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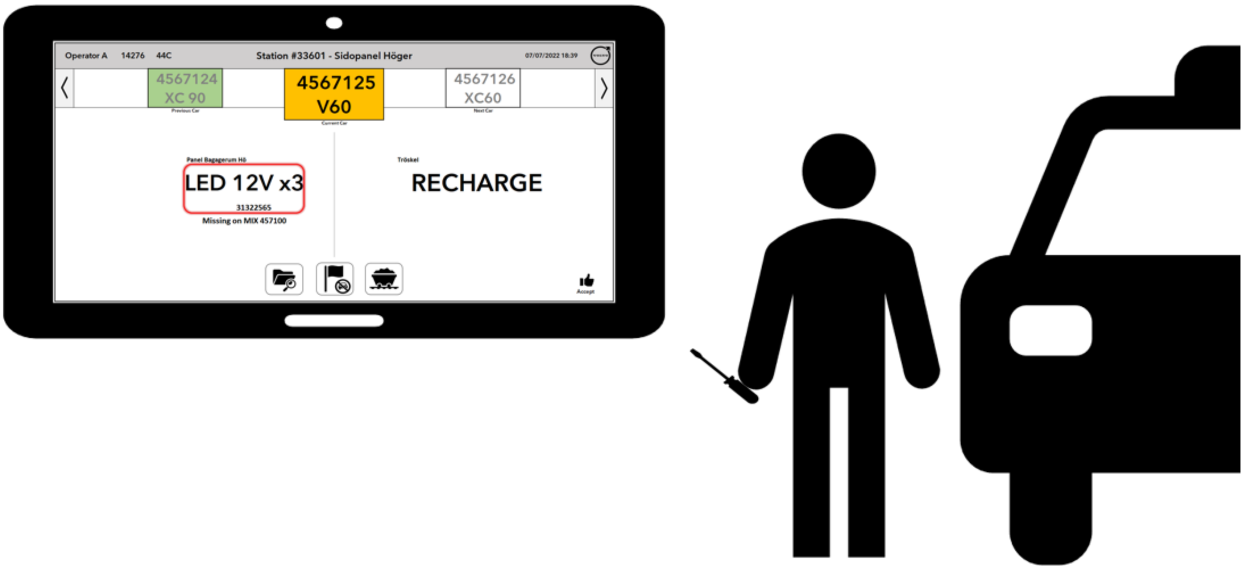

Digitalisation Concept for Personalised Assembly Information at Volvo Cars

Master's thesis in Production Engineering

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Cover: Worker information system displaying personalised work instructions and predictive alert for incoming car assembly.

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Abstract

The onset of mass customization and personalization trends within automobile manufacturing has led to an increase in assembly complexity. High variations within the final assembly stages demand a higher operator cognition in order to maintain quality and efficiency standards. To maintain production excellency, adequate information and support is required during production. With the rise of digitalization within the Industry 4.0 paradigm, providing personalized assembly information and assistive alerts digitally can potentially assist operators in their daily work and lower cognitive workloads. Thus, resulting in better quality and efficiency.

This thesis investigates a digitalization concept for the presentation of personalized assembly information and the generation of assistive alerts via a digital worker information system. By adopting a mixed method approach centred around operators, the study focuses on understanding how available assembly information and different support functions can be digitalized to offer cognitive support. The outcome involved creating a conceptual representation of personalized assembly information for a worker information system from what is deemed important for a moving line scenario.

The most optimal presentation for digital assembly information involves displaying variant-specific information for an operator working at a particular workstation. To support operators with quality, personalized assistive alerts based on their history of quality deviations displayed at the start of production (during operators' login as offline alerts) and during running production (as online alerts), can potentially aid operators in being mindful of their mistakes and remind them towards working in a standardized manner. The generation of personalised information and alerts will depend on employing a suitable system architecture (like a microservice architecture) that enables real-time streaming of data based on events occurring on the assembly line. The implication of such a setup potentially opens new possibilities for digital operator support within complex production environments.

Keywords: Personalisation, Assembly information, Information quality, Cognitive support, Final Assembly, Digitalisation, Industry 4.0, Industrial system architecture.

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Puranjay Mugur & Pravin Kumar Ravichandran,
Gothenburg, May 7, 2024.

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

API	Application Programming Interface
BOM	Bill of Materials
BOP	Bill of Processes
ERP	Enterprise Resource Planning
MES	Manufacturing Execution System
IoT	Internet of Things
SOA	Service Oriented Architecture
SSI	Simplified Station Instructions
OIS	Operator Instruction Sheet
WES	Work Element Sheet
WIS	Worker Information System

Nomenclature

Below is a list of terminology that has been used in this thesis.

