to assess and understand the individual differences between operators in the workforce that may influence the way information should be presented to an operator [5]. The operator responses were divided into physical and psychological differences to consider where physical factors include vision and hearing, while psychological factors include differences such as the desire to listen to music exemplified in table 3.4. Step 5 thereby provided the instruction creation process with factors to consider that might improve the workflow of an operator.

Table 3.4: An extract of physical and psychological differences.

Differences		Implications for instructions
Physical	Operators with degraded vision must comfortably see all information.	The instructions should support the change of text and image size.
Physiological	Operators prefer to listen to music while working.	Instructions cannot rely on using audio transmitted information.

Step 6

The sixth step of DFIP *"analyse tasks depending on placement of information content and carrier"* aims to assess how information should be presented to operators to capture attention and convey the procedure in a clear manner [5]. The findings from all previous steps were summarized in this step were the work instruction concept was created. Initially all required elements were determined that the work instruction and conveying system needs to feature such as *tools, material, assembly illustration, task information, home/overview button, report issue button, operation timeline* and *navigation buttons*. These were then placed as areas on a mockup of a computer screen to determine a conceptual layout as can be seen in figure 3.5. It was determined that there are five main information carrying elements namely *tools*, *material*, *guidelines*, *model* and *drawing* that operators need in their work. The final step of the DFIP method provided the instruction creation process with the first conceptual information presentation including layout and instruction elements which then were used as a basis for further development.

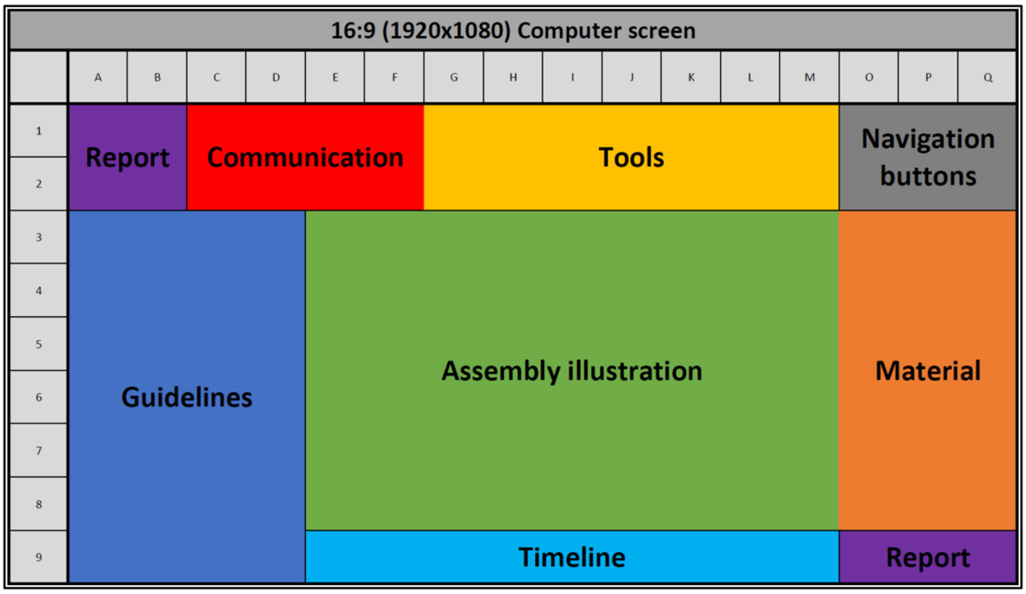


Figure 3.5: The conceptual layout resulting from step 6.

3.5 Prototype

Prototypes are fundamental in any design process and have several areas of use [31]. The prototyping process aimed to realize the theoretical principles resulting from the previously conducted DFIP method by designing graphical interfaces and developing the visual instruction content for the selected operation. This resulted in two functional prototypes for presenting information with the purpose to act as a foundation for evaluation and further development of the concepts they represent.

3.5.1 Development process

The development process commenced with the realization of the future concept described in section 4.2.2 as this concept was aimed to be implemented according to the results from the DFIP method regardless of technical barriers posed by the information system utilized at the case company. The prototyping process was iterative in its nature meaning that several different prototypes were created in the effort of reaching the final version of the concept. The development process was initiated by building upon the concept resulting from the DFIP method, referred to as *Prototype A*. Prototyping was performed with the use of the program Microsoft PowerPoint due to the possibility of intuitive and unrestricted visualization while also containing the advanced features necessary to create an interactive prototype of the generated concept. As the prototyping process for the future concept was completed and the final *Prototype C* had been created, the concept had gone through two main iterations of development from the initial concept resulting from the DFIP method, as seen in figure 3.6.

The final prototype, *Prototype C*, was then adapted to be implementable within the information system employed at the case company. This was performed by evaluating the functionality capabilities of the information system and adapting the information material applied accordingly in an iterative process similar to the development process of the future concept. This resulted in the adapted concept described in section 4.2.3.

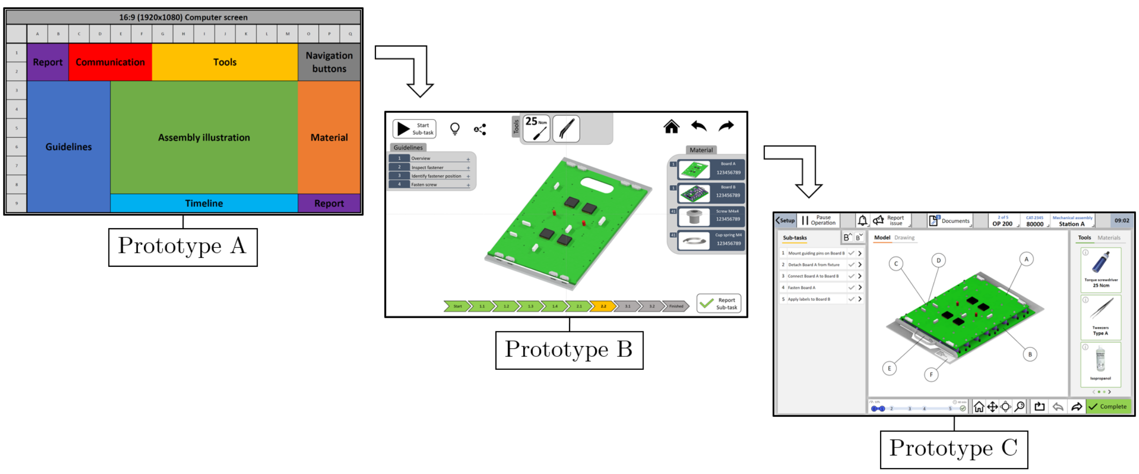


Figure 3.6: The three prototypes developed during the course of the thesis.

3.5.2 Instruction content creation

In order to create the instruction content an adaptation of the real product as can be seen in figure 3.3 was modelled using the CAD software Autodesk Inventor. The main instruction elements model and drawing view were developed using the presentation functionality[1] in Autodesk Inventor. Exploded views for parts to be assembled in every subtask were created, which were animated to create the model view as can be seen in figure 4.9. The drawing view as can be seen in figure 4.10 was created by using the drawing functionality where the positioning of the to be assembled part was highlighted using a thicker line of different color.

3.6 Evaluation

The input from a focus group is often used to gather impressions and insights to stimulate the development of new ideas and concepts, but also applied by designers to evaluate user requirements, information design or human computer interaction [32]. The advantage is the direct interaction with participants creating the possibility to follow-up on questions and exploring more interesting answers in detail [32]. Disadvantages include the risk for bias due to the group constellation, the presence of dominant members and the difficulty to replicate a real-life scenario [32].

The developed solution concepts were evaluated through the organization of a focus group. A total of eight participants, excluding the two moderating authors, took part in the focus group which is an adequate size to enable a wide spectrum of views while also being practically manageable [27]. This group composition consisted of three case company practitioners with practical experience in the preparation of instruction material as well as five researchers representing the research field of instructions. The purpose of diversifying the group composition by inviting both practitioners and researchers was to gain a nuanced evaluation of the two concepts from two fundamentally different perspectives. As the participants discussed the topics with each other and the two main perspectives met, an additional perspective on the discussed matter was formed through the interaction between the participants.

The focus group elapsed over a duration of 2.5 hours and was conducted digitally through screen-sharing via a digital platform. Both of the developed concepts were presented to the participants followed by two administered evaluation questionnaires along with separate discussions for each of the two concepts. The questionnaires and discussions aimed to evaluate the solutions based on four determined information quality criteria adapted from Kehoe et al. [21]. The collection of criteria deemed as relevant were *format, accessibility, timeliness and comprehensiveness*. Each concept evaluation was initiated with a discussion based on the prior presentation which then was followed by a concluding questionnaire. The administered questionnaires, seen in appendix B, evaluated the four criteria based on eight 1-5 rating scale questions which were identical for both concepts to enable accurate comparisons of results.

[1] `https://knowledge.autodesk.com/search-result/caas/simplecontent/content/inventor-presentation-tutorial-exploded-views.html`

4
Results

This chapter presents the obtained results from the initial state information presentation assessment, concept development and subsequent concept evaluation.

4.1 Initial State information presentation

The results acquired during the analysis of the information presentation currently in operation at the case company are divided into two key areas of interest. The *information resources* section describes the information material presented to the operator, followed by the *information handling* section that provides insights into the usage and effectiveness of the information material within the production.

4.1.1 Information resources

The information system of the case company acts as a centerpiece of providing information to operators. Information about work tasks are received through it, finished operations reported and errors that have occurred are communicated through a set of error protocols within the system. Information to operators about their work tasks is provided through a set of different information carriers as displayed in figure 4.1. All operations to occur within an order and the associated material of an order is presented directly within the information system, however most of the necessary information to perform the task has to be accessed through external documents linked within the information system. As seen in figure 4.1, these documents generally come in three different types: quality documents, assembly procedures, and other documents as described below.

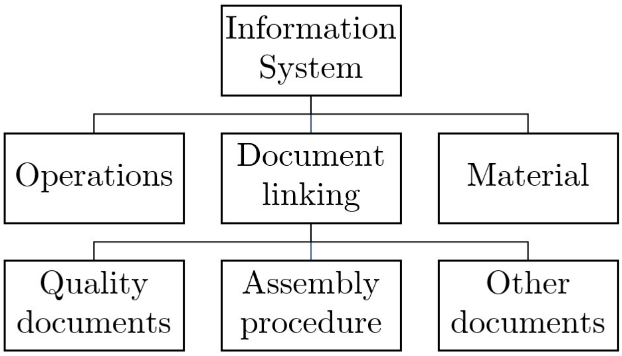


Figure 4.1: A simplified illustration of the information presentation hierarchy.

Quality documents

The quality documents are an internal adaptation from ESA (European Space Agency) guided quality standards[1]. As most customers in the space industry require compliance to these standards they determine requirements for the business according to the case company. The adapted internal version conveys detailed information about how compliance to these standards can be obtained. These documents may consist of information such as allowed tools to be used in assembly, assembly tolerances, material handling and certain assembly procedures. The documents are not specific to any operation but instead aim towards being standardized reference documents containing knowledge required to perform several operations within a specific subject. As evident by the findings from the document review the quality documents contains vast amounts of information on a plethora of areas within the subject of the document resulting in extensive documents spanning between ten and one hundred pages.

Assembly procedure

The assembly procedure contains all the details of an operation with step-by-step work instructions attached to them. This document also contains hyperlinks to other referred documents such as the quality documents, process documents and project-specific documents that have to be accounted for while carrying out the task. The hyperlinks are provided specific for each operation so that the operator knows which documents are needed for a certain operation. However, references to the location of the required information within a linked document is commonly not provided which complicates the apprehension as only small passages within the document may be relevant for the task being performed. As indicated by the document review the instructions within the operations of the assembly procedure are largely text-based in the forms of short procedural descriptions of the tasks. These descriptions reference part names, part numbers, and component positions on the accompanying drawing along with key metrics such as mounting torque. On a limited selection of the operations these descriptions are accompanied by visual support in the forms of either real photos of the component and product, highlighted drawings, or computer-rendered images of the digital model of the product.

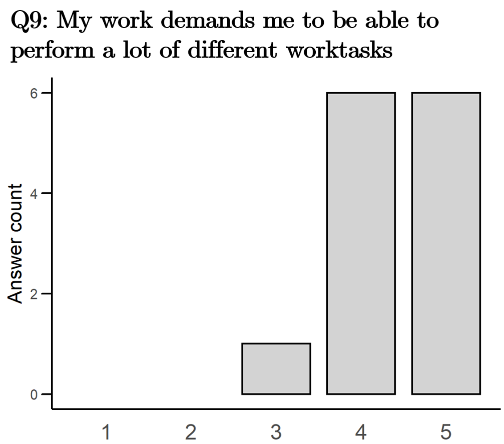
Other documents

The process documents, project-specific documents and drawings contain secondary information about the assembly. The process documents generally convey information about how to setup and use certain types of equipment, such as for example a label printer, by presenting largely text-based guidelines. The project-specific documents transmit more detailed information about certain steps regarding the project, while the drawings specify the exact location of every component on the product by employing position numbers referenced in the assembly procedure. The usage of this document type depends on the supplementary information needs beyond the coverage of the two other document types.

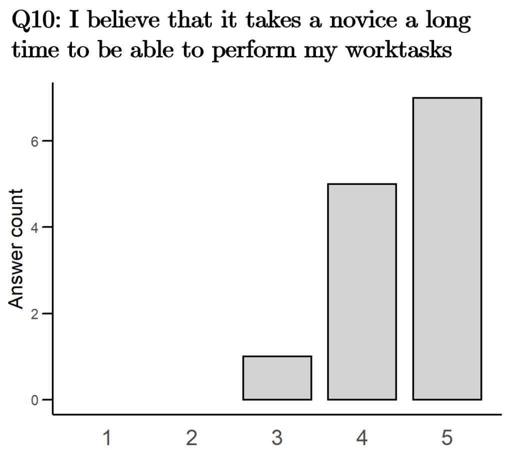
[1] `https://ecss.nl/standards/active-standards/`

4.1.2 Information handling

In the questionnaire a majority of operators stated, as can be seen in figure 4.2a, that they perceive their work to be complex as it requires them to perform a variety of different work tasks. The presence of many work tasks does according to the literature not automatically result in the work being overly mentally demanding, even though it can act as a source of complexity [14]. It has been described that the existence of multiple different product variants can create attentional and perceptional struggle for an operator affecting both working and long-term memory [10], [15]. Figure 4.2b shows that operators believe that it takes new operators a long time to acquire the required knowledge for performing their work tasks, which supports the statement that the performed work is complex. The presence of more complex work therefore may also require the presence of more information support [14]. While analyzing the questionnaire responses it became evident that operators believe that the perceived complexity could be lowered through improved information presentation where relevant information would be presented directly to them without having to search for it.



