MATERIALS AND PRODUCTION
PRODUCTION AND WORK ENVIRONMENT

Current and best practices in information presentation

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Abstract

First year report of DIGITALIS[1] (DIGITAL work InStructions for cognitive work)1
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Key words: instructions, digitalisation, learning.

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Content

Summary

Digitalization and automation in industry can have both positive and negative effects on social sustainability. On one hand it can be a basis for monotonous, uncreative, and even dangerous workplaces and in some cases might even result in people losing their work. On the other hand, it can be a base for ergonomically sound and inclusive work, engaging everyone in improvements. This project aims for moving the focus on positive effects for social sustainability while still staying cost efficient and effective in economic and ecologic sustainability for digitalization and automation of work instructions and training in manual operations like assembly, machine operation & setup, maintenance, and material handling. The Industry 4.0 paradigm offers radically increased opportunities for doing just that. For example, increased digitization can create efficiency improvements through shorter lead times and reduced disruptions to production. New generations of technology and software as well as information dissemination can be accelerated and the traceability of products and materials in the industrial systems can be greatly increased. Digitization also provides opportunities to increase industrial resilience to challenges coming from elsewhere, such as demographic change and climate threats. Advanced application of digitization is seen by industries and decision-makers as the most important enabler for achieving the strategic sustainability goals and Agenda2030.

A crucial factor for competitiveness is the human contribution. Here too, digitalisation is radically changing the conditions. In the last 20 years, work instructions have been transformed from printed text on paper into an increasingly digital representation. As knowledge increases about how work instructions for the manufacturing industry should be designed, they are rarely designed according to user conditions. At best, this results in a missed opportunity for performance improvements and at worst, it could potentially result in quality deficiencies, efficiency deficiencies and a lower degree of inclusion of staff groups. Digitization and automation permeate both society and industry more and more and there are many different technologies on the market. These can contribute to both increased efficiency and flexibility for the industry. However, there are a lot of challenges to both implement, design, and use instructions. Studies conducted in industry 2014–2018 show that operators and assembly workers only use instructions in 20–25% of cases in the operational phase when they are perceived as inefficient (Fast-Berglund & Stahre, 2013; Mattsson et al., 2018). Of course, this also increases the risks of, for example, assembly errors by not using instructions to the extent that they should be used. The corporate culture and standards are also an important part of how instructions are created and used. Depending on the structure and condition of the company and the production unit, for example, an assembly instruction at one company may include information about the product, process, and work environment, while an assembly instruction at another company includes completely different or only parts of this information. Of course, this is a natural consequence of sometimes far-inherited corporate cultures and traditions, but experience has also shown that it is to a very large extent the nature of work that defines the type of support system needed.

In line with increased automation and increasing product variation as a result of increased customisation, operators' tasks will require more creative work than before where the aim is to enable and handle the results of individual workers' creative thoughts about improvements in their own work situation, increasing cognitive load

(Taylor et al., 2020). The development of digitalisation has created new opportunities for improved communication among employees in the manufacturing industry (Oesterreich & Teuteberg, 2016). Therefore, this technological development can and should support operators cognitively (Kaasinen et al., 2020; Mattsson et al., 2016). Although many new digital technologies are being developed and are available (Romero et al., 2016), it is still difficult to implement these so that people's cognitive work is supported. This is often due to the fact that the implementation does not take place in a way that people are comfortable with (Parasuraman & Riley, 1997). In many cases, humans are expected to adapt to technology and not the other way around (Thorvald et al., 2021). To implement better support for their operators, companies should focus on identifying the information needs that exist (Haghi et al., 2018) and then visualize it in a way that is useful to operators.

The central aim for the project is to demonstrate how knowledge and systematic development of cognitive support and information design can increase quality and flexibility in future production and how this can be considered in the implementation of digital work instructions. In the industrial case studies, current state-of-practice in information presentation will be investigated and analysed together with state-of-the art knowledge and technology to map successful efforts in industry, identify what it is that makes them successful, or how a particularly challenging situation can be further improved through our knowledge of cognitive work in production.

1 Introduction

Throughout history, manufacturers have strived to improve their performance by utilizing industrial revolutions to enhance production capabilities. These improvements have historically focused on making production lines more efficient and effective, resulting in mass production of identical objects. However, in the late 20th century, consumer demand shifted towards customized products, which require workers to produce a high number of alternative versions of the same product by communicating any differences from the base product. It is essential to communicate when to make a specific variant correctly, to the right person, and support the worker in performing the assembly activity accurately to reduce the risk of manufacturing errors as an increase in the number of variables increases the risk of errors. The increased demand on manufacturing workers due to the increase in customization and higher levels of optimization enabled by Industry 4.0 means that the digital transformation offered by Industry 4.0 must also aid workers in filtering and processing information, reduce their cognitive load and support them in multiple ways, which can lead to higher worker satisfaction and performance. To support workers, one approach is to introduce assembly tasks and instructions that consider worker cognitive capabilities and limitations. Given that assembly tasks and worker capabilities can vary, there may not be a single optimal way of presenting assembly instructions for different complexity and difficulty levels, workers with varying experience levels, and under differing workloads. The aim of this project is to explore how to present appropriate assembly instructions for a particular assembly activity and worker.

2 Findings and best practices in current industry

The current state of industrial partners was captured through a visit to the companies that included a presentation of the chosen case, a tour of the factory and the chosen case, a discussion with the company in which a questionnaire was filled in together and two interviews with selected operators. The questionnaire had 18 questions (Appendix A) and served as a basis of the current state analysis. The companies Swegon, Saab (division of Aeronautics and division of Surveillance), Husmuttern, Volvo GTO, and CEJN were visited. Even though the companies differ on many accounts, they have different takt times, different challenges with variants and types of products etc., many common challenges were found.

Figure 1. Picture from when the researchers visited Saab Kallebäck.

Even though the companies included in the study were not similar the needs had an overlap specifically on four points. Together with the experiences at the tour in the factories, previous knowledge from the experts joining the tour and the discussion the following main findings were concluded, see **Fel! Hittar inte referenskälla.**. The four needs are: 1) Simplify the design of instructions, 2) Reduce training/learning times, 3) Visualize process updates, and 4) Knowledge increase in general. The four points are described below.

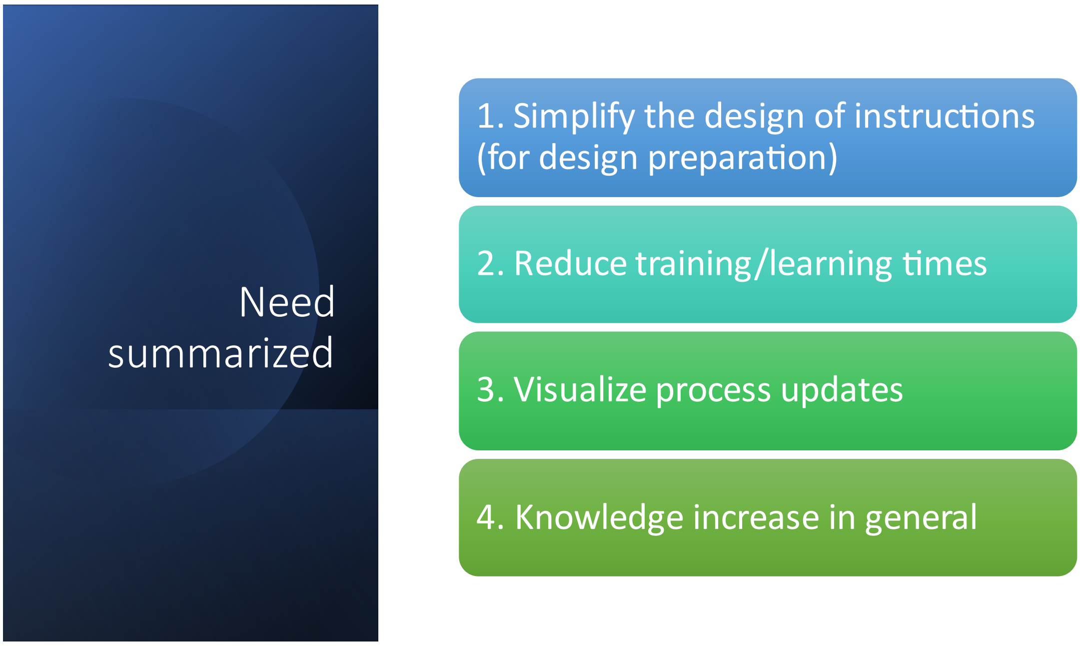

Figure 2. General needs identified at the company visits.