Mixed model assembly - An assembly sequence where in the tasks involves operators to perform simultaneously routine assembly work (volume) and non-routine (variant specific) assembly work.

Middleware - An intermediate software that enables one or more communication of data between two or more applications/services/systems.

Event - Any significant change or update in the system's state which results in alteration of the system's properties.

Event-driven Architecture - A system architectural style wherein changes in the system states trigger various processes, such as capturing, messaging, communication, etc between two or more independent services.

Data streaming Service - The act of continuously providing real-time updates in terms of data and information streams to the system.

Publishing & Subscribing - An architectural messaging style that defines communication between two or more services wherein messages are broadcasted by the publisher and relayed to the receiver of that message, the subscriber via a messaging intermediary.

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1

Introduction

This chapter presents the background behind this thesis and details the purpose of carrying out such work in today's industry. A set of research questions are formulated based on the project scope and delimitation's. The chapter concludes with a detailed case description.

1.1 Background

In recent decades, the global manufacturing industry has seen a paradigm shift. Production processes, operations, and technology have seen a great deal of evolution over the years, enabling manufacturing from the times of low volume-high variety (craft production) to high volume-low variety products (mass production) and finally towards mass customisation today. With the rise of globalisation and digitalisation, this paradigm will only continue to evolve and diversify, as seen in figure 1.1, opening new avenues for manufacturers to expand their operations by offering regionalised and personalised products (Koren, 2010).

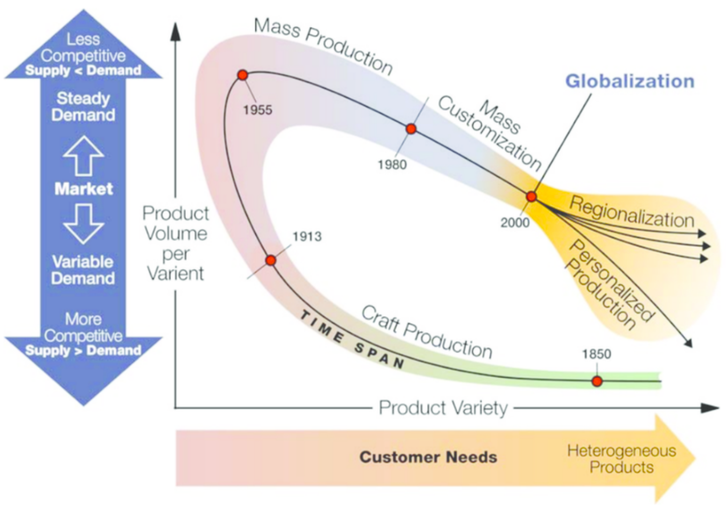


Figure 1.1: Manufacturing paradigm shift over the decades (Koren, 2010).

A result of this mass customisation trend is an increased customer demand for highly customised and personalised products or services. Satisfying this demand for high product variability and simultaneously remaining competitive in the market means that companies are adapting their manufacturing operations to a mixed model approach to enable production of complex products and their variants (Gabriel et al., 2016). This puts pressure on organisations and increases the demands from their current production systems.

The automobile industry serves as a good example where mass customisation and personalisation are prevalent. Manufacturers within this industry strive to guarantee final product quality towards its customers but also their own production quality. Operational complexity that arises due to variations (Park & Kremer, 2013) in the final assembly stages put demands on operators to handle vast amounts of information, take decisions, and assemble products in an error free manner (Mattsson et al., 2016). This, coupled with the pressure to maintain operational excellence whilst keeping with daily production targets means that operators are significantly loaded, both physically and mentally (Berlin & Adams, 2017). Currently, shop floor information within the automotive industry is presented, as a purely paper-based or a combination of paper-based and paperless visualisation (Gewohn, Beyerer, et al., 2018). The main shortcomings with this revolve around lack of the information individuality, flexibility, real-time instructional updates & quality feedback, and no user-oriented notifications alerting or supporting potential assembly reworks (Gewohn, Beyerer, et al., 2018). Hence, providing adequate support in terms of better decision making and situational awareness becomes essential for assembly operators in complex production environments (D. Li et al., 2022).

With advent of Industry 4,0 and its enabling technologies (Digital Twin, Internet of Things (IoT), Cloud computing and advanced analytics, Artificial Intelligence and Machine Learning) gives rise to the development of new and innovative solutions (Cañas et al., 2021). For manufacturing organisations, the integration of digital assembly information opens new possibilities for operator support in terms of information visualisation. Moreover, the abundance of production data available today, from the shop floor enables the possibility of combining several data points to develop smart support systems capable of alerting and supporting the operator on a need and situation basis. The ability to control the amount of information so that the operator receives information in the right amount through such a system can possibly help lower cognitive workloads, minimise error rates, increased assembly work awareness and motivation whilst making the operator smarter (Romero et al., 2016).