(a) Mean: 4.4, Median: 4



(b) Mean: 4.5, Median: 5

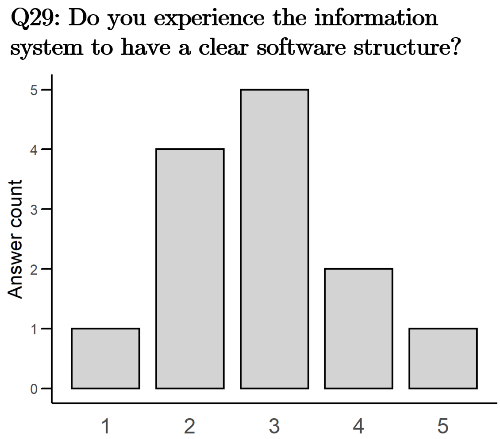
Figure 4.2: Questionnaire input for perceived work complexity

Before a new product is introduced into production it was mentioned that an operator representative often is involved in the process of preparing documentation for production in cooperation with instruction preparers. The active participation in the creation process can contribute to reduced stress levels for operators [22], [15]. The documentation is then improved through an iterative process sending documents back and forth between operators and instruction preparers. This process aims towards increasing the intrinsic information quality domain of the documentation. It was described that this communication mainly is conducted before a project starts, after a project is running an operator mentioned that it is more complicated to get documentation changed. According to an operator this has led to a scenario where improvement suggestions are not mentioned that often as operators have experienced the feeling that they will not get implemented. Negative feelings towards involvement have the potential to impact both operator performance and trust towards the organization [15], [18]. The idea of implementing a more direct communication protocol between instruction preparers and operators was brought up as a solution to this problem by an operator. It was described that this measure could improve the communication and increase trust significantly as the report of information quality issues only should be “one pressed button away”. Another issue regarding instruction creation that was mentioned by an operator is that documentation often is reused without implementing updates when the same product reoccurs in production meaning that previous detected defects can remain within.

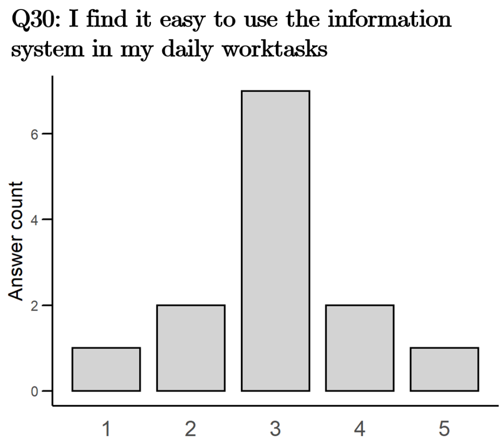
A wide range of opinions regarding the case company information system can be identified among the operators as indicated in figure 4.3a and 4.3b. The majority of operators find it neither easy nor difficult to use the system in their daily work tasks and it was pointed out by an operator that it can be troublesome to use. It has been amplified that the document handling with many information sources can be quite tiresome as indicted in figure 4.4b. All the required information for performing a task sometimes is not provided directly to an operator, but has to be acquired through searching the documentation as indicated in figure 4.5b which can lead towards triggering a misleading mental model [10]. Also, as can be seen in figure 4.5a, operators state that they on a regular base need to ask for more documentation to complete their work tasks which indicates that the provided documentation sometimes is deficient [20].

The document review revealed the presence of representational problems within the analyzed documents in the extrinsic information quality domain as it became evident that documents of the same kind do not always follow the same structure [20]. A production engineer stated that over the past years a philosophy has emerged that information often only is added to documents, but seldom taken away resulting in the presence of irrelevant and ambiguous elements within the instructions [20]. Furthermore, another mindset was stated that rather too much information is presented than too little leaving the operator with an information overload combined with the decision to assess which information is relevant [20], [14]. The existence of several information layers contributes to operators frequently asking each other how to perform a task instead of conducting the provided documentation. This can be considered as a result of perceiving it to be time-consuming to handle the amount of required documents as indicated by a slight majority of operators in figure 4.4a.

A production engineer mentioned that in a small amount of cases required information of for example certain tool setups can be inaccessible for an operator which demands trial-and-error procedures to be performed [16]. As a result of having deficient and ambiguous information within the documentation it was mentioned that more attention than required with the current information presentation can be devoted towards understanding what and how to do a task more than actually doing it. This can require the activation of mainly knowledge-based behavior where operators have to combine previous experience to actively find a solution [11],[16]. The presence of such task dimensions can in the long run lead to a risk of an increase in observed mistakes [10].

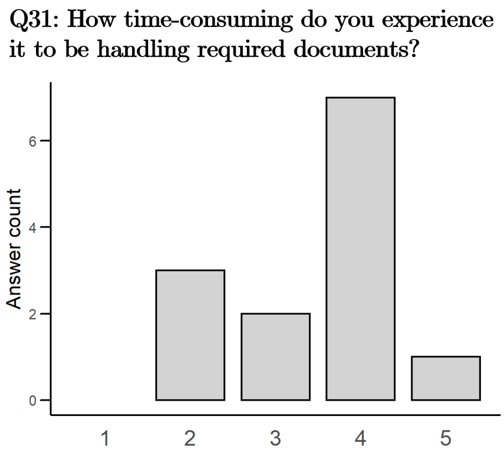


(a) Mean: 2.8, Median: 3

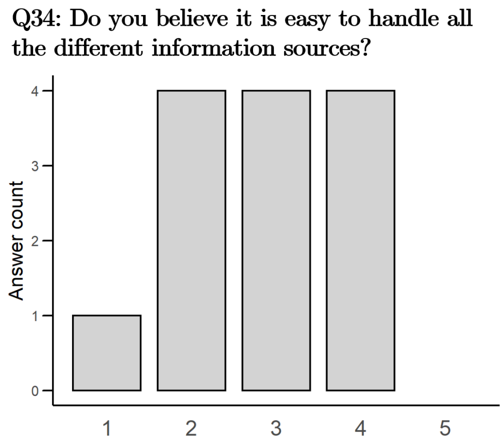


(b) Mean: 3, Median: 3

Figure 4.3: Questionnaire input for information system perception.

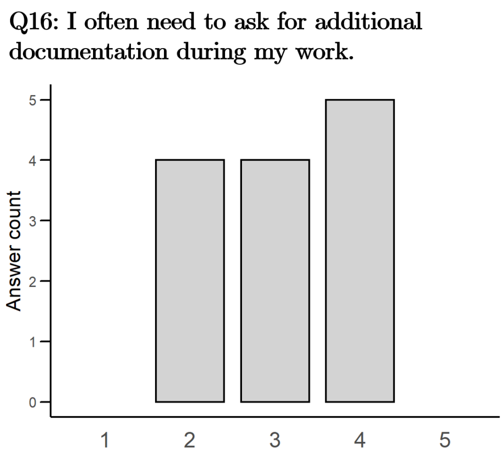


(a) Mean: 3.5, Median: 4

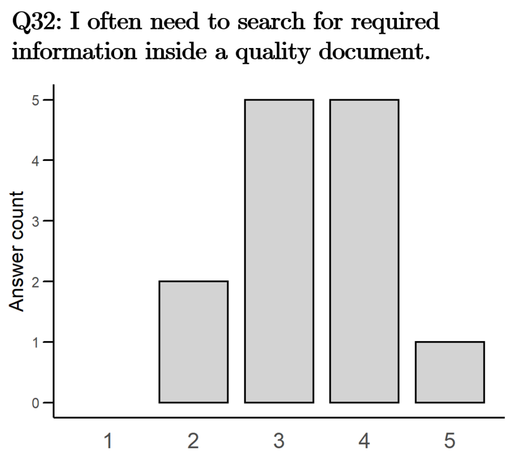


(b) Mean: 2.8, Median: 3

Figure 4.4: Questionnaire input for document handling and information sources.



(a) Mean: 3.1, Median: 3



(b) Mean: 3.4, Median: 3

Figure 4.5: Questionnaire input for accessibility issues.

During the observations some operators expressed that they appreciate the current structure of the assembly procedure as it features a complete overview over all the operations that a product is required to undergo gathered in a single document. It was also expressed that pictures in combination with instructional text supports operators well during assembly of a product, especially in comparison to a past scenario where only text-based instructions were provided. However, some operators mentioned when asked about improvement suggestions that they would appreciate the inclusion of more pictures or other types of media such as animations or 3D CAD models in their instructions. They emphasized that pictures contribute towards making it easier to understand their work tasks which can lead to a reduction in perceived cognitive workload [13]. An operator brought up that the amount of pictures in the instructions has decreased recently and figured that this could be a result of the occurrence of images containing incorrect assembly information.

There have been issued attempts in the past within the case company to change the information presentation by integrating the separate assembly procedures into the case company information system. These have, as an operator stated, not been received well among the operators as the common perception is that linking between pictures and guidelines does not work very well providing an insufficient operation overview. The operator described a scenario where they refused to work with the changed instruction. The refusal of these instructions therefore can be described by operators neither experiencing perceived usefulness nor perceived ease of use of them [19]. The operators were not involved in that improvement process which can act as an explanation to some of their doubts towards the suggested instruction [22], [15].

4.2 Instruction design

Two different information presentation concepts have been developed into prototypes fit for evaluation, the future concept and the adapted concept. The future concept was created without adhering to the boundaries of the current information system with the purpose of evaluating how information may be presented in a more distant future. Conversely, the adapted concept aimed to implement the principles within the boundaries of the case company information system in order to investigate how a concept with higher short-term feasibility compares to a more technically immature concept requiring investments into new software and system integration.

4.2.1 Instruction elements

The created instructions for both prototypes consist of five main elements to convey information in the forms of *material*, *tools*, *guidelines*, *model view* and *drawing view*. It was determined that the relay of information through these elements mainly should be conducted through the utilization of 3D models accompanied by pictures and complementing text. The instruction content within the concepts is predominantly the same, with the exception of minor adaptions made to better fit the format of the concept in which they are being used.

Material

The information about a material that an operator needs to get presented was decided to be an image, the material name, article number and material quantity as can be seen in figure 4.6. The image shows what the material looks like so that the operator easily can identify the real component on the work bench. The name and article number is required as it conveys information about the specific component and makes it unique in regard to other components especially if components look alike so that exclusively top-down processed data is avoided, as stated by the 6th principle by Osvalder et al. [22]. The quantity is also specified so that the operator knows how many units of this part need to be added to the assembly. The format of the material element has deliberately been diversified from the tool element to avoid confusion caused by similarities of objects [22].

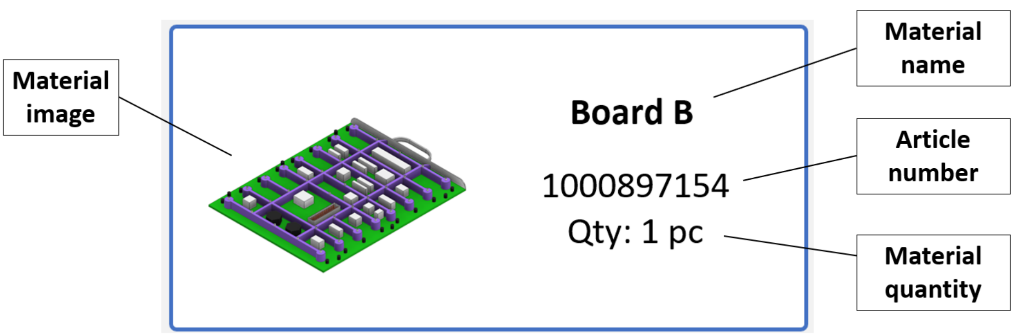


Figure 4.6: An example of a material representation and its main constituents.

Tools

It was determined that the required information of a tool should consist of an image combined with the tool name and the distinct tool variant as shown in figure 4.7. As tools are typically used more often by operators an image presenting the real tool was deemed to be effective in triggering the correct mental model [22]. The tool name specifies the tool to use which in this example is a group of tools *Torque screwdriver*, which is then further specified with the distinct tool variant *1.1 Nm* which is the exact tool in order to avoid information exclusively based on the mental model of the operator in the event of similar tools [22]. Furthermore, the tool description was complemented with an option to find additional information, such as tool id and location, about the described tool as a means of increasing the comprehensiveness of the instruction element.

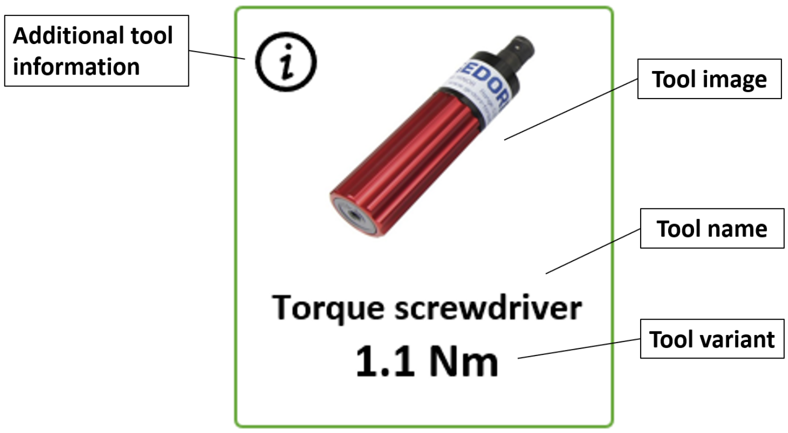


Figure 4.7: An example of a tool representation and its main constituents.

Guidelines

It was determined that text-based guidelines should accompany the visual information since they will decrease the risk for misinterpretation while acting as a complementary medium for conveying information difficult to visualize [22], [26]. The setting of short but descriptive headers was concluded to be important as good descriptions provide experienced operators with the opportunity to solely focus on the headers [23]. In figure 4.8 guideline steps for subtask 2 of the chosen operation are presented. An effective approach of developing the guideline text was ruled to be starting with a verb conveying what to do, then to specify the position where something should be done to be concluded with a tool explaining how the task should be executed. It was decided to use clear highlighting with bold text to separate both material and tools from the other text so that operators easily can identify the tools and materials to be used in the subtask [23].

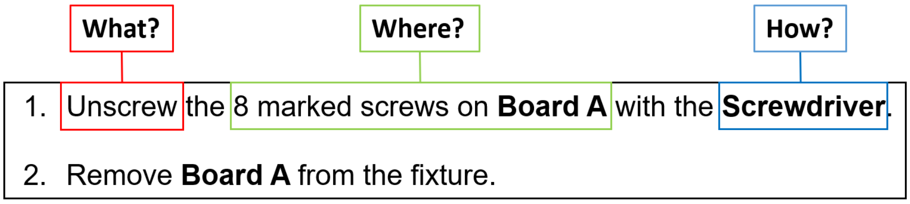


Figure 4.8: An example of the guidelines creation for subtask 2.

Model view

In the model view a 3D representation of the part is shown where relevant parts in this assembly step are moved into position as can be seen in figure 4.9. It was determined that showing the created model using a realistic and isometric design approach makes it easier to interconnect between the shown image on a screen and the real product in front of an operator during assembly as the same view angle looking obliquely from above is deployed. The purpose of this view is to provide information in a format that represents reality as closely as possible to aid comprehension of the information, in accordance with the 12th principle discussed by Osvalder et al. [22]. Furthermore, it was decided that lines should be used to convey information about the positioning of a to-be assembled component as it clearly conveys both the orientation and the direction of a component. The orientation of the view remains in the same physically realizable setting across the complete operation to avoid confusion [25].

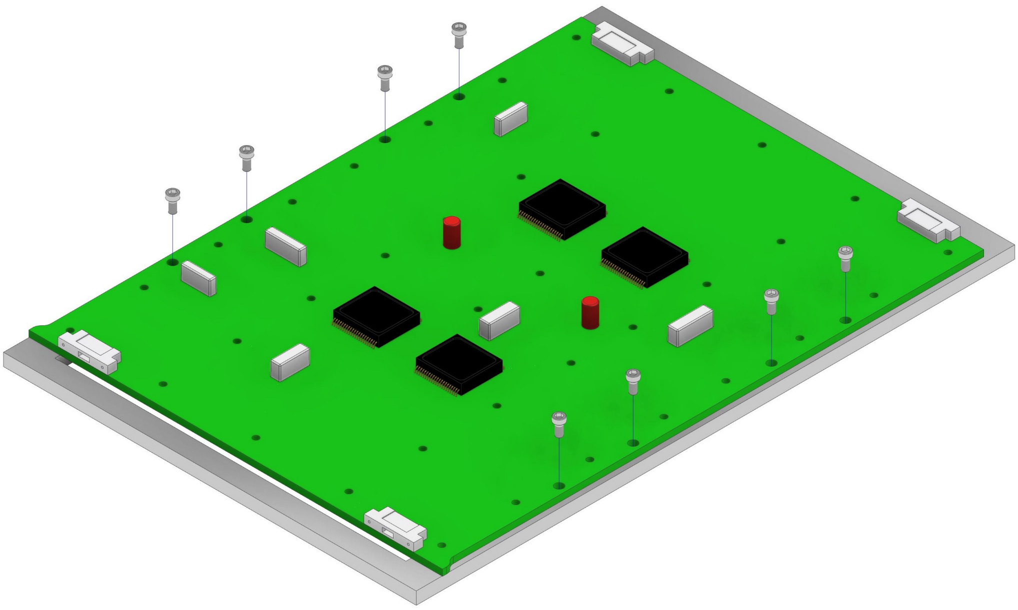


Figure 4.9: An example of the model view for subtask 2.