The first need, **Simplify the design of instructions** (1, for design preparation), emerged due to that there is a need for creating instructions in a more efficient way. Even though product variants for the chosen stations is low in general the development of instructions is prioritized since the companies generally has a high product variance. The variance creates challenges for the design preparation and many companies are thinking about how the process of making instructions can become more efficient e.g. even automatic. Today many companies have a lot of different types of instructions e.g. different in design, notes, visual aids and standards and/or strategies for developing instructions are missing i.e. for design preparation in particular.

Another need is to **Reduce training or learning times (2)**. The characteristics of the stations are i) long learning times, ii) different types of competencies and that iii) a visualization of the end product is missing. Today many companies have experienced that new operators don't stay longer than 2 years at the same place today and today many companies are hiring personnel from consultant firms to perform the assembly which puts a lot of stress on the learning and information handling system.

The third need is to **Visualize process updates (3)**. In general, it was seen that few assembly product errors are seen, but instead companies are experiencing process errors. This could be due to that operators do not understand or perceive the changes that are performed to the process. Some companies have worked with continuous improvements and highlight changes in e.g. meetings and separate instructions that are signed by all assemblers but still there are process errors. Maybe this could be represented in another way. In addition, operators want to so the end product in the instructions.

In general companies want a **Knowledge increase in general (4).** Even though many companies have been working with instructions and have good instructions they feel that they are lacking competence and knowledge to create instructions in a structured way. Standards and/or strategies for information presentation as a support is missing. As an example, the companies report that they don't know where instructions should be placed and how they should best be presented e.g. many types of instructions are presented using different colors and symbols. Tips and tricks is wanted to support companies in increasing their knowledge in a fast way.

These findings were validated by the companies at the project meeting in Skövde 25th of January 2023. At the meeting results from the interview analysis were also presented. The data collected from each company is seen in Appendix B.

2.1 Results from interviews

Interviews were conducted at 6 partner companies to assess the current state of instructions at the companies, with an emphasis on the tacit knowledge held by employees. Each company presented their requirements at project meetings and was subsequently visited where they presented in more detail the design of the information presentation for assembly instructions on selected assembly stations, how assembly is nominally performed, and diverse processes for e.g. improvement and quality control. The facilities were then toured, and assembly operations were observed.

Two workers were interviewed at each company. Workers' experience ranged between 2 to 25 years. Audio was recorded of each interview except at one company due to policies in place. In this case, notes were taken. The interviews were transcribed verbatim, and coded for themes. Codes were analysed to find similarities, or dissimilarities. Transcripts were further analysed from the standpoint of 3 main points: Worker experience (beginner/experienced), assembly complexity (simple/complex), and how common the variant is (common/rare).

These themes are used to present the findings from the interviews. Note that some findings may be (or seem) obvious, but even these should be included. The interviewed personnel generally showed an excellent understanding of their systems and an interest in making improvements. Furthermore, interviewee criticisms and preferences are mostly supported by current state-of-the art in usability and user experience design.

2.1.1 Findings

The findings are presented as general findings, and then categorised by the three themes that have been introduced: Worker Experience (beginner/experienced), Complexity of Task (simple/complex), and Variants (rare/common). Findings in the categorised sections may in some cases replicate the those presented as general findings, in which case explanations mostly apply to the specifics of the preference as it pertains to the current category.

In general, workers preferred:

- Simplified visual instructions as the focal point and mentioned CAD images as being far preferable to photographs.
- A picture of the final, assembled product after the current assembly step.
- Step-by-step, with suitably small steps.
- Show text as support where needed. In some cases, by interacting with the instructions (e.g. clicking on a particular image).
- A viewpoint on the image that matches the assembly worker's viewpoint was seen as being important.
- Clear and simple highlights on images.
- Standards, i.e. that all instructions follow the same standards for style and formatting. That highlights do not differ based on who made the instruction.
- Making the instructions representative of how the assembly is performed. If not, assembly workers find their own way.
- Integrating the assembly instructions into the task if verification is required. Workers report that where they should read one instruction, perform an assembly step, go to the computer to verify, then read the next instruction etc. they instead glance at all the instructions, perform all the assembly steps, then go to the computer, and verify all at once. They are aware that this increases risks of mistakes but argue that the risks are low and that mistakes can be caught at the next station. Workers ask for easy, low mental/physical/time cost ways for verification.
- Photographs are disliked by interviewees, who mention photos unprompted as being inferior (although having a photo is seen as being better than no graphical support at all). Interviewees made comments to the effect of photographs being hard to read in good conditions, but in bad conditions (e.g. poor lighting in the

photo) or at the typical assembly distance then the photographs are generally not seen as being helpful at all.

- A simple connection between parts/tools in instructions and in the world. Avoid parts numbers for screws or tools, use instead a concept that works with human attention and both short term and long-term memory. Concepts such as "10mm socket wrench" or 8x10mm screw are helpful, part numbers cause problems.

Highlights on the CAD image that show WHERE the screws or objects should be mounted are particularly highlighted by workers where either variants may have wildly differently mounted elements, or many points that need attention for screws, sealant, or other specific tasks to be performed or double checked. For this, the workers showed a preference for the clearest and simplest method used in their own company, in many cases red circles or the like.

Experience:

- Beginners: Step-by-step instructions are seen as more important for beginners.
- Beginners: Require all steps to be included, in the correct order.
- Beginners: Video instructions, including looping video, is seen as being helpful.
- Experienced: Can handle more types of instructions and more complex assembly. Need little support for standard assemblies.
- Experienced: Prefer mostly images that can be seen from the assembly station and avoid going to the screen for verification more than necessary.
- Experienced: Do not notice gaps in instructions or questionable order of operations. Assemble "their way" anytime instructions are unclear. More precise instructions help with keeping a standard. Experienced workers mostly notice gaps or problems with assembly order when training new personnel.

Somewhat surprisingly, experienced assembly workers not only pointed out the benefits of simplified visual instructions for beginners, but also preferred those for themselves. The experienced workers showed a strong preference for simplified 3D images showing the product ready after the current assembly. The preference was particularly clear when it came to assembling variants that are less common or require unusual manoeuvring of objects. An extremely experienced worker said, "I can work with text instructions that say, for example 'fasten clamp, connector inwards'", but they then follow that by stating that having images is much better for beginners, and also better for themselves, and visual instructions for orientation of elements such as clamps or other fasteners is helpful.

Complexity of task:

- Low complexity: Detailed instructions only needed for beginners, then step-by-step graphical instructions are seen as better, or videos.
- High complexity: Interactive 3D CAD images were seen as being helpful for complex assembly work.
- High complexity: Markings highlighting location of screws, sealant, or other items that must be placed correctly is critical. Text instructions were described as particularly unhelpful for this, even for highly experienced workers.

Higher task complexity, unsurprisingly, led to a preference for more detail, but also a better overview. Experienced workers with access to displays that showed the product ready in a main picture and steps in images below were extremely positive as to how useful that type of display is, while workers with simpler tasks pointed to that kind of display as being useful to train beginners.