Drawing view

In the drawing view a 2D representation of the part is shown where relevant features are clearly highlighted as can be seen in figure 4.10. The created drawings use clear contrasts with a black and white representation of the part so that elements easily can be detected. Important parts such as the screws that shall be removed in this task are highlighted to aid the perception of the operator [11]. The highlighted features have a greater line thickness than other parts in the drawing. A realistic view is provided as a cutout presenting information about what the highlighted component looks like to provide an intuitive view that connects the positions of the drawing to reality and thereby aiding the receivers mental model [22]. The purpose of the drawing view is to provide the operator with the positions of the components when the assembly process has been fully comprehended, experienced operators may only need to access this view as memory support if the process is known.

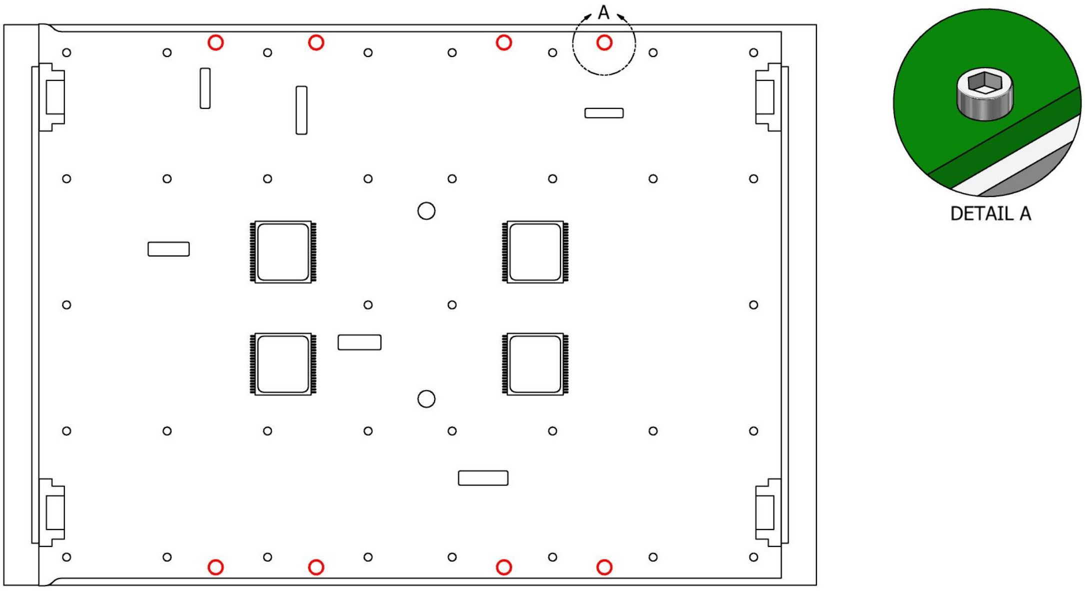


Figure 4.10: An example of the drawing view for subtask 2.

4.2.2 Future concept (FC)

The future concept is composed out of two main views that the operator will have access to during the operation, the setup view and the procedure view. Upon the start of the selected operation the setup view is presented to the operator with the purpose of providing all the information required to locate and prepare the tools and materials for the operation. The completion of the setup will transfer the operator to the procedure view where all the information required to perform the task is provided. The concept is fundamentally built around seven different modules that contain the required information along with the functionality to navigate the information system. A modular approach enables logical and consistent grouping of information leading towards less attention divided while localizing the information, especially for experienced operators [22], [23]. A snapshot of the setup view can be seen in figure 4.11 along with descriptions of its modules.

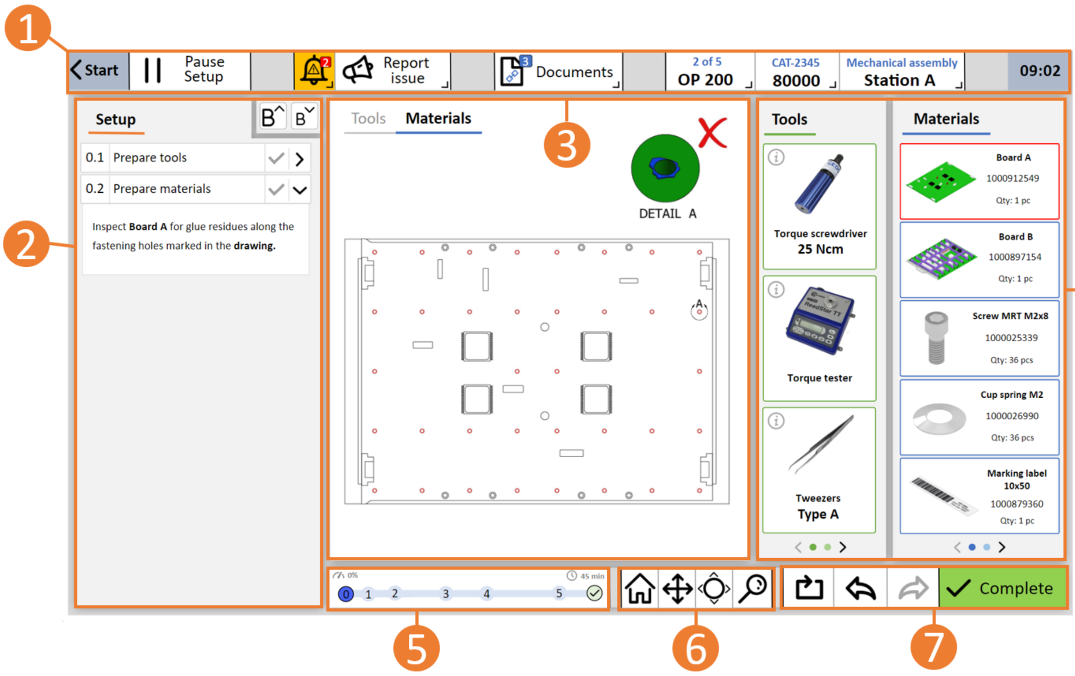


Figure 4.11: The setup view of the future concept along with its modules

1. **Overhead bar**

   The overhead bar contains functionality to navigate between different views as well as pause or resume the operation. Furthermore, the overhead bar provides references to complementary information available for the operation. The overhead bar along with the bottom collections of bars, marked 5-7, are formatted according to the principle of proximity by utilizing grouping to highlight their connection and thereby enable easier navigation [22]. Starting from the left, the view navigator along with the pause button can be found. Following these, a button with the purpose of informing the operator if any errors or important information have been reported by either an operator or instruction preparer along with a function to report a new issue can be found. This functionality enables fast and effortless communication between the operator and instruction preparer, potentially leading towards more comprehensive and accurate instructions.

   Furthermore, a menu containing all documents related to the order can be found. This menu provides the operator with references to all available documentation relevant to the operation. Following the document menu, a section with the purpose of providing information of prior and proceeding operations, the complete product and order as well as information about the workstation can be found. This section provides background information and the ability to gain an overview of the full process the operator will perform on the product. Finally in the right corner, a conventional clock is used to inform the operator of the time of day.

2. **Subtask module**

   The subtask module contains a tab for each of the subtasks that must be completed in either the setup or procedure stage of the operation. These tabs contain the subtask name along with a check mark used to report the subtask as completed. The tab of the current subtask can be expanded and contains exclusively the guidelines for the specific task being performed since only information relevant to the task at hand should be shown to minimize extraneous cognitive load [26]. Acting as a controller for the instruction system, the subtask module dictates the behavior and content of the other modules by a series of links to information in the "Graphics" and "Tools & materials" modules.

   The fundamental principle of the module is to provide the novice operator with detailed information and assistance while being able to act as a checklist environment for the more experienced operator who needs less information. Consequently, the experienced operator will be exposed to less repetitive information that more swiftly can be overviewed while also providing the novice operator with comprehensive information required in learning and performing the task [23]. Each operator is also provided with the option to change the text size in the top corner of the module according to individual needs and preferences.

3. **Graphics module**

   The graphics module contains all the graphical instruction material that is needed for the task. In the setup view the module is divided into two different sections linked to the tool and material setup subtasks in the guideline module. The module needs to be able to display both drawings and interactive models, where as many of added parts of the assembly as possible should be visible while also maximizing their visible features to improve recognition and thereby reduce the risk of assembly errors [24], [25]. Therefore, as this module provides the most integral information content it occupies a large portion of the screen in the center of attention.

4. **Tool & material module**

   The tool and material module contains all the tools and materials that are used within the operation so that the operator can ensure that required resources are available at the workstation. This view can display up to 3 tools and 5 materials at the same time on the screen, additional material is shown by advancing to the next page within the module. The grouping into the different module pages aims to aid perception and short-term memory by providing the information in more manageable chunks [11]. The material and tools in the module are highlighted by clickable links in the subtask module so that the operator quickly can identify referenced components and aids.

5. **Progress bar**

   The progress bar is used to present the operator with the current progress on the operation. The indicator is divided into each of the subtasks in the operation including setup and gives the operator an idea of the magnitude of the tasks at a glance. Approximate time until completion and percentual completed portion of the full operation is presented based on average data collected on previous reported completion times of the operation. Thus enabling the operator to be proactive and utilize the short-term memory on the task at hand instead of on the prediction of the future states of the operation, as supported by the 10^{th} principle presented by Osvalder et al. [22]. Furthermore, the progress bar provides an element of gamification in which the operator may feel more motivated by completing a subtask if it is clear that each step provides a tangible progression of the operation [5].

6. **Graphics navigation bar**

   The graphics navigation bar is used to control the interactive material shown in the graphics module. From the left, the bar contains a button that resets the material to its home state followed by two buttons used to drag and, for three-dimensional material, rotate the view along with an option to zoom the content. The underlying principle of this bar is to provide the operator with the option to interact with the instruction material and assimilate the required information in the way that is preferred since individuals have different information needs and process the information in different ways [5].

7. **Operation navigation bar**

   The operation navigation bar's function is to navigate the basic functionality of the operation from a single place. The bar offers the possibility to replay animated visuals as well as navigating between subtasks and report the current subtask as completed. The purpose of being able to navigate the core functionalities from the same place is to avoid re-directing the attention of the operator to finding the correct subtask and thereby improve the accessibility of the information presentation, in accordance with the proximity principle presented by Osvalder et al. [22].

The previously presented modules, containing the information content, are placed according to the principle of prioritized information along the diagonals. This means that the most integral information should be placed along the diagonal spanning from the top left to the bottom right, while less important information should be placed along the other diagonal in order to support perception [5]. The procedure view that the operator is shown upon the completion of the setup remains consistent with the previous view except for minor alterations in the modules to support previously learned behaviors of the system, as supported by the 11^{th} principle by Osvalder et al. [22].

Within the subtask module the setup tasks has been replaced by the tasks that must be performed during the procedure part of the operation. The graphics module has been adapted to provide a choice between the display of either the previously mentioned model or drawing view for the current task. Furthermore, the tools and material module has been collapsed to only show either the materials or tools at once in order to enable a larger portion of the screen to be used for the graphics module. However, only the tools and materials used within the current operation will be shown within the module in order to guide the operator to the exact tools needed for the task and the material that the task should utilize. A snapshot of the procedure view and its adapted modules can be seen in figure 4.12.

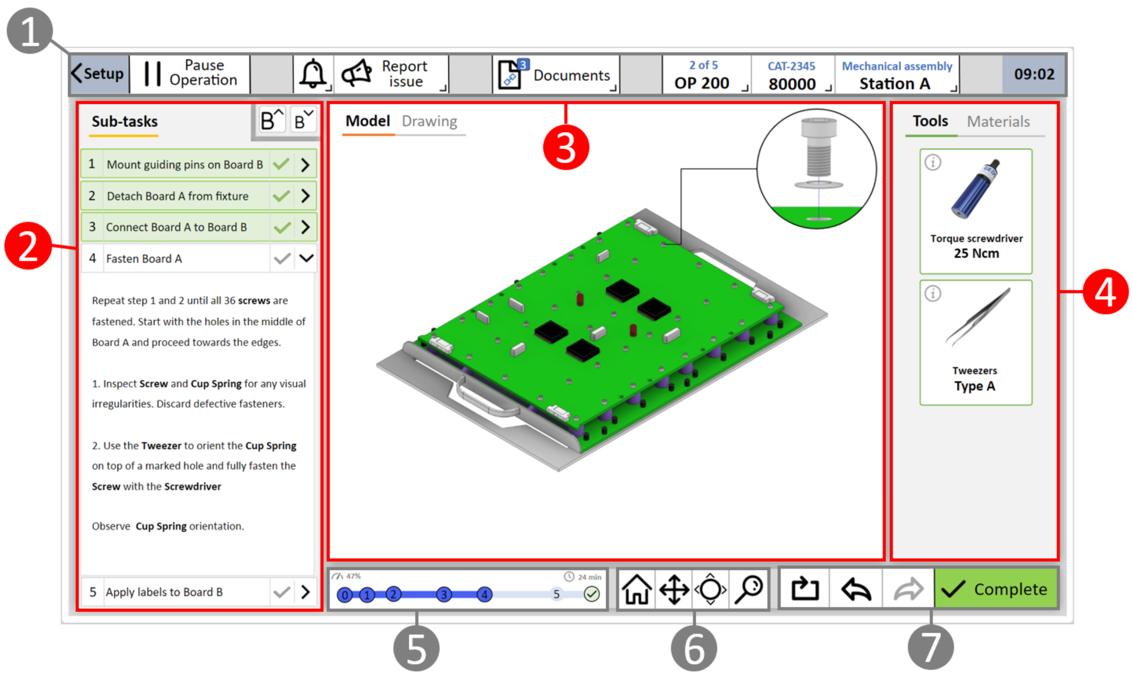


Figure 4.12: The procedure view of the future concept along with its modules.

4.2.3 Adapted concept (AC)

The resulting concept adapted to the case company information system contains a single workbench view from which all information on the operations to be performed on a product can be found. The view contains a plethora of functionality for different purposes where 6 different elements was deemed as plausible to be used to carry information to the operator. The interface of the workbench is customizable in terms of the portion of the screen each section consumes, meaning that if the size of one section increase another section must decrease in size. However, elements can not be reformatted, moved or deleted by the user which limits what may be achieved in terms of format and accessibility. A snapshot of the implemented concept within the case company information system can be seen in figure 4.13. Highlighted information elements are explained below.

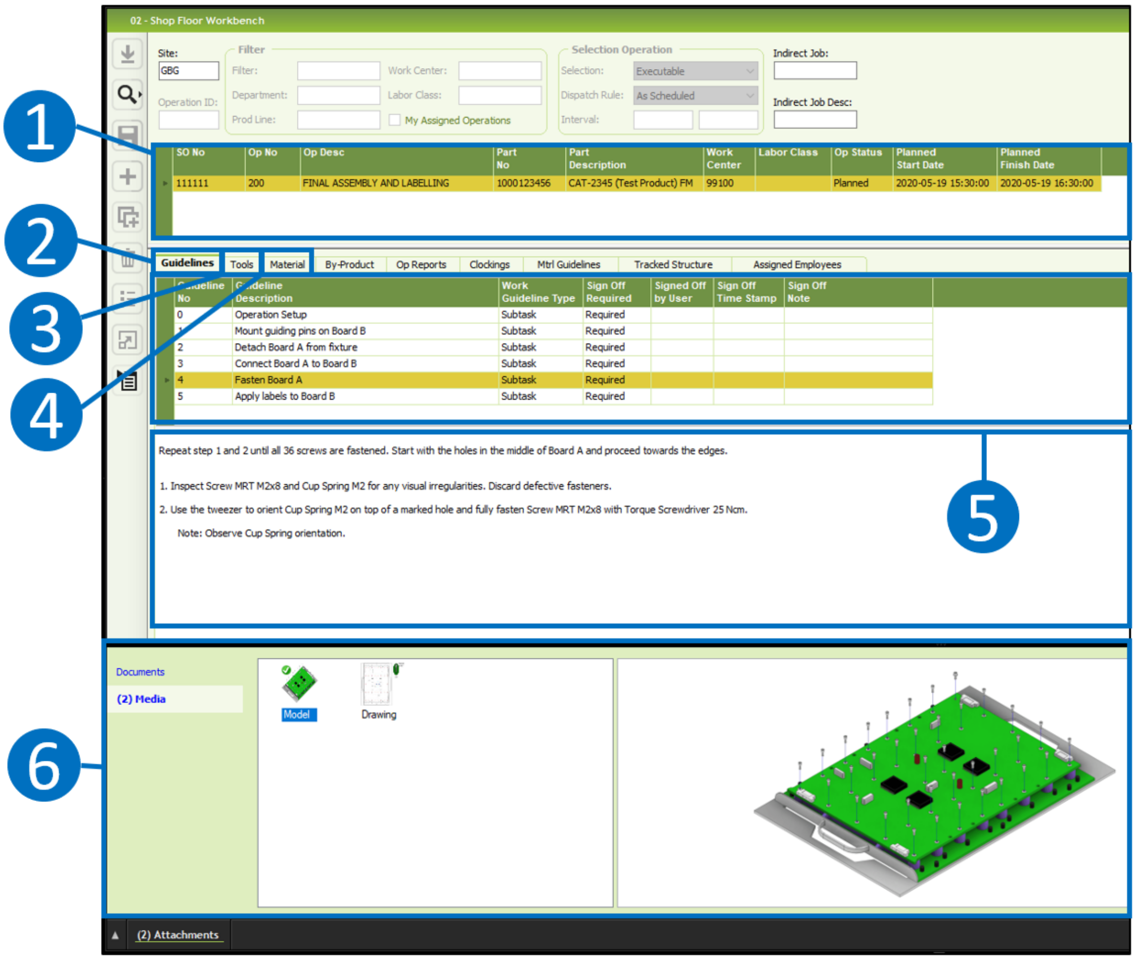


Figure 4.13: An overview of the adapted concept along with highlighted elements.

1. **Operation**

   This section is used to present all the operations that the product is undergoing. All subtasks along with tool and materials and their attachments lies under the operation and the information content of these elements are therefore dictated by the selected operation. Background information such as the workstation, order number and product is also present on the operation line. It was determined that the operation element should consume the least amount of screen space as it only functions as a medium for selecting the operation.

2. **Guidelines**

   The guidelines tab reveals all the subtasks that needs to be performed in order to fully complete the operation. The guideline window also provides information whether the subtask must be signed off by the operator or if additional inspection by a third party is required upon the completion of the subtask. Every guideline has a specific guideline window associated to it combined with an attachments window where the associated images and drawings for the specific subtask are shown. Consequently, the guideline element controls the instructional content that is provided through element 5 and 6.

3. **Tools**

   The tools tab as can be seen in figure D.6 reveals all the tools that are connected to the operation. Linking towards a specific subtask is established by using the notes tab where the specified numbers correspond to the subtask where the tool is to be used due to the limitation of only one tool element per operation. The tool tab contains various information about the tool such as a tool identification number and name used to identify the correct tool. Furthermore, each of the tool lines are connected to an unique attachments window where an image of the tool is shown to support the mental model of the operator.

4. **Material**

   The materials tab, as can be seen in figure D.7, shows all the associated material for the operation. Linking to a subtask is established following the same technique as deployed for tools by using the notes tab. Similarly, to the tool tab the material tab contains information on the article number, part description and the quantity of the material. Each material element is connected to an attachments window used to convey a visual representation of the material to aid the identification by the operator.

5. **Guideline text**

   The guideline text window contains the guideline text element for each of the subtasks in the operation. The text may only be written in plain text since no functionality required to accomplish effective highlighting exists in this version of the case company information system. The guideline text section is static and no changes can be made to the text by the user, however, the attachments window may be minimized if all the guideline text cannot be seen.

6. **Attachments window**

   The attachments window contains all the graphical content used within the instruction and therefore also consumes the biggest portion of the screen. The attachments window is composed of two different environments, the document environment containing the functionality to attach documents to the subtask and the media environment containing the functionality to attach several types of media files. Furthermore, a menu containing thumbnails of the media is used to control the viewing window located to the right of the menu. This menu contains the previously mentioned model view in the form of a repeating animation as well as the drawing view along with clarifying images. The operator has the option to enlarge the media as well as zoom within it if required.

4.3 Concept evaluation

The feedback that was raised during the focus group concept evaluation session can be divided into four different information quality criteria *format, accessibility, timeliness and comprehensiveness* that are described by Kehoe et al [21]. Generally the discussion concluded that the future concept (FC) was more well-received among the focus group participants as it features more functionality and provides greater potential to reduce an operators cognitive workload than the adapted concept (AC). This was confirmed in the questionnaire response as the future concept outperformed the adopted concept on every criteria. The participants that were more familiar with the case company shop floor deemed both concepts to have the potential to improve operations at shop floor level.

Format

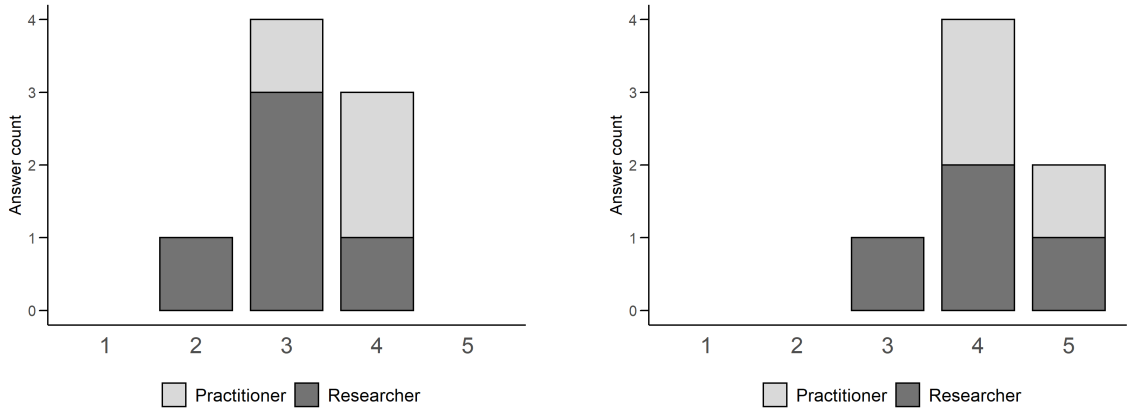
The format of the instruction concepts was discussed by the participants of the focus group. The opinion was raised that more simple 2D instructions assembly instructions like for example used by IKEA[2] for the assembly of furniture could be used instead of having the proposed 3D model as simpler designs often can convey information more easily. On the contrary it was also brought to attention and agreed upon by all participants that when the complexity of an assembly operation increases it becomes more justified to use additional 3D information sources as more detailed information can be conveyed. During the discussion two camps emerged among the participants with one camp being very positive about the inclusion of new technologies in the instructions while the other camp featured a more traditional view. A researcher suggested that common ground could be found by integrating the possibility for an operator to customize details such as view, color-coding and text size as default settings while entering the system. The company representatives stressed that it must be taken into account that the 3D models have to be easy to create in order for them to be feasible to implement in real production.

It was pinpointed by several participants that the color-coding that was used to indicate positions and highlight objects is not well adapted for colorblind people and its use should be limited as supported by literature [11]. The suggestion was instead made that a change of object shape making rectangles round or increasing line thickness could be used to support attention. In general the participants said that the AC creates a more simplistic design impression than the FC which makes it easier to grasp where to find information without requiring any pre-knowledge of symbols. However, it was said that the overall layout of the FC provided an easier setup for comprehending the information.

The FC was perceived as more suitable for the work in terms of format than the AC as indicated by the questionnaire input in figure 4.14. Supporting arguments in the discussion could be identified as it was stated that the information flow in the FC follows a diagonal line from top-left to bottom-right corner which makes it easier to

[2] https://www.ikea.com/gb/en/customer-service/product-support/assembly-guides/

grasp the information [5], while in the AC all information is stacked above each other using a vertical flow making it more difficult to grasp. Another supporting factor was mentioned in the positioning of the graphic content which in the FC is placed in the center of the screen thereby attracting more attention than the placement in the bottom as done in the AC.



(a) Adapted concept - Mean: 3.3 **(b)** Future concept - Mean: 4.1

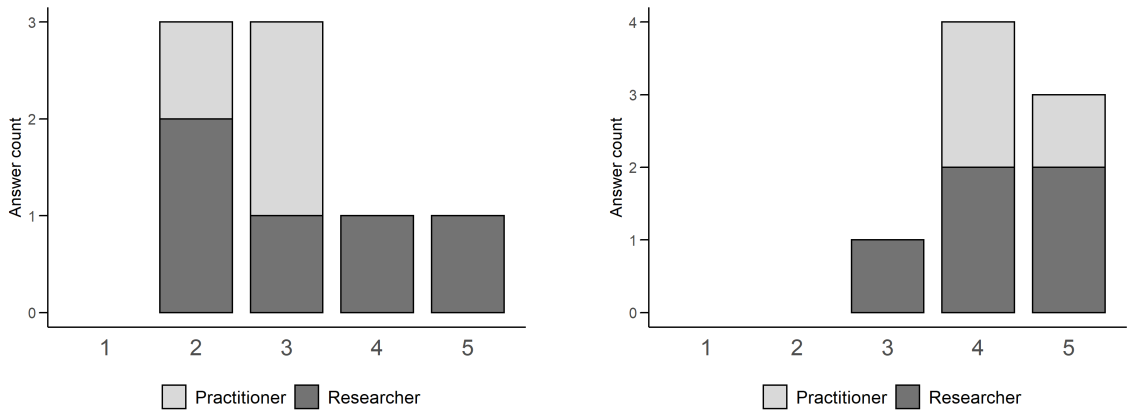
Figure 4.14: Q2 - The instruction format is well adapted for the work.

Accessibility

The criteria accessibility was evaluated and several perspectives were raised throughout the discussion. It was elevated that in both concepts several mouse clicks are required to access all the different kinds of information, while it was highlighted that fewer clicks are required in the FC. This was related to the *3-click-rule* by the researchers which states that users potentially will abandon a website if information cannot be accessed within a few clicks [33]. A potential solution that was mentioned was that more information about tools and material could have been implemented in direct relation to the drawing and model view to reduce the amount of required clicks to obtain all information. This was however intensely discussed as it on the other side results in more information being presented on the screen at the same time which can reduce the overall accessibility of the concept as it potentially becomes harder to navigate the instructions. One researcher mentioned that negative space in terms of having a white background creating a more simple design can be beneficial and make the task appear more easy, but is a matter of opinion that would require further evaluation to assess.

A common feedback was that the FC features a great amount of icons that are associated to different functions that might cause confusion for a novice operator as they will have to acquire knowledge about their meaning. However, the common perception among the participants was that this learning process would be fairly easy as the underlying structure of the design was perceived as logic and easy to understand. The company representatives mentioned that both concepts provide substantial improvement in terms of accessibility of information compared to the current work instructions. This was according to them mainly achieved by employing a clear layout structure where it is easy for operators to know where to find certain types of information. Another benefit that was communicated is that operators can develop a greater degree of trust towards the instructions as they know where the information can be retrieved.

In general the participants regarded it to be easier to navigate and access information in the FC then in the AC as indicated in the questionnaire input in figure 4.15. This was supported in the discussion as it was mentioned that more relevant content was displayed that more easily could be accessed for each subtask.



(a) Adapted concept - Mean: 3

(b) Future concept - Mean: 4.3

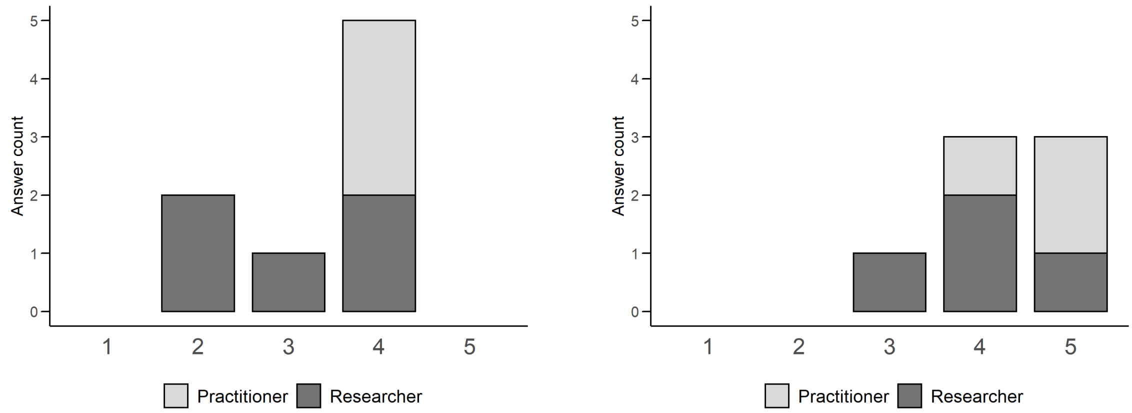
Figure 4.15: Q3 - It is easy to navigate within the instruction.

Timeliness

In the discussion some researchers mentioned that the functionality of the drop-down menu on the left side of the FC where the level of information detail can be selected is a good adaption of the theory that different levels of information detail should be available for novice and experienced operators [23] [5]. A company representative mentioned that both concepts feature a significantly improved timeliness compared to the current work instructions as the required information for a specific task is given directly to the operators. The division of an operation into more specific subtasks where only the information required in that subtask is presented was specified as the main contributor by the representative. The relation between required information and a subtask is more clear in the FC as only required material and tools can be assessed while the established connection in the AC can be misinterpreted as all the information can be assessed. This is majorly supported by the fact that all required information is collected in the same interface which does not require extraction from a separate document.

A suggestion that emerged in the discussion was that through more balanced subtasks in terms of execution time more timely instructions can be presented. Subtask 4 was taken as an example as it includes the longest assembly sequence with the fastening of 36 screws. A potential division into six subtasks with 6 screws each could achieve more precise instructions for each subtask that could be easier to comprehend. Another supporting argument for this claim was mentioned by long task durations creating difficulties for reconnection to the work task if interrupted by breaks or other unexpected situations.

In general the participants regarded the information presentation within the FC to be more timely than in the AC as indicated in the questionnaire input 4.16. This finding was supported by the discussion input that the presentation of either tools or material beside the model and drawing view provides that information more timely than having to change the tab in order to access material and tools as in the AC. Especially within that concept therefore it was highlighted that the integration of additional tool and material information in the drawing and model views to minimize disruption by clicks would be beneficial as described in the accessibility criteria.