Variants:

- Rare variants: Getting CAD generated images of rare variants was requested by most workers.
- Rare variants: Video (including looping video) was also suggested by some workers as being helpful for rare variants to assist the memory, even for experienced worker.
- Common variants: Minimizing the information shown, after training. Workers reported not using instructions for common variants, except for verification after assembly.

Surprisingly many interviewees pointed out problems with getting visual instructions updated. The more complex visualisations such as CAD images animated CAD videos were particularly prone to be missing steps, not be updated quickly for the a version of the assembly, or even having less common variants missing, all of which was reported as being problematic. The workers further pointed out that situations where easy to use instructions were most likely to be missing were the ones where good instructions make the most difference in assembly, such as with uncommon variants, new assemblies, or complex assemblies.

2.2 Use case examples

This section will describe two instruction examples and characteristics from the selected cases. At Swegon work with instruction development has been performed. Figure 1 shows how the instructions are presented.

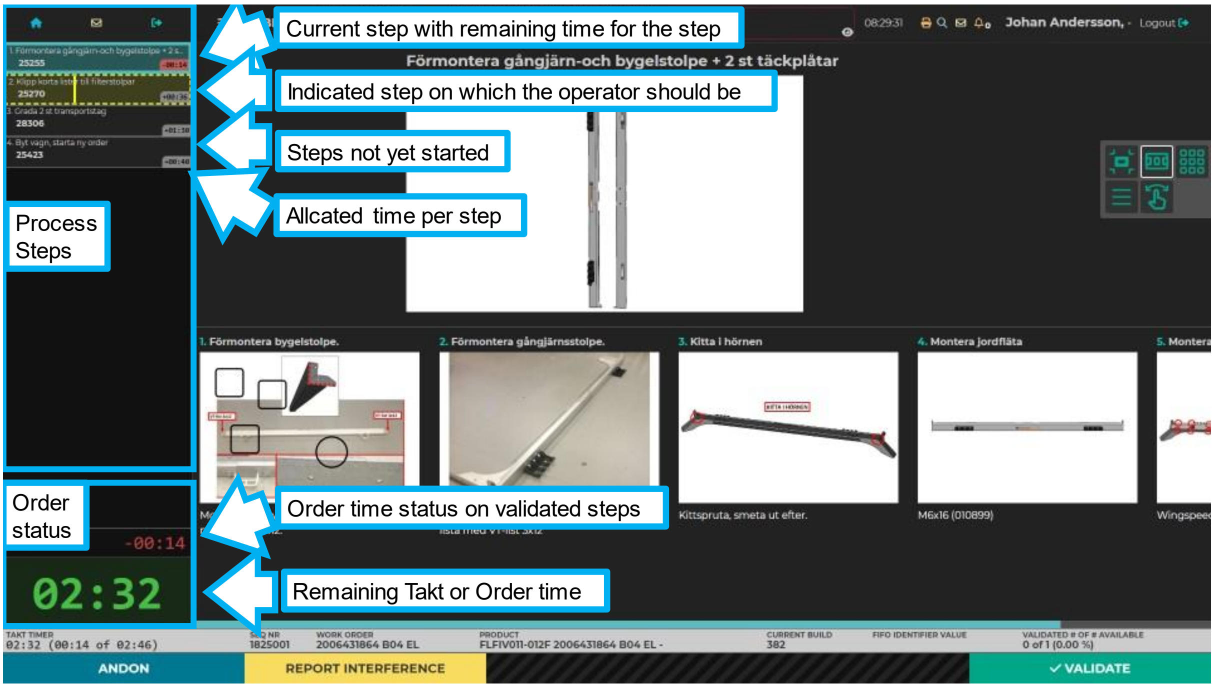

Figure 1. How instructions are presented at Swegon.

While they have not identified a standard for working with the creation of instructions. The following characteristics are seen: Several techniques are used to create instructions, there is no written standard for how instructions should be designed but there is an explicit standard for coloring of markings and arrows as well as cutting of images, but it is not followed 100% by all. As an example, Figure 2 depict different styles of instructions developed at Swegon.

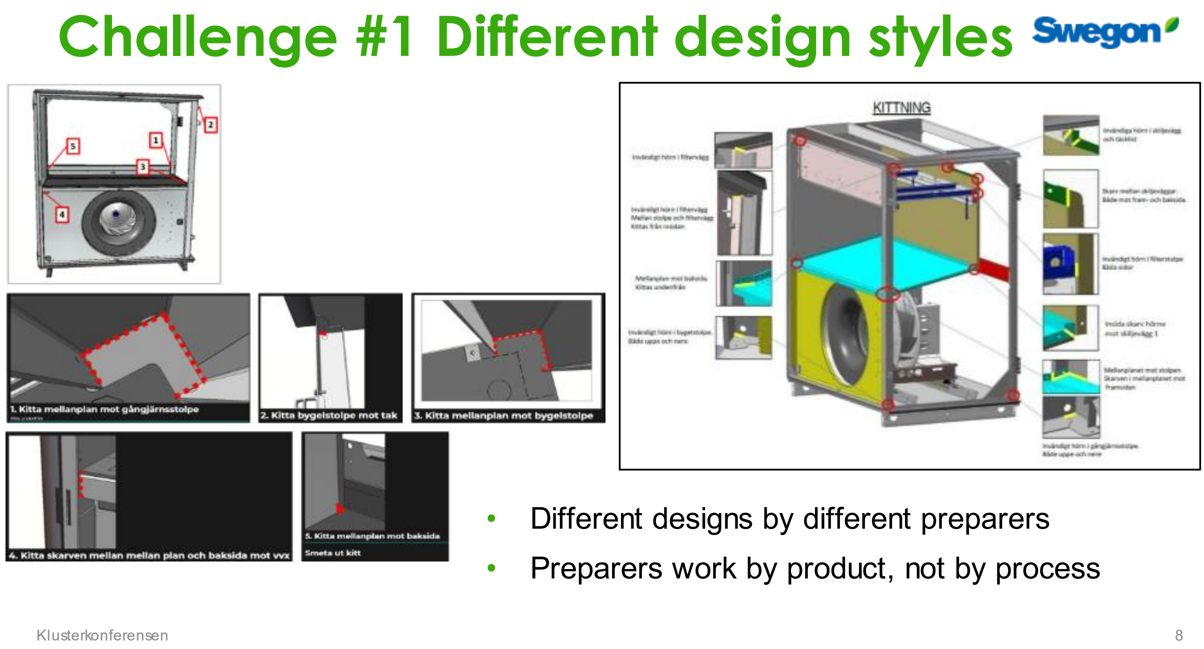

Figure 2. An example of two different design styles by different preparers at Swegon.

In another example, Figure 3, show an example of how different types of information is presented in similar ways. In this case differences and commonalities are indicated the same way which may be a source of errors.