(a) Adapted concept - Mean: 3.4 **(b)** Future concept - Mean: 4.3

Figure 4.16: Q5 - The information is presented when the operator needs it.

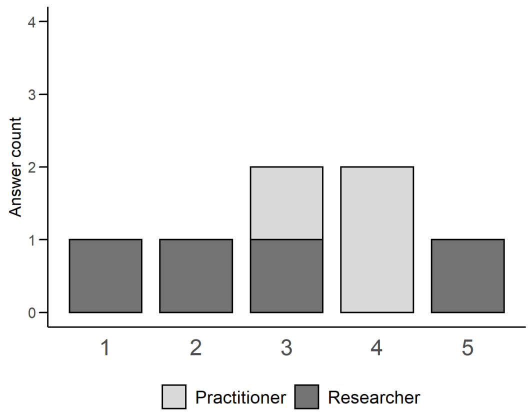
Comprehensiveness

The amount of text provided in the text guidelines in both concepts was regarded to be too extensive and it was suggested that only important information about for example certain variants, risks for potential mistakes or information from quality documents should be included. Another suggestion for text reduction was made with the idea to transfer text-based information about for example inspection procedures to symbols (using a triangle containing an eye) that are easily recognizable for operators and thereby trigger the correct mental model [5]. It was expressed from the company side that a reduction of text would be something that they would like to test and the transfer of information from text to model/drawing was something to desire. Researchers mentioned that the use of text often is beneficial in an operator training phase but should be limited in live production.

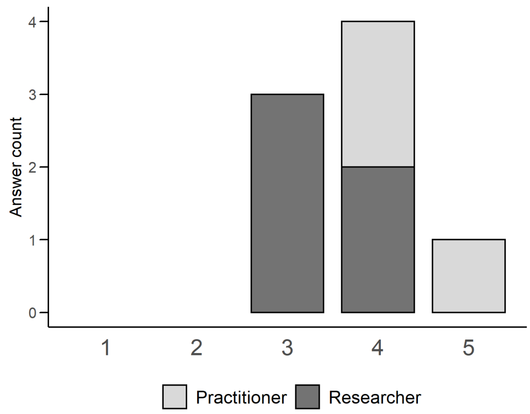
The functionality of the proposed 3D-Viewer in the FC was discussed among the participants regarding the extent of which an operator should be allowed to manipulate and spin the 3D model. It was mentioned that by granting unguided model manipulation an operator could lose track of the model orientation and thereby potentially mount components wrongly. A researcher mentioned that this kind of defect had occurred in a similar setting in a work instruction demonstrator. Some participants therefore suggested that with the use of predefined views or limited angular manipulation that would be zoomable, the described risk of loosing orientation could be mitigated. However, on the contrary this limits the operator to only being able to assess the 3D model with the predefined settings created by the instruction preparer which can lead to the absence of required views for operators. Additionally, it was mentioned by a researcher that the created 3D animations in the instructions featured similarities to LEGO[3] assembly instructions which makes them easy to understand.

The researchers mentioned that the inclusion of a progress bar in the FC is very beneficial for an operator while performing the work task as it creates an overview over how much progress has been achieved so far and can activate a mental model of what should be done next. It was also mentioned that it provides an element of gamification of the process capturing an operators attention and interest as also described in the literature [5]. One of the company representatives however argued that only a single step without any information about other subtasks should be displayed at a time to increase the amount of attention devoted to that task, but was convinced about the advantages regarding the establishment of an overview.

In general the participants experienced the information content to be less redundant in the FC than in the AC as indicated in the questionnaire input in figure 4.17. The difference in these answers was deemed particularly interesting as the information content in both concepts in terms of displayed text and graphical content were the same which indicates that the instruction format matters. The support for the perceived difference could be found in the discussion where it was stated that the information content within the drawing and model views featured better adaptation to the FC than the AC creating a perception of less repetitive information.



(a) Adapted concept - Mean: 2.8



(b) Future concept - Mean: 3.8

Figure 4.17: Q8 - The information in the instruction is NOT perceived as being too redundant.

[3] `https://www.lego.com/en-us/service/buildinginstructions`

5
Discussion

This chapter discusses the suitability of selected research methods, the quality of the research, stated findings within this thesis and implications for future research.

5.1 Applied research methods

The use of the DFIP methodology, as a central part of the instruction system design process within this thesis, allowed for the opportunity to be more creative and unrestricted in the design process than for example if a matrix-based decision method had been applied. The risk with that kind of decision method would have been that good design options are dropped in a subjective iterative process while eliminating options [34]. The potential benefit on the other side could have resulted in a more transparent selection process of instruction material. Nevertheless, it was ensured that by following all six design steps in the DFIP methodology that all the relevant principles designing a work instruction were touched upon in a structured manner. The data on which the method was based, was not collected with the intention to be used within this method. Therefore, the data lacked connection to the specific operation selected as the base for the development which resulted in that conclusions for the specific operation had to be made based on solely general data. Targeted feedback could have provided more detail about the task at hand, however it was considered that the general input provided enough detail to create meaningful results.

In previous research it has been mentioned that while applying the DFIP methodology the result possibly can be based upon personal feelings and reflections of the instruction designers [29]. In relation to this statement the design process in this thesis could have been affected by the subjective bias of the authors. The feedback from other people outside the thesis group and the company supervisor could have been collected more thoroughly during the iterative process of designing the concepts to increase their validity. Operators should have been actively involved in the design process of the instructions as they are the ones that actively interact with them on a daily basis. Observed feedback in discussions with operators could have significantly improved some parts of the concepts to make them more relatable to the production environment. However, in this project this was not possible due to circumstances beyond the control of this thesis, which led to the cancellation of planned semi-structured operator interviews regarding instruction design input.

5.2 Quality of research

The selected mixed-method approach in this thesis was beneficial for the establishment of deeper understanding of the task under review. The use of several data sources enabled the application of methodological triangulation which led to a more complete understanding of the subject [27]. A disadvantage of performing mixed-method research is the need for the researchers to develop skills in several fields which is time-consuming [27]. Consequently, parts of the underlying research could have benefited from the thesis authors having greater previous experience within the conduction of interviews, focus group and questionnaire design.

The featured observations were conducted using a simple observational plan establishing structure for the observation. This was deemed sufficient for the collection of qualitative input about procedures and information handling. However in hindsight the establishment of more specific observational schedules could have provided more systematic observations that could have ensured comparability between occasions [27]. The performed short unstructured interviews did not allow for any extensive investigation into a topic as they were performed on a conversational level. The interviewees briefly elaborated on their opinion regarding information presentation and handling of the case company information system. However, this less formal approach allowed for a more relaxed interview atmosphere. Interviews featuring a more structured approach such as semi-structured interviews could have provided the study with more details regarding specific information handling issues [27].

The first questionnaire that was administered can in hindsight be regarded as too extensive. But at the same time through its extensive nature it provided valuable input about the general perception of the workplace. Denscombe states that a questionnaire only should ask questions that are absolutely vital for the research [27], while in contrary the applied design for the questionnaire in this thesis was very broad. Denscombe also argues that the length of a questionnaire should be kept to a minimum as otherwise mental fatigue can take place, leading either to unanswered questions or an answer following a certain rating scale pattern [27]. More focus therefore should have been devoted towards designing a questionnaire with fewer questions that provides more valid answers.

The evaluation of the concepts was performed by conducting a focus group featuring both researchers and company practitioners. This composition of participants was selected to ensure the provision of both an academic and an applied industry view to provide a more nuanced discussion. However, due to some members being more present in the discussion than others the obtained qualitative data could feature a certain bias towards these views, therefore the moderators should have invited less active participants to share their views more often [32]. Another influence could have been the digital conduction of the focus group without effective direct visual contact with all members [27]. This introduced the risk of participants feeling more remote through the digital communication barrier. However, without using digital communication the achieved composition of participants would have been unlikely.

The interaction between the participants in the focus group provided an understanding of the underlying reasoning behind the statements and presented valuable feedback on all parts of the concepts. However, it was experienced as difficult to provide an adequate picture of the operators role within the production process to the extent that all participants could assess the concepts from a common operator perspective. Consequently, the validity of the results partially have to be questioned as the assessment of the selected information quality criteria was supposed to be conducted from an operators perspective. It was mentioned that the criteria *timeliness* was especially difficult to assess as some participants without previous knowledge of the shop-floor operations were unable to relate to the current state. Under this pretense especially the quantitative results from the questionnaire have to be regarded with more caution. Nonetheless, the questionnaire still is considered to provide conclusive information about the difference among the concepts as the FC outperformed the AC on all criteria.

5.3 Research question 1

How is an operators cognitive workload influenced by the current information presentation in the complex production environment?

In the initial state information handling assessment it was found that operators face a growing amount of information, which poses the risk for information overload [14]. This risk originates from the attitude that the operator should receive all available information. That creates a relevance problem for the operator as resonating mental processes need to be activated to assess which information is relevant [16],[20]. However, even though all information should have been provided, operators still have to request more information on a regular basis. The organization puts responsibility on the operators to be up-to-date with the documentation and perform all tasks in relation to the specific quality standards stated in the documentation. The presence of this attitude can therefore be seen as a root-cause problem in the current information presentation as it directly influences issues within both the intrinsic and extrinsic information quality domain. As stated by Haug “poor quality instructions need more processing than high quality instructions” there is a direct relationship between the perceived cognitive workload of an operator and the quality of a presented instruction [20].

The presence of intrinsic information quality issues such as deficiency, ambiguity and repetitiveness within the received instructions can create difficulties for an operator to understand what to do [20]. Within the extrinsic domain problems occur such as inconsistently structured documents, inaccessible information about tools, untimely delivery with too much information and poor reputation through reoccurring errors. All of these described complications can lead towards an increasing risk of misdirecting an operators attention resulting in unknowingly performing mistakes [10]. The existence of the described challenges require active problem solving which may sound unacceptable for many industries, but within this environment this may be a part of what makes the work interesting.

Even though several problems can be identified with the current information presentation the operators are mostly content with their instructions. This attitude could possibly be explained by the absence of alternative instruction concepts within the organization to be used for inspiration combined with the fact that most operators have been accustomed to be working with the current instructions. Operators should be actively involved in the process of creating instructions to maintain appreciated instruction elements and expand upon them. A direct communication between information receiver and sender can contribute to the inclusion of information requests and improvement suggestions, but also to the reduction of perceived stress levels for operators [11]. Accordingly it can be said that there is potential for reducing the cognitive workload by adjusting the information presentation.

5.4 Research question 2

How can information be presented in the future in order to decrease an operators cognitive workload within a complex production environment?

The creation of the concepts aimed towards eliminating the pervading issue of information irrelevant to the task being presented to the operator. This can be achieved by incorporating the required information into a single source of information that only contains the information relevant to the task and thereby reduces the cognitive workload. The fulfillment of the information quality attribute of relevancy stated by Kehoe et al. resulted in a considerable impact on each of the other attributes in the information quality framework [21]. This consequently lead to an improvement of the overall information quality, due to the reduction of the amount of information. It was thereby found that a prerequisite for reducing cognitive workload through information presentation is that all provided information should be relevant.

It was found that the format of the instruction should be as simple and intuitive as possible and thereby make information that can be considered as complex appear less complicated. Therefore, tasks considered as uncomplicated may benefit from utilizing more simple information while more complex procedures motivate the use of more detailed information in the form of 3D-models. The comprehensiveness of the information therefore carefully has to be adapted to the complexity of the task. Furthermore, it was found that differences in operators experience levels pose different information needs for the same task. Thus, each operator should have the ability to customize the information according to their needs to ensure the presentation of an appropriate amount of detail in regard to their experience. It may be concluded that an effective presentation should be consistent with the human process of perception, by for instance placing important information along the diagonals of the screen or using visual representations closely linked to reality [5], [22].

In order for a user to perceive the provided instruction as accessible the information needs to be structured clearly in the applied layout [22]. The layout displayed in the FC was deemed to be easier to navigate than the AC since it was structured more logically and that less interaction was necessary in order to reach the same information. However, reducing the number of interactions required inevitably leads to more information being presented on the screen at the same time, consequently reducing the effectiveness of the presentation. Furthermore, it was found that the provided information should be timely and deliver required information to the user when needed. It was concluded that this can be achieved by employing a clear connection between the subtask and the information required to perform it, for example by solely presenting relevant tools for a specific subtask. This division of information reduces the risk of information overload as well as the risk for potential quality errors caused by mixing up information across tasks.

5.5 Implications of case company implementation

The implementation of the developed concepts into operational production will have several implications for the case company. These implications will affect the case company on different layers as it influences the daily work of both the information giver and the information receiver. As the information system acts as an interface between these two entities it will also be affected by the changed characteristics of the information presentation. The purpose of developing two different concepts is to evaluate how information presentation implementable within different time horizons may reduce the cognitive workload of an operator. As the adapted concept is built upon the information system employed at the case company today the implementation does not require any fundamental changes to be made to the information system itself but rather the way in which it is currently utilized. However, the future concept will pose demands on the technical aspect of the information system as it currently does not have the capabilities required to realize the core functionality of the developed information presentation. This concept will therefore require development of new supporting software or a transition into another information system entirely, which means that the barrier of implementation is significantly greater than for the adapted concept.

A successful implementation of the developed concepts will influence the work of an instruction preparer as the instruction creation process will require the development of specialized drawings and 3D-models for every subtask. This will likely increase the time spent for an instruction preparer creating instructions compared to the current state. However, it became evident in the document review that some newer assembly procedures already use pictures of CAD-models within the instruction, therefore the step towards using 3D-models more intensively should be regarded as feasible in a not too distant future. In order for the information presentation to be feasible on a larger scale for all products the instruction creation process should be supported by IT systems that automatically creates parts of the instruction and thereby reduces time spent by an instruction preparer. This may be achieved by establishing a connection between the product and the procedures through assigning information to the individual components where for example the occurrence of a certain screw would specify the use of a certain screwdriver. A study has shown that computer-automated instructions following a set of instruction principles has the potential to match manually created instructions for simple assembly operations [25]. It can be assumed that deploying an automated instruction creation also would reduce the time required to create instructions. However, efforts in advance must in that case be committed towards developing a system that is capable of creating the required instruction. As of now the developed instruction material for every subtask needs to be created manually using a CAD software, which requires more effort being spent. However, the presence of fluctuating production volumes with temporary need for external consultants might justify the increased effort as the hurdle for new operators that require basic training could be reduced with more clear, timely and relevant instructions.

The outcome of the thesis may have several implications in terms of sustainability if used as a foundation for further development and implementation. The work has examined the cognitive workload of operators in a production environment characterized by high complexity and work demands. A work demand that is not adapted to the cognitive capabilities of the operators performing it may lead to impaired well-being of the personnel [35], [11]. Information presentation resulting in reduced cognitive workload may decrease the stress and frustration often induced by operating from inadequate information, thereby increasing the operator well-being [15]. However, further development of the information presentation may decrease the problem solving element of the work, which consequently can lead to under-stimulation and thereby affect both the well-being and performance of the operator negatively if not adapted properly [15]. Therefore, future development and implementation should involve operators in the process to ensure that the social aspects of the information presentation is considered.

Successful implementation of improved information presentation may also lead to increased operator performance in terms of reduced quality errors and increased capacity [15]. The increased performance primarily leads to improved economic sustainability as a consequence of process time reductions and less time spent on reworking defective products. Furthermore, achieved performance gains would yield environmental benefits as a cause of less scrapped electronic components, even though complete scrapping is a rare occurrence in the industry.