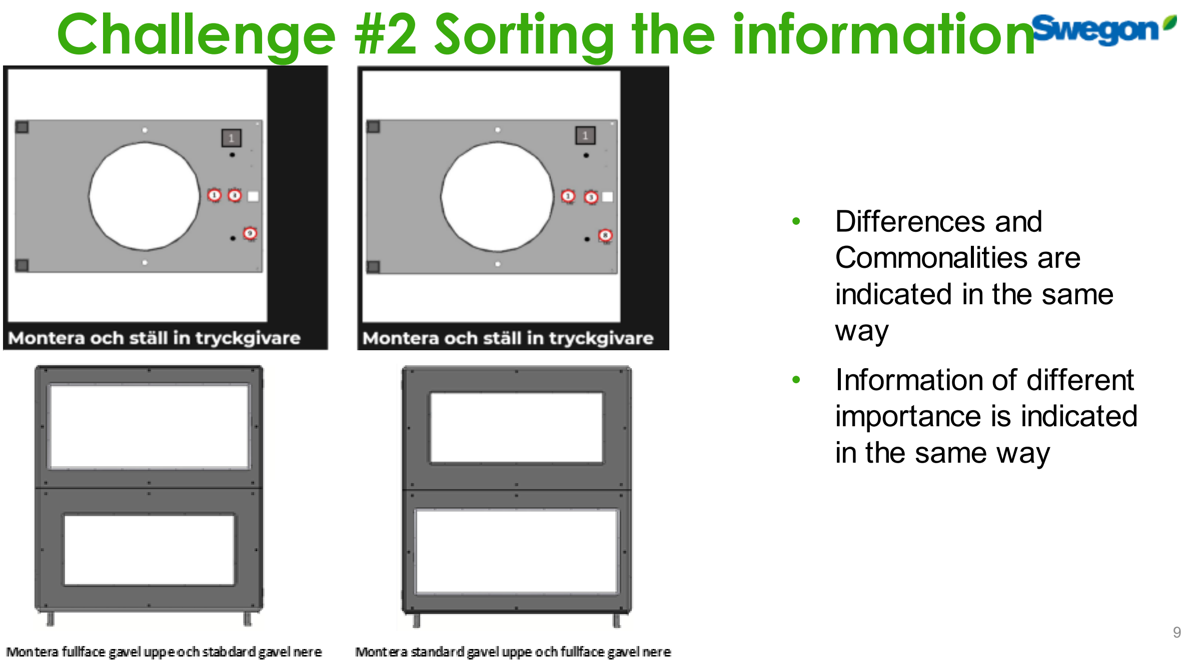

Figure 3. Another example of how the lack of information standards is presenting possible assembly issues.

At another company, that also experience challenges with presenting information another type of information support is used. In Figure 4, a socket rack that is connected to the information system is used to show the operator what socket should be used for that operation and product variant.

Figure 4. Socket rack used for supporting operators with information.

3 State of the art in industrial work instructions

Instructions are a vital aspect of manual assembly processes, as they provide guidance to workers on how to perform their tasks effectively and efficiently. Essentially, instructions can be seen as a form of information that someone must act upon. They can be given in different formats, such as auditory, tactile, and visual, depending on the receiver's sensory preferences and abilities. Regardless of the mode of presentation, it is crucial that the receiver accurately decodes what the sender is requesting to be done and acts accordingly. In a manual assembly line, this means that the worker receives instructions on what to do, interprets and decodes them correctly, and then executes the task. The process then repeats itself, where the worker either receives similar or a new set of instructions, creating what is known as an assembly cycle. The central aim of the assembly process is to achieve the highest possible overall performance, which means that the assembly cycle must be both effective and efficient. The Lean philosophy defines effectiveness as doing the right thing, while efficiency is doing things the right way. Effectiveness is connected to quality and reducing errors, while efficiency is focused on reducing time and effort.

Instructions play a crucial role in both effectiveness and efficiency during the assembly process. They must be well-documented, clear, concise, easy to use by the intended user, and interpreted in the exact same way by different receivers to minimize the risk of confusion and errors, as well as to guarantee quality. However, the quality of the instructions is not the only factor that can lead to confusion and errors. Even if the instructions are crystal clear, if the assembly operation itself is causing problems, the worker might still question if either the instructions are incorrect or if they are misinterpreted, even though there is a chance that neither is true. In such situations, the worker would like to know as soon as possible and with minimum effort what is causing this discrepancy. The question being explored is: In what way should instructions be provided to the manual assembly worker to maximize assembly performance?

One aim of the DIGITALIS project is to analyze and assess the factors that influence the effectiveness of instructions in manual assembly operations and predict how to deliver instructions in the most effective way for certain manual assembly operations. The identified factors of influence include the difficulty of the respective assembly operation, the information that needs to be conveyed through instructions, the format or mode that the information is delivered in, and the experience and skills of the manual assembly worker. By considering these factors, it is possible to design and deliver instructions that maximize assembly performance, minimize errors and increase worker satisfaction.

Kuipers et al (2021) suggests that there is no consensus on what can be considered best practice when it comes to manual assembly instructions, at least not at this time. However, they were able to find some commonalities within the academic literature:

1. Performance is measured in efficiency (time) and effectiveness (number of errors).
2. The assembly process can be divided into retrieving a part, handling a part, positioning a part, and joining a part.

3. Operations can be of different complexity, depending on the complexity of the part, the liaison, and the intricateness of the product, leading to different levels of mental effort.
4. A strong correlation exists between increasing complexity of the task and decreasing performance (increase in time and errors).
5. The assembly process must be channeled and explained through instructions: what must go where and how.
6. A set of instructions must be decoded and interpreted by the worker, and then acted upon, which contributes to mental load.
7. Mental load and mental effort are both factors in an assembly cycle and are additive.
8. Tasks are divided into a series of subtasks (actions).
9. Beginners perform better with step-by-step instruction-based information, while trained workers are prone to err more using the same information and prefer a more holistic approach to instructions.
10. Conventional (paper-based) step-by-step instructions still perform well in comparison with modern technologies.
11. Instruction presentation through current head mounted display (HMD) products and technologies were not seen as leading to higher performance. The results further indicate that current HMD systems increase the mental load experienced by the user, even though many users find it an interesting medium to use.

While some of what is listed above is highly generic and mostly serves to establish a baseline and common ground among researchers (the definition of performance being one such example), the latter part of the list does raise some interesting points.

If *mental load is additive (*or accumulative) then whatever improvements we make to instruction presentation, will assist in keeping mental load down, even if this improvement is made in an area where issues have not been reported. For example, an assumption at the beginning of this project was that a common source of errors was product variation leading to the wrong part being assembled. However, all the companies visited unanimously said that the most common type of assembly errors were process errors, the correct part being incorrectly assembled. Still, an effort to aid in part identification would generate a lower mental workload and thus contribute to the overall performance at the work station even though the mounting of the wrong part was not a common error.

Beginners perform better with step-by-step instruction-based information, while trained workers are prone to err more using the same information, which is further confirmed by the in-depth interviews carried out in DIGITALIS. And furthermore, all interviewees reportedly wished for a holistic image to be presented as part of the instructions. A picture that showed what the product should look like when it left their work station. Holistic approaches to work instructions have been suggested before (Thorvald, 2011, 2013; Thorvald et al., 2012), although they do undoubtedly deserve deeper attention.

The fact that instruction presentation through current head mounted display (HMD) products and technologies were not seen as leading to higher performance, is not very surprising as in fact, empirical studies performed since Kuipers et al's (2021) review have further confirmed this (Drouot et al., 2021). While several successful industrial AR applications have been developed in the last century since the technology became widely available, few if any of them have been applied to high volume production but have rather been applied to use cases in maintenance, remote guidance, and seldom occurring or particularly challenging assemblies.

3.1 Sequencing of information

Minimalism of design is a concept that often occurs in Human-Computer Interaction (HCI) (Brockmann, 1990; Carroll, 1998). It is a concept that emphasizes the presentation of as little information as possible to reduce the perceptual strain and visual search of the subject. However, in manufacturing, state of the art information presentation is rarely minimalistic. Rather, organizations tend to push out as much information as possible without necessarily concerning themselves with how this information is presented to, or perceived by, the worker. Obviously, there are several potential ways of addressing this issue. Perhaps the most evident way is to simply reduce the amount of information that is presented and only present the essentials. However, this is not always possible due to internal policies of organizations etc., and so the question is, how can information be minimised without removing bits of it? One way to do this is to consider the sequencing of information and the reduction of redundant information and the use of sequenced information presentation, i.e. if two identical parts are to be assembled, they can be presented sequentially and separately or they can be batched together. Figure 5 shows an information interface where the information is sequenced.

Part	Quantity	Description
Part A	1	Assemble part
Part B	1	Assemble part
Part A	1	Assemble part

Figure 5. Sequenced information.