5.6 Future work

The resulting findings discovered over the course of the thesis have highlighted several areas of interest for further research and development. The concepts have been developed containing the core functionality required to evaluate the integrated principles. It is therefore recommended that the concepts are thoroughly tested and validated together with the operators. An operator-centered validation would be able to evaluate the concepts with greater accuracy and validity as it is the operators who posses the greatest knowledge of both the process and the information presentation required to reduce the cognitive workload involved in its execution. This kind of validation could potentially capture essential design aspects, such as user satisfaction and quantifiable performance changes as a cause of information presentation, beyond the scope of investigation in this thesis.

Furthermore, it is recommended that future development of information presentation should be conducted in closer collaboration with the operators by including them in every part of the development process and thereby enable satisfactory usability of the system to be achieved.

Another area appropriate for further research regards how the information presentation suggested in this work can be managed from the perspective of the instruction preparer tasked with creating the instruction content. This matter has only been slightly touched upon within the scope of this work due to the extensive nature of each of the perspectives. Nevertheless, the perspective of the information giver is of equal importance as the studied information receiver perspective since the creation of the information presented to the receiver must be feasible in order to be implemented in the operational production at the company. Further research into how the creation of complex assembly instructions can be simplified through for instance automation and systematization could have a significant impact on the feasibility of the instructions and thereby in extension, the quality of the instructions presented to the receiver [24].

The research conducted within this work has been limited to examining how the presentation of digital information content influences cognitive workload. However, cognitive workload may also be influenced by the introduction of cognitive assistance solutions such as for instance alternative information carriers or physical support technology in the forms of fixtures, smart tools or picking systems [11]. Further studies should be conducted to evaluate how the task complexity can be reduced through the introduction of cognitive aids or carriers, which in extension could eliminate certain cognitive workload issues difficult to solve through the use of exclusively digital information presentation.

6 Conclusion

In this thesis, it has been found that there are several factors prevalent that influence an operators cognitive workload within the complex production environment prevalent in the space manufacturing industry. One of the fundamental challenges that an operator faces within this environment is the handling and processing of large amounts of information. Cognitive resources are primarily used to locate and comprehend the relevant information rather than only performing the task at hand. Therefore, it was concluded that the improvement of information presentation revolves around solely presenting relevant information in a timely manner within a format that is easy to comprehend.

There is no clear structure or procedure to be identified in the literature that in detail presents an effective formula for how to create work instructions, as it was found that each type of industry, production environment and operator poses different needs. By applying a cognitive process oriented approach that considers active cognitive processes of the user in the creation process, this thesis has shown that a more effective information presentation may be achieved.

The evaluation process in this thesis has shown that there are many different opinions regarding the presentation of information to be found among researchers and practitioners. As a consequence, it can be concluded that it is difficult to develop an instruction that satisfies everyone. In order to truly succeed with supporting an operators cognitive workload the most important stakeholder, being the operator, needs to be satisfied as they are the sole users. Therefore, a recommendation for future work beyond this thesis is to evaluate the developed concepts with operators to determine their true usability.

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A
Operator questionnaire

Appendix A contains the unedited version of the questionnaire that was printed and distributed to operators during the data collection phase of the initial state analysis.

Enkät - Utvärdering av arbetsstöd i produktion

Svarstid: 10-15 minuter
Målgrupp: Operatörer i produktion **27 februari 2020**

Hej!

Tack för att du tar dig tiden att besvara denna enkät. Som en slutförande del av vår utbildning inom produktionsutveckling på Chalmers utför vi nu ett examensarbete inom produktionen här på RUAG Space där vi undersöker hur väl presentationen av arbetsinstruktioner stödjer er operatörer i er dagliga verksamhet.

Målet med vårt examensarbete är att utveckla en demonstrator som påvisar hur arbetsinstruktioner bör visas hos RUAG i framtiden. Därför behöver vi din hjälp för att förstå vart förbättringspotentialen ligger, vilken typ av lösning ni efterfrågar och hur den skall utvecklas för att vara så användbar som möjligt för er.

Enkäten är fullständigt anonym och om du känner att du inte förstår, inte vill svara eller tycker att en fråga är irrelevant så får du givetvis hoppa över den frågan.

Tack för din medverkan!
Jakob & Viktor

Demografisk & Arbetsrelaterad information

Detta avsnitt ämnar åt att samla lite mer allmän information för att vi skall kunna tolka era svar på bäst möjliga sätt när vi utvärderar enkäten.

1. Vilken ålder innehar du?

   ◯ 20 - 40 år ◯ 40 - 60 år ◯ 60+ år

2. Är du fastanställd på företaget eller jobbar du som konsult?

   ◯ Fastanställd ◯ Konsult

3. Hur många år har du jobbat på företaget?

   ◯ <1 år ◯ 1 - 10 år ◯ 11 - 20 år ◯ 20+ år

4. Hur många år har du jobbat på din position som operatör?

   ◯ <1 år ◯ 1 - 5 år ◯ 6 - 10 år ◯ 10+ år

5. Vilken avdelning jobbar du på?

   ◯ Digital ◯ Mikrovåg ◯ Annan: ____________________

6. Brukar du även jobba på andra avdelningar inom företaget?

   ◯ Ja, ____________________ ◯ Nej

7. Är du höger eller vänsterhänt?

   ◯ Högerhänt ◯ Vänsterhänt

8. Passar något av de följande påståenden in på dig?

   ☐ Nedsatt hörsel
   ☐ Nedsatt syn (färgblind eller dyl.)
   ☐ Inget av ovanstående

Arbetssituation

Detta avsnitt ämnar till att förstå hur ni som operatörer upplever er arbetsmiljö, om stress uppstår och hur produktstrukturen påverkar er i produktion.

9. Mitt arbete kräver att jag kan utföra många olika arbetsuppgifter.

   Instämmer inte alls ① ② ③ ④ ⑤ **Instämmer helt**

10. Jag tror att det tar lång tid för en ny operatör att lära sig mina arbetsuppgifter.

    Instämmer inte alls ① ② ③ ④ ⑤ **Instämmer helt**

11. Jag upplever mitt arbete som komplicerat.

    Instämmer inte alls ① ② ③ ④ ⑤ **Instämmer helt**

12. Hur ofta känner du dig stressad i ditt dagliga arbete?

Jag känner mig aldrig stressad	1	2	3	4	5	Jag känner mig dagligen stressad

13. Hur påverkad känner du dig mentalt av jobbet när du kommit hem?

Jag känner mig inte alls påverkad	1	2	3	4	5	Jag känner mig mentalt utmattad

14. Är det något arbetsmoment du upplever som problematiskt? Beskriv gärna.

Arbetsinstruktioner

Detta avsnitt ämnar till att förstå hur väl dagens arbetsinstruktioner hjälper och stödjer er i utförandet av ert dagliga arbete.

15. Tycker du att det är enkelt att förstå vad som ska göras under en operation?

Jag förstår sällan vad jag ska göra	1	2	3	4	5	Jag förstår alltid vad jag ska göra

16. Jag behöver ofta be om kompletterande information under mitt arbete.

Jag ber aldrig om mer information	1	2	3	4	5	Jag ber dagligen om mer information

17. Jag tycker det är enkelt att förstå hur man bygger en ny produkt.

Instämmer inte alls	1	2	3	4	5	**Instämmer helt**

18. Efter att jag läst arbetsinstruktionen så vet jag alltid hur det förväntade resultatet av operationen kommer se ut.

Jag vet <u>sällan</u> hur resultatet kommer att se ut	1	2	3	4	5	**Jag vet <u>alltid</u> hur resultatet kommer att se ut**

19. Är det enkelt att förstå hur man uppnår det förväntade resultatet av operationen?

Det är <u>svårt</u> att förstå hur jag ska göra	1	2	3	4	5	**Det är <u>enkelt</u> att först hur jag ska göra**

20. Hur nöjd är du med dagens arbetsinstruktioner?

Jag är inte alls nöjd	1	2	3	4	5	**Jag är väldigt nöjd**

21. Om du inte är väldigt nöjd med dagens arbetsinstruktioner, vad beror det på?

Arbetsstationer

Detta avsnitt ämnar till att förstå hur ni jobbar vid er arbetsstation, samt hur väl ert arbete stöds av dess layout.

22. Hur ofta lyssnar du på musik, podcast eller liknande när du arbetar?

Jag lyssnar aldrig på musik	1	2	3	4	5	**Jag lyssnar alltid på musik**

23. Hur ofta känner du att relevanta verktyg saknas vid din arbetsstation?

Jag måste sällan hämta verktyg jag behöver	1	2	3	4	5	**Jag måste ofta hämta verktyg jag behöver**

24. Verktyg/fixturer som jag behöver till mitt arbete är ofta upptagna av andra operatörer.

Instämmer inte alls	1	2	3	4	5	**Instämmer helt**

25. Jag tycker alltid det är lätt att förstå vilket verktyg jag ska använda.

Instämmer inte alls	1	2	3	4	5	**Instämmer helt**

26. Är du nöjd med nuvarande layout av din arbetsstation?

Jag är inte alls nöjd med min arbetsstation	1	2	3	4	5	**Jag är helt nöjd med min arbetsstation**

27. Om du inte är helt nöjd med din arbetsstation, vad beror det på?

Informationssystem

Detta avsnitt ämnar till att förstå hur väl ert dagliga arbete stöds av IFS, samt hur ni påverkas av mängden olika informationskällor som ni jobbar med.

28. Jag tycker att IFS stödjer mig väl i mitt dagliga arbete.

Instämmer inte alls ① ② ③ ④ ⑤ **Instämmer helt**

29. Tycker du att IFS har en tydlig programstruktur?

Jag tycker att det är svårt att hitta rätt ① ② ③ ④ ⑤ **Jag tycker att det är enkelt att hitta rätt**

30. Jag tycker att det är enkelt att använda IFS i mitt dagliga arbete.

Instämmer inte alls ① ② ③ ④ ⑤ **Instämmer helt**

31. Hur tidskrävande upplever du det är att hantera nödvändiga dokument?

Jag tycker inte alls det är tidskrävande ① ② ③ ④ ⑤ **Jag tycker det är väldigt tidskrävande**

32. Jag behöver ofta leta efter nödvändig information i en QSTD under mitt arbete.

Instämmer inte alls (1) (2) (3) (4) (5) **Instämmer helt**

33. Jag tycker det är enkelt att förstå information jag läst i en QSTD.

Instämmer inte alls (1) (2) (3) (4) (5) **Instämmer helt**

34. Hur upplever du mängden olika informationskällor?

Jag tycker att mängden källor är svårhanterlig (1) (2) (3) (4) (5) **Jag tycker att mängden källor är lätthanterlig**

35. Vilken informationskälla använder du mest i ditt arbete?

Framtiden

Detta avsnitt ämnar till att förstå hur ni ser på förändring av er arbetsplats, arbetsinstruktioner, samt arbetssätt i framtiden.

36. Jag känner att jag aktivt kan påverka förändring på min arbetsplats.

Instämmer inte alls (1) (2) (3) (4) (5) **Instämmer helt**

37. Hur ser du på förändringar av ditt arbetssätt?

Jag tycker inte alls det är nödvändigt	1	2	3	4	5	**Jag tycker att det är mycket viktigt**

38. Tror du att en förändring av dina arbetsinstruktioner kommer underlätta ditt arbete?

Det kommer inte att underlätta	1	2	3	4	5	**Det kommer att underlätta mycket**

39. Finns det andra arbetsstöd i instruktionsväg som du skulle vilja inkludera i ditt arbete?

40. Har du några övriga rekommendationer eller kommentarer till oss?

Tack för din medverkan!

B
Focus group questionnaire

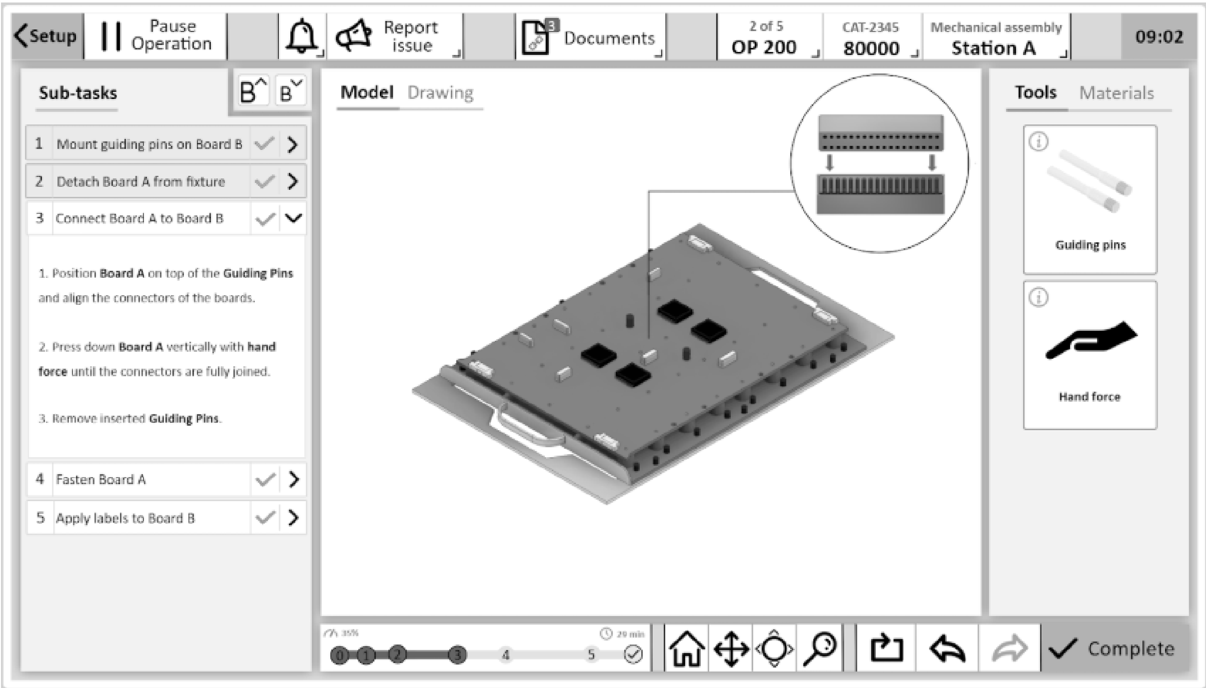
Appendix B contains a typeset version of the questionnaire that was distributed digitally to each of the participants of the focus group conducted during the evaluation phase. A similar questionnaire with identical questions to the future concept questionnaire was distributed for the evaluation of the adapted concept.

Enkät - Framtidskoncept

Kriterierna som kommer användas för att bedöma konceptet bygger på de 6 informationskvalitetskriterier som Kehoe et al. (1992) presenterar. Utifrån dessa har vi valt att använda kriterierna Format, Accessibility, Timeliness och Comprehensiveness för att utvärdera vår implementation.

Kehoe, D., Little, D., & Lyons, A. (1992). Measuring a Company IQ. In 1992 Third International Conference on Factory 2000, 'Competitive Performance Through Advanced Technology, London, July 27-29 (p. 173 - 178). York.

Interaktivt koncept hittas på: https://thesisconcept.github.io/Concept/



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1. Är du forskare eller företagsrepresentant?

   ◯ Forskare ◯ Företagsrepresentant

Format

Detta kritierie ämnar till att bedöma hur väl det visuella formatet på arbetsinstruktionen stödjer uppfattningen av den presenterade informationen. Instruktionens format utgörs av det grafiska informationsmaterialet såsom exempelvis model- och ritningsvy samt övergripande layout.

2. Instruktionens innehåll är enkelt att förstå.

Instämmer inte alls	1	2	3	4	5	**Instämmer helt**

3. Instruktionens format är väl anpassat för arbetsuppgiften.

Instämmer inte alls	1	2	3	4	5	**Instämmer helt**

Accessibility

Detta kritierie ämnar till att bedöma hur väl innehållet i arbetsinstruktionen är strukturerat för att på ett enkelt sätt kunna tillgodogöra sig den information som behövs för att utföra arbetsuppgiften. Instruktionens tillgänglighet påverkas exempelvis av hur enkelt det är att hitta i systemets menyer.

4. Det är enkelt att navigera i instruktionen.

Instämmer inte alls	1	2	3	4	5	**Instämmer helt**

5. Det är enkelt att hitta den information som behövs.

Instämmer inte alls	1	2	3	4	5	**Instämmer helt**

Timeliness

Detta kritierie ämnar till att bedöma hur väl relevant information levereras i arbetsinstruktionen vid den tidpunkt då den behövs. Instruktionens timeliness påverkas exempelvis negativt om en operatör behöver leta efter nödvändig information för uppgiften.

6. Information presenteras när operatören behöver den.

Instämmer inte alls	1	2	3	4	5	**Instämmer helt**

7. Enbart information som är relevant för deluppgiften presenteras.

Instämmer inte alls	1	2	3	4	5	**Instämmer helt**

Comprehensiveness

Detta kritierie ämnar till att bedöma hur väl informationsmängden i arbetsinstruktionen är anpassad för arbetsuppgiften. Instruktionens comprehensiveness påverkas negativt om detaljgraden är för hög eller om informationen upplevs som onödigt repetitiv.

8. Instruktionens detaljgrad är väl anpassad för denna typ av arbetsuppgift.

Instämmer inte alls	1	2	3	4	5	**Instämmer helt**

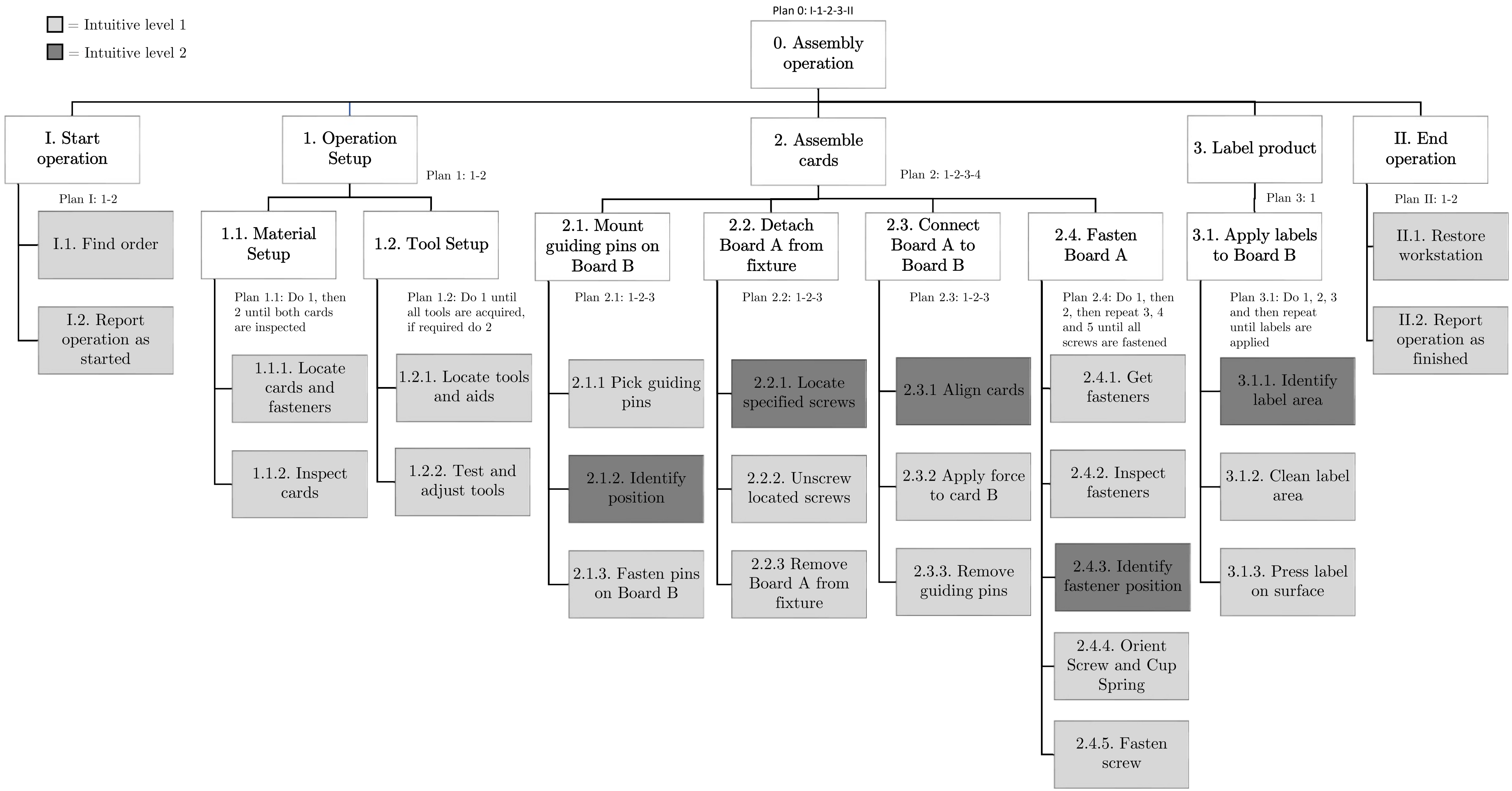
9. Informationen i instruktionen upplevs INTE som för redundant.

Instämmer inte alls	1	2	3	4	5	**Instämmer helt**

C

Hierarchical task tree

Appendix C contains the hierarchical task tree, along with the categorization of tasks based on level of intuition, as developed during the first two steps of the Design principles For Information Presentation (DFIP) method. The tree describes the mechanical assembly operation selected as the basis of improvement within this work.


= Intuitive level 1
= Intuitive level 2
Plan 0: I-1-2-3-II
0. Assembly operation
I. Start operation
Plan I: 1-2
I.1. Find order
I.2. Report operation as started
1. Operation Setup
Plan 1: 1-2
1.1. Material Setup
Plan 1.1: Do 1, then 2 until both cards are inspected
1.1.1. Locate cards and fasteners
1.1.2. Inspect cards
1.2. Tool Setup
Plan 1.2: Do 1 until all tools are acquired, if required do 2
1.2.1. Locate tools and aids
1.2.2. Test and adjust tools
2. Assemble cards
Plan 2: 1-2-3-4
2.1. Mount guiding pins on Board B
Plan 2.1: 1-2-3
2.1.1 Pick guiding pins
2.1.2. Identify position
2.1.3. Fasten pins on Board B
2.2. Detach Board A from fixture
Plan 2.2: 1-2-3
2.2.1. Locate specified screws
2.2.2. Unscrew located screws
2.2.3 Remove Board A from fixture
2.3. Connect Board A to Board B
Plan 2.3: 1-2-3
2.3.1 Align cards
2.3.2 Apply force to card B
2.3.3. Remove guiding pins
2.4. Fasten Board A
Plan 2.4: Do 1, then 2, then repeat 3, 4 and 5 until all screws are fastened
2.4.1. Get fasteners
2.4.2. Inspect fasteners
2.4.3. Identify fastener position
2.4.4. Orient Screw and Cup Spring
2.4.5. Fasten screw
3. Label product
Plan 3: 1
3.1. Apply labels to Board B
Plan 3.1: Do 1, 2, 3 and then repeat until labels are applied
3.1.1. Identify label area
3.1.2. Clean label area
3.1.3. Press label on surface
II. End operation
Plan II: 1-2
II.1. Restore workstation
II.2. Report operation as finished

D
Developed concepts

Appendix D contains supplementary unedited images of the two concepts developed over the course of the thesis. Section D.1 encloses images of the Future Concept (FC) and section D.2 encloses images of the Adapted Concept (AC).

D.1 Future concept

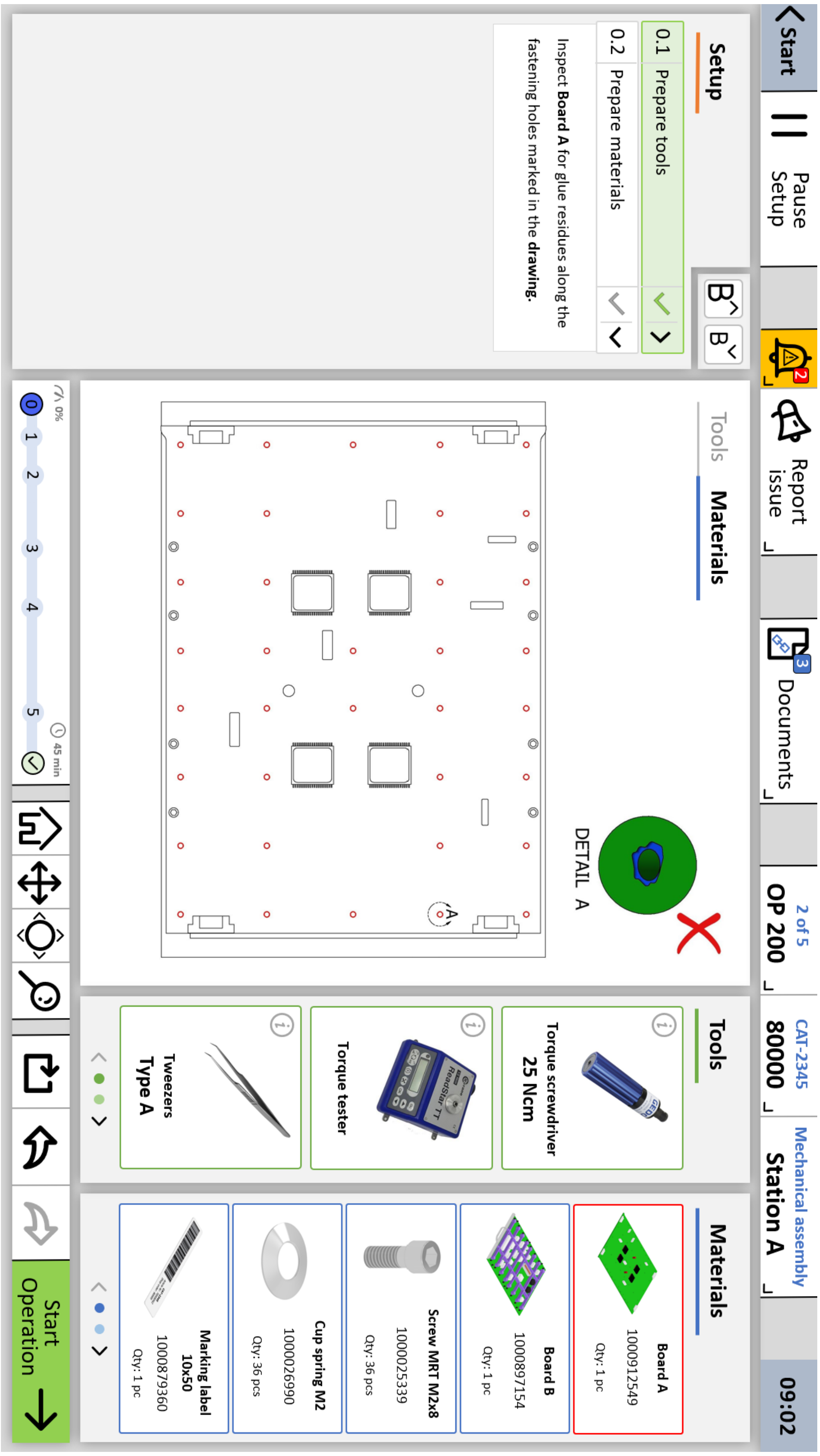


Figure D.1: The material setup section seen at the start of the operation.

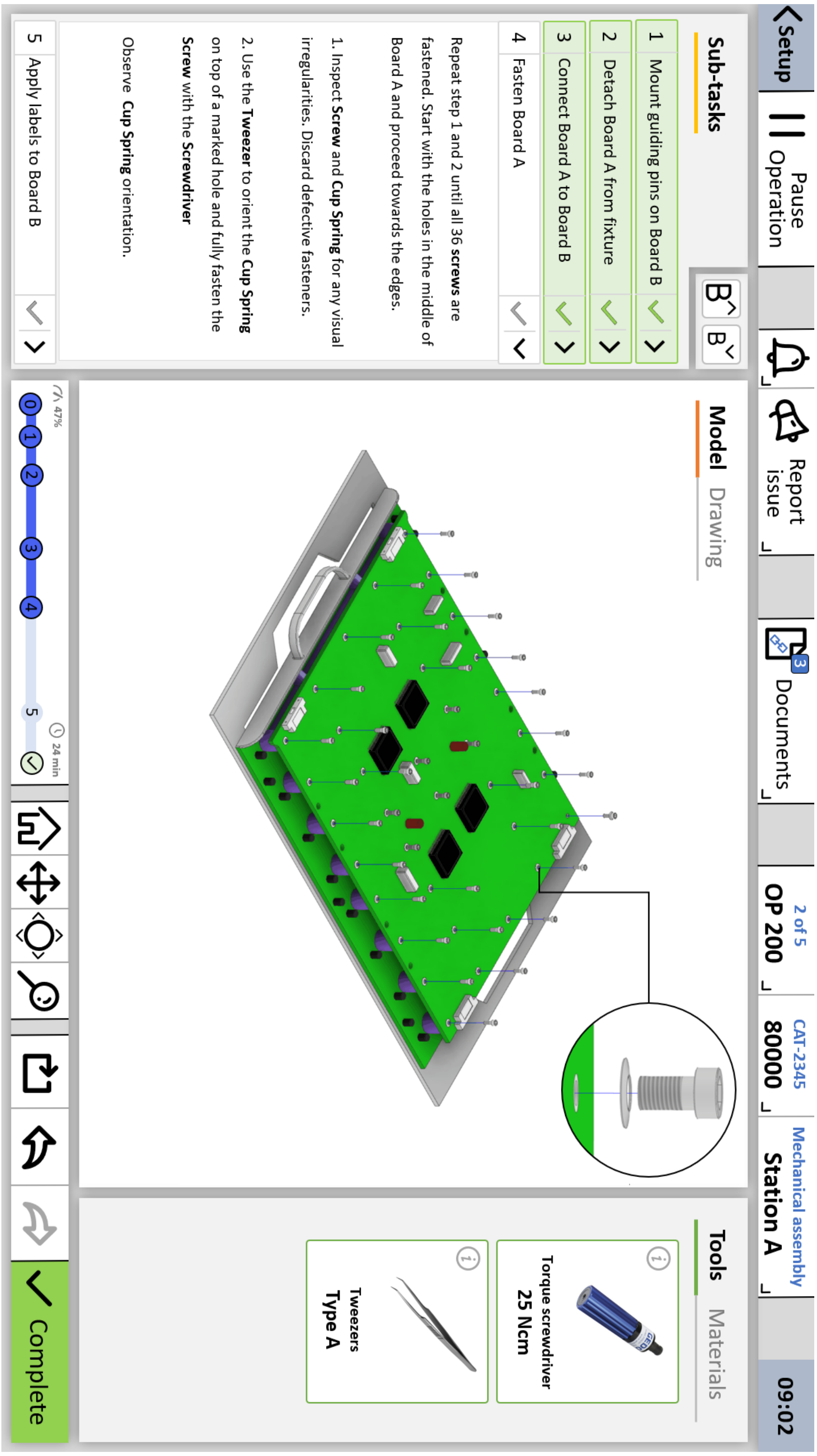


Figure D.2: The operation section where the model view describing subtask 4 along with required tools can be seen.