Sequenced information presentation is, as in the case in Figure 5, where the same part occurs several times in the interface. The reason it is dubbed a sequential way of presenting information is because the parts are presented in the sequence they are to be assembled, i.e. they present some kind of process information about how the work is to be carried out. This leads to a paradigm question for each organization interested in these matters to ask themselves; is the information source meant to present *process information* (related to *how* to assemble) and/or *product information* (related to *what* to assemble)? Naturally, assembly information without process information requires adequate training in the assembly process. In such case, the workers must know *how* the assembly is to be done, as the information interface will rather tell them *what* is to be assembled. Indeed, process information should always be available to a worker as the *how* can be equally important as the *what*. However, process information often remains the same, even though a part may be changed to a variant part; this new part is usually assembled in the same way.

Part	Quantity	Description

Part A	2	Assemble part
Part B	1	Assemble part

Figure 6. Sequenced information.

In Figure 6, the information is unsequenced as each part is only listed once regardless of the sequence of assembly or the quantity of the parts. While this may be seen as a small gain of a.

3.2 Minimalistic design

A natural result of sequencing information is the reduction of the design. Minimalist design has long been a topic of research in Human-Computer Interaction (HCI) (A. Dix et al., 2004; Preece et al., 2002; Preece et al., 1994). Through minimalism, interfaces are uncluttered and only include essential information, there to meet the specific needs of the users.

The results of the above investigation at our collaborative companies, coupled with the ideas of minimalist design, leads us to propose two strategies for minimalistic design: the prototype product strategy and the difference from last product strategy.

The *Prototype product strategy* proposes the establishment of a prototype product to serve as a baseline upon which all other products can be based. This prototype is ideally the most common or most “standard” product at this workstation. For a whole line it might be difficult to identify a prototype according to these requirements but on a workstation level, it should be possible. We then suggest basing all information on additions or subtractions to this prototype product whose assembly sequence and associated parts are learnt in training or available through secondary information sources. The aim is that when a prototype product is being made, no information is needed. When a product that differs from the prototype is to be produced, only the parts and processes that differ from the prototype need to be presented. Benefits are that the interface is very easy to get an overview of the information, it utilizes long term memory (Baddeley, 1999) rather than short term memory which is more stable, reliable, and has larger capacity for storage.

The *Difference from last product strategy* is like to the prototype strategy but instead of utilizing a prototype product, the baseline is taken from the last product produced. So, if no information is on the screen, the same product as the last should be made, but if something is on the screen, then something else is to be made. Similarly, to the prototype strategy this strategy is easily overviewed but does rely on short term memory rather than long term memory which makes it more fragile. It does, however, not require a prototype product to be established.

Both, the prototype product strategy, and the difference from last product strategy have the additional advantage that it is easy to get an overview of the screen even from a distance. If the screen is empty (which often can be seen from a distance) then no more information is needed. If the screen is not empty (which can also be seen from a distance even if the detail on the screen is not fully readable) then there is information that the worker needs to collect.

3.3 Information range and mobility of information

The physical dimensions of a workstation along with the visual range of an information source is a rarely researched but highly relevant aspect of industrial information delivery. Thorvald et al (2014) utilized mobile information units to increase information range and showed a substantial improvement in quality. From the perspective of range, two theoretical stances can be complementary.

The stimulus-response gap has proven to be a significant “dark horse” when it comes to problems in assembly documentation. As the term suggests, the problem arises when the worker is somehow not allowed to directly act on a piece of information and when this information is not presented or attended continuously (Dix et al., 1998). An example directly from the automotive assembly industry is a quality measure where a worker must sign off on performed work. Let us say that this is represented by a blue symbol representing a blue button that is used for signing off on the work. The blue symbol is added to assembly where something is out of the ordinary. Perhaps something needs to be assembled differently or something is replaced by something else. A common assembly strategy here is to, at arrival of the work piece, look over the assembly documentation, notice if anything is out of the ordinary, and begin assembly. If the information, the blue symbol in our case, cannot be acted upon directly, it is likely to be forgotten due to the stimulus response gap. Remedies for this include supporting users to have more of a real time access to assembly documentation so that every bit of information can be acted upon directly, or by allowing for a continuous activation of the stimuli. As this problem generally arises when something differs from the standard, this extra trigger, like our blue symbol, should be made available and should be attended continuously. In this case, the symbol is available continuously, but it is not attended continuously due to the assembly documentation being located away from the work piece.

Related is the concept of information range which in turn can be seen in the light of the expectancy-value model (Wigfield & Eccles, 1992; Wigfield & Eccles, 2000) or the similar cost-benefit model (Boardman et al., 2006; Jonides & Mack, 1984). Both models deal with the cost of doing something and the value or benefit that this action is likely to yield. Thorvald et al (2014) argued that by increasing the range of information, i.e. the area within a work cell where information can be consumed (in their case though mobile units), the cost of gathering the information is minimized leading to information that can be easily attended (even if not continuously). The results of the experiment in Thorvald et al (2014) confirmed their hypothesis and observations revealed that subjects were much more inclined to “double check” their information when doing so was relatively cheap in terms of effort.

3.4 Draft of guidelines

One of the main deliveries of the DIGITALIS project is the “Guidelines for industrial information presentation” to be delivered at the end of the second year. A draft of these guidelines has been developed and presented to the project. The guidelines, as they are presented here, are a result of the academic state of the art in information presentation. In summary the guidelines describe the following:

- Information is costly – Any cognitive or physical effort to collect information is judged against the subjective assessment of its value.
- A picture says more than a thousand words – While pictures are a great aid for easy communication and overview, photos are often much harder to visually process due to their abundant information content.
- Visual hierarchy – The human perceptual system responds in order to; movement, contrast, colours, and details.
- Different users, different demands – Novices and experts want and perform differently with different types of information.
- The AR paradox – While users generally are positive towards AR HMD's, empirical study shows no positive effect in performance.
- Time changes everything – If time was not a factor in professional assembly, all instructions would look like IKEA instructions.
- The stimulus-response gap – The longer time between a stimulus and the proper response, the less likely it becomes that the action will be carried out, or carried out successfully.
- UX guidelines – Follow established UX guidelines.

3.4.1 Information is costly

Research has shown, mine and others, that the cost of gathering information is leveraged against the hypothetical benefit that the information offers (Thorvald et al., 2010; Thorvald et al., 2014). The benefit of information in such a case would simply be, do I think that this piece of information is important to my current task? This is weighed against the cognitive and physical cost of gathering said information. If the information is easily collected by its placement, design, and relevance, this low cost will always overcome the potentially low benefit of the information, but if for some reason the cost is high because we've made key information hard to reach, hard to read, or, as is often the case, hidden among a bunch of other irrelevant pieces of information, cost will too often be deemed too high compared to the benefit. It won't happen every time, it might not even happen very often, but it will happen. Figure 7 shows how an expected high information value will always result in the collection of information but a low information value coupled with a high effort of collecting it, might result in the information not being collected.

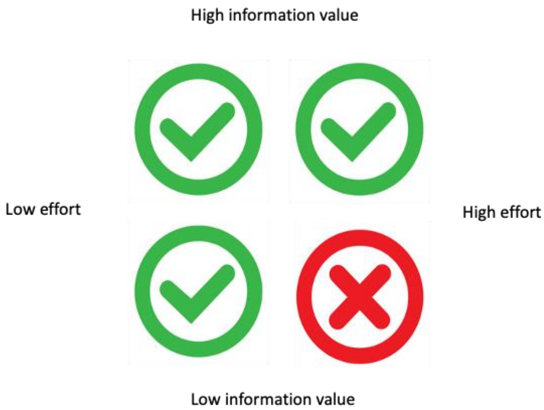

Figure 7. A schematic of the relationship between information value and effort.

So, when designing an assembly instruction, remember that there is always a cost to collecting a piece of information. Help your personnel by making that cost as low as possible. There are several ways to do this but considering the less-is-more principle is one of them. Consider what information it is that your personnel actually need and looks for and make this stand out. Make it visible from a distance by removing other information or perhaps increase the range of your information system by introducing handheld information units or larger screens that can be seen from afar.

3.4.2 A picture says more than a thousand words

In our research we have found that simplified visual instructions and CAD images are often popular among workers (Kolbeinsson et al., 2023). Many stating that suitably small step-by-step instructions and/or an image of the product after the current task is preferred. But beware of using unedited photos as information carriers as photos carry much more information than is required and can easily end up overloading the visual input and claim much more cognitive capabilities to process than a simpler sketch or wireframe would. There is a reason why IKEA instructions look as they do. Also, remember to produce the picture from the same viewing angle as the worker would have over their task.

3.4.3 Visual hierarchy

There are an abundance of ways that one can view different types of visual hierarchies and visual input prioritization (Rust & Cohen, 2022; Zelinsky & Bisley, 2015). Many of them are employed in UX to guide designers towards using contrasting colours or negative space among other aspects of design. For this recommendation, we will simply suggest the internalization of the inherent order in which humans process items in the visual array. Movement is the highest priority in visual processing as it most likely has been associated with an evolutionary advantage where it helps to warn humans against potential threats (Rookes & Willson, 2000). While movement is a very powerful tool due to its intrusiveness, it should also be used with extreme care as it can become very annoying and create unnecessary visual noise if overused. The second item on the list is contrast. Contrast in terms of light on dark or dark on light is very powerful in catching the user's attention and guiding them towards a piece of information. This is one of the reasons why a word written in **bold** stands out in a piece of text. Third, and more than halfway down the scale, colour is a wonderful tool in the designers toolkit to make sense of a piece of information, but perhaps not the best way to catch the attention of a user. Also, bear in mind that up to 8% of males suffer from colour vision deficiencies (only about 0,5% in females) (Simunovic, 2016).

3.4.4 Different users, different demands

The user category can be cut in many ways but in these recommendations, we will focus on different levels of experience. A novice and an expert don't just differ in terms of the explicit knowledge they have but a higher level of experience affects how users organize and interpret the information that is available. They simply become very good at recognizing and interpreting patterns in the information that is relevant to their work and can therefore ignore the information that they do not need. Information that is important to the novice may be superfluous to the expert. This was also one of the main findings of both Kuipers et al (2021) as well as the industrial study we made (Kolbeinsson et al., 2023); b*eginners perform better with step-by-step instruction-based information, while trained workers are prone to err more using the same information and prefer a more holistic approach to instructions*.

3.4.5 The AR paradox

Industry 4.0 is an industrial paradigm very much focused on enabling technologies (Hermann et al., 2016) and the human centered aspects of it are no exception. Enabling technologies such as collaborative robots, exoskeletons, extended reality, among others are very central to the human centricity aspects in Industry 4.0 and have been explored under the typological umbrella of Operator 4.0 (Romero et al., 2016; Ruppert et al., 2018; Thorvald et al., 2021). For information presentation, augmented reality (AR) is of great interest and many academic and industrial efforts have been undertaken during the last decade, trying to utilize AR for information presentation with varying success (Danielsson et al., 2020; Danielsson et al., 2023; Henderson & Feiner, 2009; Syberfeldt et al., 2015). Some of the first and, still to this day, most successful applications have regarded remote guidance and support (Lapointe et al., 2020), and for this type of work in the disruptive phase of work, AR has proven most promising. However, application of AR in assembly instructions has to a large extent failed to show effective results (Kuipers et al., 2021). In fact, more recent empirical studies have shown that using AR head mounted displays result at best in no improvement in performance and often even in worse performance (Drouot et al., 2021; Drouot et al., 2022), even though workers subjectively seem to be very positive towards the technology and reportedly want to use it (Kuipers et al., 2021). Hence, the AR paradox.

3.4.6 Time changes everything

Some of the most known instructions in the world are those of Swedish furniture retailer IKEA. Their instructions, very well researched, are globally used and directed at all types of users all over the world, from those who work professionally in assembly industry to those who have never held a screwdriver before in their life. When viewed as such, one cannot argue with the fact that IKEA instructions are very well designed indeed. The characteristics of and IKEA instruction is that they are pictogram or infographics based with hardly a written word in them. They utilize stylized pictograms to convey information about both the product to be built and the process that should be undertaken. So, with that in mind, why don't we use IKEA type instructions for professional assembly? Well, because time changes everything. An IKEA instruction and the level of detail that goes into it is designed to be correct, not necessarily to be time efficient because to the IKEA customer, if something takes another couple of minutes to assemble, this is not a big problem. If we had the same attitude to professional manufacturing, that time was almost completely unimportant, we would run into huge efficiency problems. Assembly instructions for professional assembly need to be minimalized to reduce the cost of gathering information and it often does not need to include both product and process information as the way to assemble a product should have been taken care of in training. At least this is true for volume production.

3.4.7 The stimulus-response gap

To further the understanding of the stimulus-response gap as Dix, Ramduny-Ellis and Wilkinson (2004) presented it, consider yourself receiving a text message on your phone that you are expected to respond to. What would the implications be if you were unable to respond right away? Perhaps you are interrupted, and your attention is required elsewhere or maybe the response requires investigation of something first. The trigger that the incoming text message signal constitutes, in terms of responding to it, is lost. You would have to actively remember that you are to send a message, or you will fail to respond. A plausible and existing system in the assembly industry is that when a work piece arrives at an assembly situation, the worker investigates the information system, gathers information, and receives triggers that inform the worker on what is to be assembled differently from the usual scenario, a common item of assembly might be changed due to customization, and finally continues to perform the required actions. Let us say that article B is to be used in place of article A, which is the more common one. If the worker cannot perform the assembly of the article at once after the information is consumed, there is a great chance that the most common one is assembled in the haste. So, trying to reduce the gap between the consumption of information (the stimulus) and the action to be carried out (the response) would be recommended. Either by rearranging the work process so that the response can be carried out directly or by editing the information source so that it is readily available when and where the response is to be carried out. Very much related to the cost of information that we discussed above.

3.4.8 UX guidelines

The creation of successful professional work instructions is not merely about what happens on the screen, as we have hopefully established in this report. The nature of the work and the workers is of equal or perhaps even larger importance as the consumption of information starts long before even the first glance at the graphical user interface. However, once this has been established, following UX guidelines for interface design is very important for effective information collection. The below list is a collection of established UX guidelines deemed relevant to this domain.

- Use understandable syntax by using an objects physical properties as identifiers; For example, the red key rather than key #9 (Lindblom & Thorvald, 2014).
- Use highlights sparingly. Bold text, colour contrasts etc, will draw the attention of the user, so use it with afterthought.
- Avoid using capital letters as they are more difficult to read in running text.

- Use proper alignment (Figure 8) and directions (Figure 9) to the interface to improve navigation (Mullet & Sano, 1995).
- Similarly, to using an understandable syntax, use objects and language that is known to the user. Recognition rather than recall (Hartson & Pyla, 2012).
- Standardize instructions by design and syntax so to enable recognition.
- Use mapping and matching concepts to create conformity between the system and the real world (Hartson & Pyla, 2012; Norman, 2002).