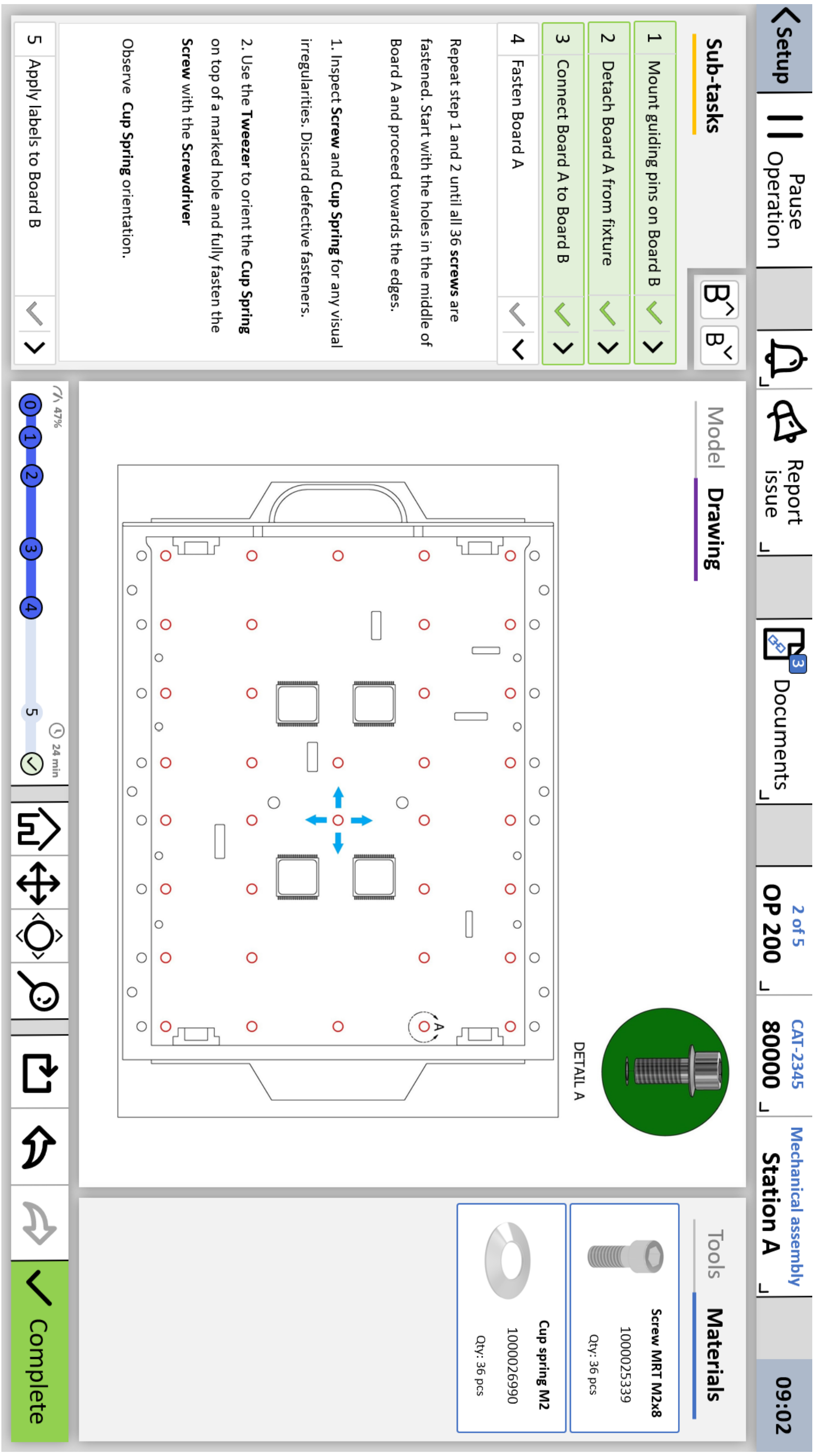


Figure D.3: The operation section where the drawing view describing subtask 4 along with the consumed materials can be seen.

D.2 Adapted concept

Figure D.4: The instructions for subtask 4 where the model view is selected.

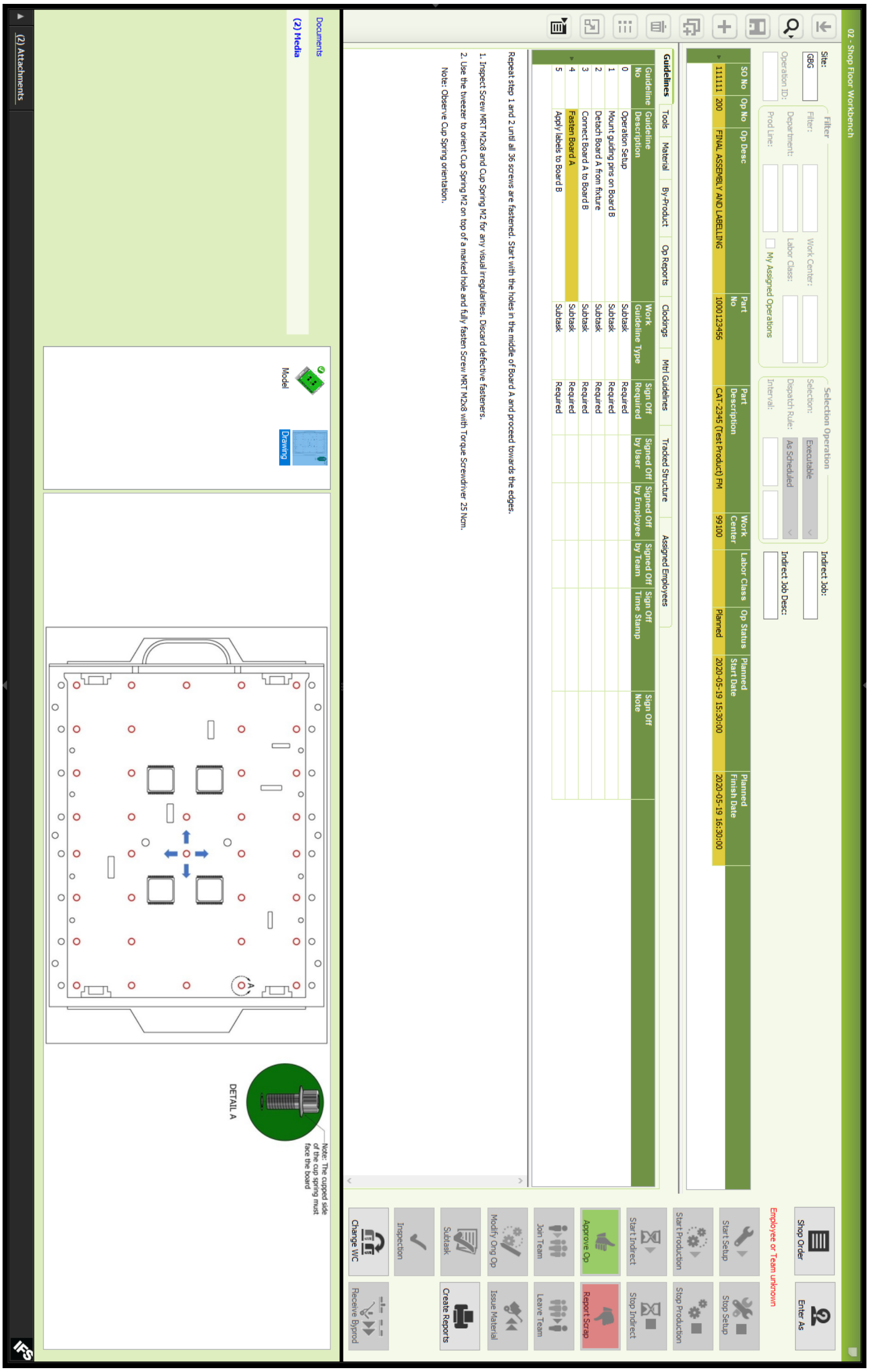


Figure D.5: The instructions for subtask 4 where the drawing view is selected.

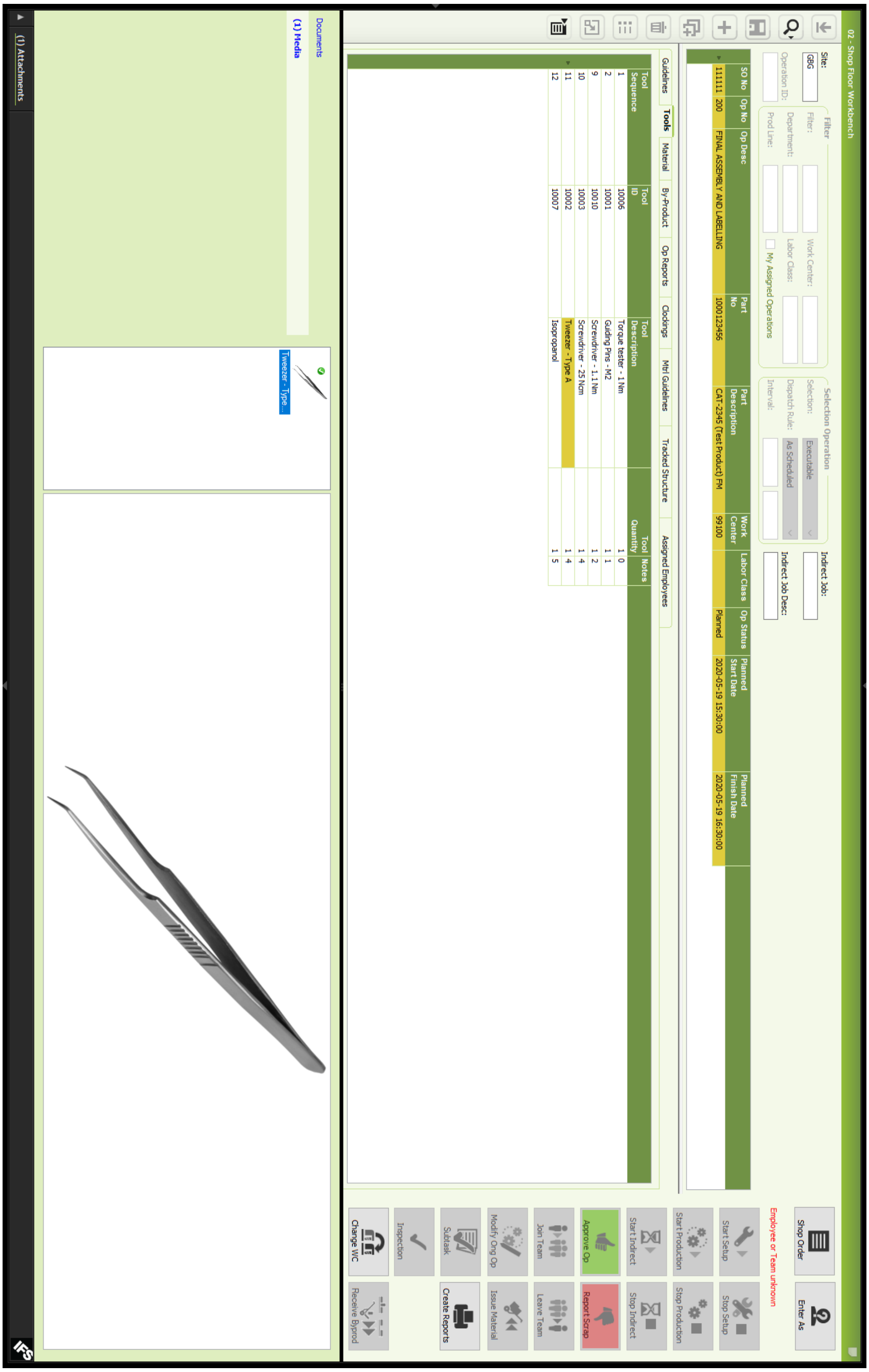


Figure D.6: The tools section of the complete operation where all tools used within the operation can be seen.

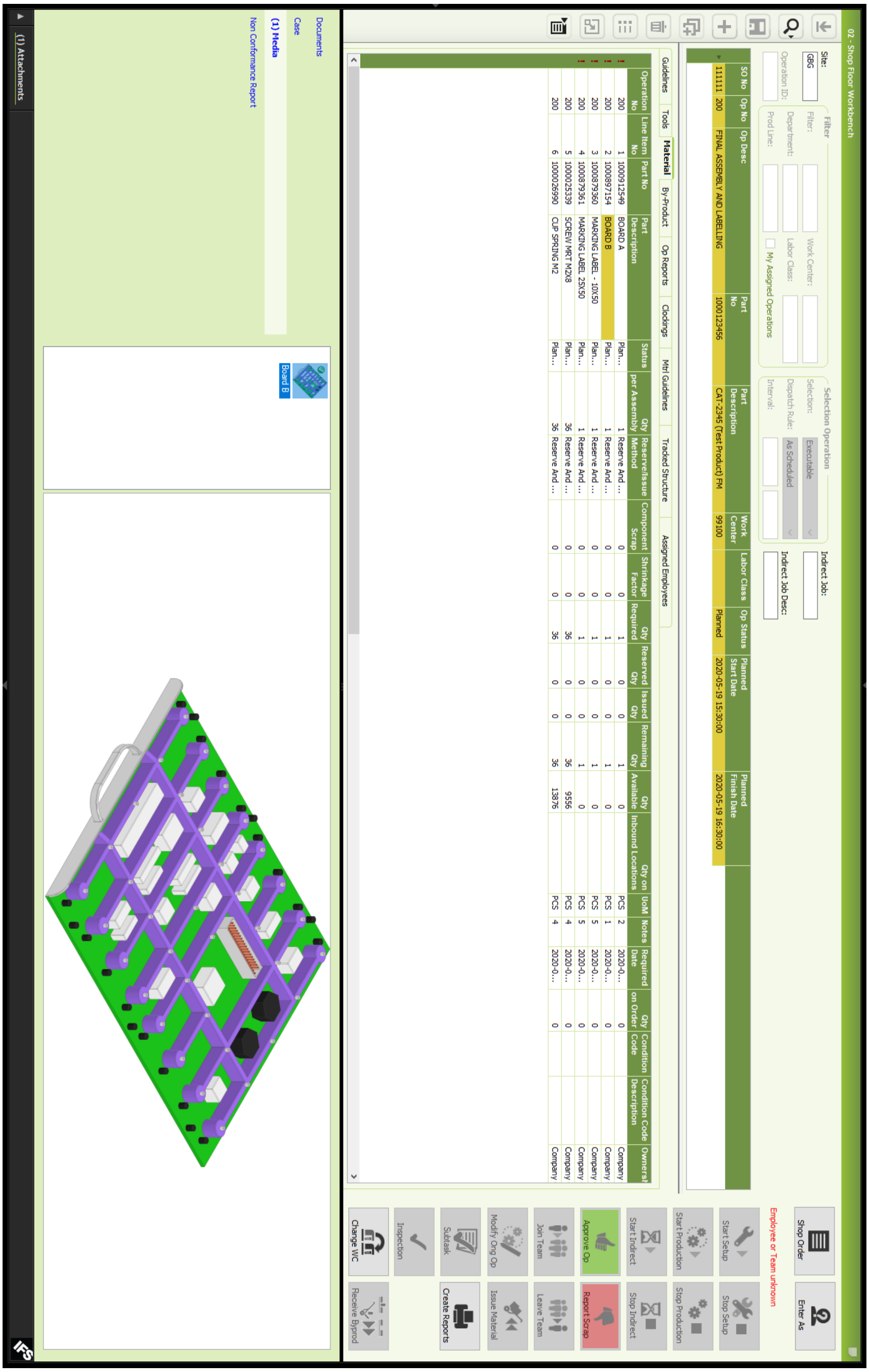


Figure D.7: The material section of the complete operation where all material consumed within the operation can be seen.