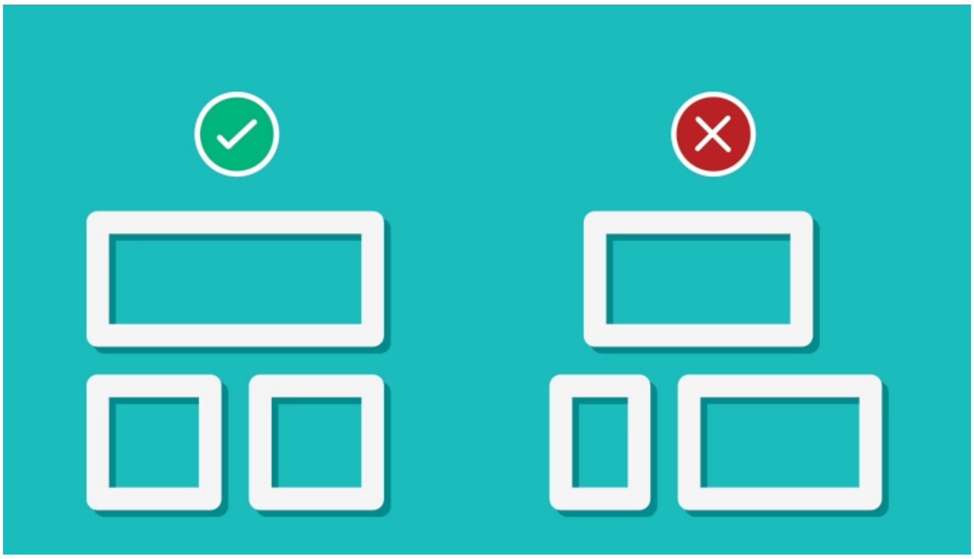

Figure 8. Illustration of alignment.

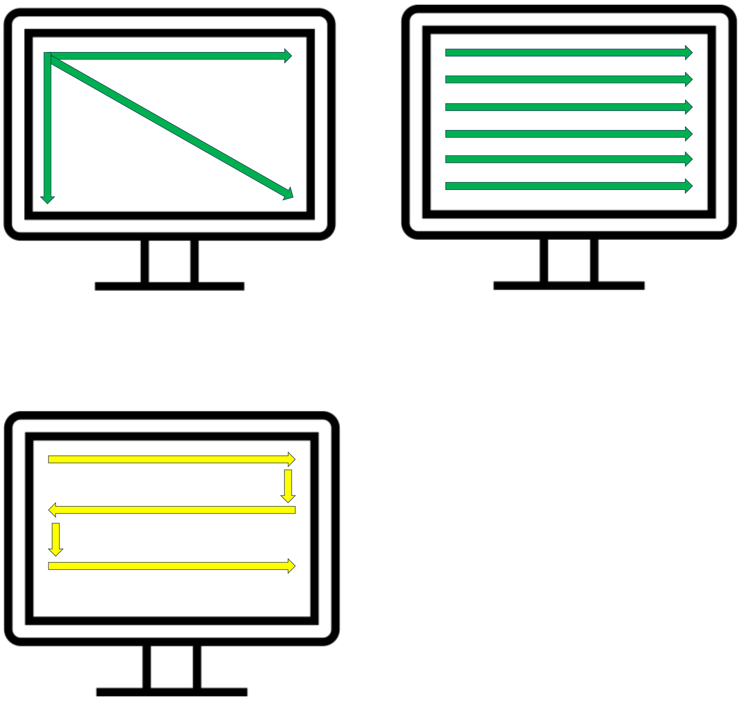

Figure 9. The direction that a screen is scanned.

4 Technical state of the art in information presentation

Using technology to convey assembly instructions to operators is crucial, significantly enhancing clarity, standardisation, and comprehension (Li, 2021). Moreover, it enables real-time updates and multilingual support, boosts training and onboarding procedures, and simplifies data analysis for the process optimization (Gong et al., 2017; Li, 2021). By incorporating technology, organisations can elevate their productivity, minimise errors, and attain higher levels of quality in their manufacturing operations.

Incorporating visual components, such as images, videos, and animations, into instructional materials through technology can enhance comprehension, minimise errors, and prevent confusion (Fast-Berglund et al., 2018). Technology allows the standardisation of assembly instructions, promoting consistency among operators, shifts, and locations. These instructions can be centralised by digital platforms, making updates and distribution simpler, leading to fewer errors and increased quality and efficiency. Thanks to technology, assembly instructions can now be updated in real-time. Whenever changes are made to a product's design or manufacturing process, these updates can be quickly implemented and shared with operators. With this level of agility, operators are always equipped with the latest instructions, significantly reducing the risk of errors resulting from outdated information.

To operate in a globalised manufacturing environment, having a diverse workforce with individuals from different linguistic backgrounds is common. To ensure effective communication and precise instruction following, it is imperative to leverage technology for translating assembly instructions into multiple languages. This approach eliminates language barriers, allowing all operators to access the instructions regardless of their native tongue. Technology provides interactive training modules and simulations that prepare operators for assembly tasks, reducing errors and boosting efficiency (Smith et al., 2020). Digital systems can track assembly process data, including task completion times, errors, and operators. Analysing this data can identify areas for improvement, optimise processes, and improve productivity and quality control.

4.1 Infographics

Infographics are visual representations of data or information that use a combination of text, images, and graphics to communicate complex concepts clearly and concisely (Castillo, 2019). Infographics are an excellent tool for presenting assembly instructions or procedures to operators. They simplify complex steps or processes by visually representing them through images, icons, arrows, and text. This makes it easier for operators to understand and follow along, highlighting key actions or components. By presenting information visually, infographics help operators quickly grasp the sequence of tasks, reducing the chances of errors or misunderstandings.

Infographics make it easier for operators to analyse and interpret statistical information by presenting it visually through graphs and charts. They summarise performance metrics and highlight improvement areas, empowering informed decision-making.

Infographics help present safety guidelines, hazard warnings, and emergency procedures to operators. They are particularly effective in industries where safety is crucial, as they can convey important safety information visually and engagingly. Icons, symbols, and colour-coded visuals can represent different safety measures, enabling operators to quickly identify potential risks and necessary precautions. Additionally, infographics can be used to illustrate emergency response procedures, guiding operators on what actions to take in critical situations. Using infographics to present safety information, operators can easily understand and remember the necessary safety protocols, reducing the risk of accidents or injuries.

Infographics simplify complex instructions, convey data, and communicate safety guidelines. They visually represent assembly procedures and tasks, condense data, and improve comprehension. Infographics are handy in presenting safety guidelines and emergency procedures, promoting a safer and more efficient working environment for operators.

4.2 Augmented Reality (AR)

Augmented Reality (AR) technology adds virtual objects/information to the real world, improving engagement and interaction. It revolutionises the communication of assembly instructions, enhancing guidance, training, efficiency, and safety while reducing errors (Smith et al., 2020).

AR has a significant advantage when it comes to providing information to operators. It can overlay digital instructions directly onto the physical workspace. This is much better than traditional methods like paper manuals or computer screens, which require operators to switch their focus between the instructions and the physical task they are doing. With AR, step-by-step instructions, diagrams, or 3D models are projected directly onto the objects, eliminating this need to switch focus (Jeffri & Rambli, 2021).

AR technology helps operators receive up-to-date contextual information through sensors or cameras, leading to increased assembly precision and better product quality. AR has proven valuable in training new and existing operators (Lai et al., 2020). With the ability to create virtual simulations and interactive training modules, AR provides a safe and controlled environment for operators to practice assembly tasks (van Lopik et al., 2020). Immediate feedback allows errors to be corrected and confidence to be gained before performing tasks in a real-world setting. AR-based training provides an enhanced learning experience, reduces onboarding time, increases operator proficiency, and improves productivity while reducing training costs.

AR can improve safety in assembly processes by displaying warnings, alerts, and virtual barriers to prevent operators from entering hazardous areas or performing tasks incorrectly. By highlighting potential risks, AR helps reduce workplace accidents and injuries, creating a safer working environment (Damiani et al., 2020). AR technology also allows remote collaboration and assistance; Operators can connect with experts who offer real-time support and guidance through the AR device. This helps faster problem-solving, reduces downtime, and facilitates knowledge transfer among team members.

4.3 Virtual Reality (VR)

Virtual Reality (VR) is a computer-generated environment that immerses users in a virtual world. It improves operator training, simulates complex situations, and enhances decision-making and problem-solving skills (Nåfors, 2021). VR technology can benefit training and onboarding processes by providing realistic, interactive simulations of assembly tasks and operating procedures. With VR headsets, operators can be transported to a virtual environment that closely mimics their real-world workspace, where they can practice tasks, manipulate virtual objects, and follow step-by-step instructions in a safe and controlled setting (Gong et al., 2017). This immersive training allows operators to gain hands-on experience, refine their skills, and become familiar with the assembly process before working with physical equipment. As a result, the risk of errors is minimised, operator confidence is boosted, and the learning curve is shortened. Individuals can enhance their comprehension and proficiency in dealing with diverse situations by engaging in virtual environments that closely mirror their work settings. In addition, VR technology can enhance operators' decision-making and problem-solving abilities (Dayarathna et al., 2020). VR can challenge operators to make crucial decisions without risks by simulating various scenarios with different variables and potential outcomes.

5 Summary

This report has been developed to conclude the first year of the DIGITALIS research project and has had three main parts; a summary of the data collection done at the case study companies which is also published in (Kolbeinsson et al., 2023). Followed by state-of-the-art reports on both academic and technical aspects of work instruction presentation and lastly a draft of the guidelines for technical information presentation as was declared in the proposal. The coming year in the project will be spent on developing four demonstrators for work instruction presentation and filling the identified knowledge gaps to complete the draft of guidelines.

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Appendix A Data Collection DIGITALIS

6

Company ______________________ Date: __________ Time: ________

Short case description

(describe why there are challenges)

7 The Product

Question 1: What type of product is it and what operations are conducted on the selected area?

Notes:

Question 2: What is the estimated takt time?

Notes:

Question 3: What is the approximate saturation within the estimated takt time?

Example: If takt time is 100 seconds and balancing indicates that it takes 90 seconds to finish all tasks at the workstation then saturation is 90%

Notes:

Question 4a: Is there any product variation at the workstation? Is the selected product a common variant?

Notes:

Question 4b: How much product variation (approximately in percentage)?

Notes:

Question 4c: How is product variation dealt with in relation to high-volume products (e.g. batching)?

Notes:

8 The Instruction and Information

Question 5: What type of information is predominantly presented?

Example Product information, process information, both, BOM, SOP etc.

Notes:

Question 6: Is there any specific strategy for how the information is presented?

Example: Minimalistic design, successive information, etc.

Notes:

Question 7: With what techniques is information delivered (PDA, computer, paper, AR, pick to light, etc.)?

Notes:

Question 8: What modalities/syntaxes/languages are used to mediate information?

Example:	Text, audio, video, photo, symbols, animations, drawings, etc.
Notes:	

Question 9:	What is the range of the information in relation to the workstation's spatial conditions?
Example	Is the information portable or stationary? Does it require moving through a greater area to obtain the information if it is stationary?
Notes:	

9 User

Question 10:	What is approximately the personnel's average age?
Notes	

Question 11:	Approximately how long is the training period at the workstation?
Example:	Time that is required before being allowed to work independently
Notes:	

Question 12:	In what way is training executed?
Notes:	

Question 13: What is the estimated level of experience among the personnel?

Example: High turnover in personnel would indicate a lower experience level

Notes:

Question 14: Between what stations is work rotated at the selected case and other stations? How is rotation executed?

Example Rotation of the station where product is produced and station 3 occurs regularly

Notes:

10 Additional Information

Question 15: Are there universal challenges and/or strengths concerned with your instructions you would like to mention?

Notes:

Question 16: Is there any interest and opportunity for investing in instruction systems?

Notes:

Question 17: Is there any knowledge in particular that you find yourselves missing when it comes to digital instructions?

Notes:

Question 18: What are the most common issues/quality defects in the selected area?

Notes:

11 Additional Notes

Add additional notes.

Appendix B Results summary

Description	Summary	Comment from interviews	Reflection
Case descriptions	Varying cases and slightly varying problems. Two companies have a more similar production and there are also similarities between two other companies when it comes to bench assembly in batches. However, there are big differences in complexity and pace time. Two companies approaches are similar to other companies but with less variation.		In general, the need is an increased understanding of how to make instructions and how to train in large product variation
Comment	Great agreement in the wishes. Standards and strategies for information presentation are lacking. General increase in knowledge about instructions across the spectrum. From syntax to structure to technology support.		They want to get an evaluation of existing instructions
Chosen product	Large products (Swegon, SAAB Surv.), medium-sized products (Volvo, SAAB Aero) and small products (CEJN)		
Tact time	Very great variety. Consideration needs to be given to both shorter batch production and long operations of several hours.		
OEE	Varying within the cases but estimated around 80-85%. Has potentially high impact.		
Product variants	Fairly low variation according to collected data.		
Distribution of product variants	Different among cases. Variation is still something that we must include as it is extremely central to instructions.		
Managin product variance	Lots of manual balancing. Deprioritized		
Information types	Two companies are similar. Others present a lot more information		
Instruction strategy	One company has a well-thought-out strategy for the usability of instructions. Can be developed, very relevant	Most are working with the actual problems, and want to improve, but interviews show a lack of even clear	There is a strategy for how information should be interconnected.

		improvement processes. Volvo maybe closest, as they have some processes for instruction improvement in volymflow. Saab kallebäck have a kind of an improvement process, but it is mostly a roll of the die from my analysis. Mostly relies on contacting konstruktör and hoping that the improvement suggestions propagate (same kind of goes for some of the others). Operators get very little feedback on how their suggestions are taken/acted upon (that runs the risk of being demotivational)	However, not how it will be used by whom, although on the other hand we have not delved into that much
Technics for presenting information	Paper or screen	A lot of screen, with extra information either in another system on the screen that works completely differently, or in binders away at some central station. These binders are not used much, even when they are needed.	
Modalities/syntaxes/languages for information	Text, image (photo, sketch, cad). Color coding occurs and less often video	A lot of text and images. A lot of photos. In most cases, these are not appreciated by fitters. Simplified visualizations are preferred in most cases. Text is rarely preferred.	
Range to information	Limited spatial conditions	Large screens in the booth station, but small text. Pictures often also too small. A lot of surface area goes under lists of regular" assembly"	
Estimated average age	Around 35-40 seems most common (higher than expected)		

Training time	Long training times!	Long. Interviews suggest that training time could be shortened significantly by having: -a more unified system -visualisations that fit the task	
Training execution	Training and tutoring	Long training times, bad instructions are affecting that a lot. Interviews suggest that a lot of uncertainty during training comes from instructions in multiple places/systems, lack of visualisations for important elements, unnecessarily complex codes, etc.	
Estimated level of experience	Great variety	High. Lowest level has been high, experience level and skill levels between companies seems uniformly high	
Rotation	Great variety. Also product-dependent as you do not rotate at long pace times.	Healthy. Staff really appreciates the variation due to rotation	
Company challenges and/or strengths	Low knowledge level		
Investments potential	Yes	Technically focused investments, slow, lack investment in understanding/strategy. Knowledge gap. Companies are very willing to improve and show understanding that there is something to improve, but presentations and interviews show that knowledge about information presentation and information improvement is lacking.	
Company need	Visualization	In this matter we see that very basic UI/UX support could provide a lot. There is a possibility that some of their systems have been developed with some consideration for this (e.g. Swegon), but in the big	

		picture their several systems are in many cases very different / scattered in their information design approaches	
Most common error	A lot of process errors, few product errors.	How do we get fitters to double check? Requested in interviews: Simple 3d models of assembled part, highlighting of important parts, visible from where the work is being done (they don't/won't switch to a screen) Make it easy to verify correct assembly	How to follow up on errors (source for improvements) in day-to-day operations, systems exist but do they generate the desired result in terms of improvements?
Additional notes		Lack of “Why” in the instructions. WHEN is that required. STRATEGY should include this sort of thing We need to develop: Design strategy for instructions Improvement strategies for instructions	A guideline: understand what the problem really is. Then an overall picture is required, which we think we can highlight. We can tell the difference between analysis and what was said in interviews, which is important.

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