1.2 Purpose

The purpose of this thesis is to investigate how a worker information system (WIS) can aid operators through the presentation of focused assembly information and personalised alerts. Using an operator centric approach, the study will focus on understanding what kind of information support assembly operators rely upon for their work, how this can be best visualised if presented on a digital screen. In addition, how alerts that are personalised to the operator and his work can be escalated to support work tasks.

The outcome of this thesis will detail a digital worker information and support system that complements operators as a cognitive support function in executing error free assembly tasks in mixed model final assembly lines where the takt times are about one minute.

1.3 Research Questions

The purpose of this thesis is ascertained through two research questions. The question will be answered through information presented throughout this thesis, using the presented methodology.

Research Question 1: *How can assembly operators be supported through effective information presentation displayed digitally during assembly work tasks?*

- Research question 1 focuses on studying what information should be presented to operators via these personal assistants. The intention is to review in detail the concept of a worker information system and suggest the best information content to be presented from an operator support perspective. Here, the amount of information displayed digitally should be appropriate such that it aids operators during short takt times rather than overburdening them whilst performing tasks.

Research Question 2: *How can personalised alerts be generated to aid operators in performing assembly tasks accurately?*

- Research question 2 focuses on the escalation of personalised alerts for a particular operator at a station/line. The intention here is to suggest a conceptual representation of how personalised alerts are escalated based on available data points (quality deviations, shift rotations, etc).

1.4 Scope and Delimitations

This thesis will be based on investigating a concept for a worker information and support system. The study will include reviewing its past and current iterations, identifying further improvement potentials in terms of the appropriate information content to be displayed, and how instructional & informational alerts can be raised for the operator based on their history of assembly quality deviations. The focus areas within this research, are predictive quality and data-driven personalised information that is dynamically visualised using various information sources.

Based on the project scope, this thesis will be confined to investigating the best content that is to be displayed to an operator that will effectively support them and enable the production of products in a quality-assured way. A conceptual representation for instruction alert generation for the operator will be worked upon, depicting how the alerts could be raised. The actual deployment of a working prototype will remain out of scope due to time and IT development constraints. In addition, no changes will be made to the existing assembly work instructions or information.

1.5 Case Description

Volvo Cars Corporation (VCC) are one of the major automotive giants in the automobile manufacturing industry. With net revenue of 282 billion SEK in 2021, the company manufacturers 700,000 cars globally (VolvoCars, 2020). In Sweden, the Volvo Cars facility at Gothenburg is located at Torslanda and caters to the manufacturing of 6 car models (XC90, XC60, V90, V90CC, V60 and V60CC) and their variants at the TC-assembly plant. With a cycle time of just under one minute, 90% of the final assemblies at this factory are manual in nature, making it a fast-paced production environment.

Today at the case company, on moving assembly lines, general assembly information and work instructions are predominantly paper-based. These information sources are presented to operators on incoming cars and by the line side. All operators are subject to training before their deployment on the line. However, given the short cycle times at each workstation, they do not have time to refer to detailed instructions during running production and must rely on their training and past assembly experience to carry out their tasks. In addition, the mixed model nature of operations during final assembly requires operators to perceive different amounts of information from their surroundings. The significant cognitive loading that stems from their performance demands and requirements to meet daily production targets raises the potential to make errors during assembly. This throws emphasis on effective and efficient information support and dissemination.

With the ongoing digital transformation towards a smart and connected factory, the case company are investigating the potential of digital operator support via a smart interactive personal assistant capable of assisting the operator during assembly. Pilot studies within the scope of this concept have been successful at the case company, giving credence to continue towards its realisation. Presently, the concept of such a worker information and assistance system exists only as high-level specifications.

The goal now is to develop this concept further and understand the best information content to be displayed for operators for a moving line. The information presented should enable personalised operator support based on their history of assembly quality deviations. The intention is that by providing focused information and raising personalised alerts the level of operator support gets enhanced, enabling them to execute their tasks with higher precision. This, will potentially reduce the number of quality errors on the assembly line and eliminate the need for rework.

From the case companies' perspective, such an implementation would enhance operator support and enable operators to receive only the necessary information concerned with their work at their respective assembly station/line. On lines where cycle times are longer and the number of assembly tasks to perform is more, presenting digital assembly instructions would assist operators in remembering variant-specific instructions, lowering their mental workload. This is especially beneficial for newer operators. On lines where cycle times are shorter, presenting information about upcoming cars beforehand would mentally prepare them on what assembly tasks to carry out on upcoming cars. This would increase the speed of information delivery and the preparedness of operators for the task. Digitalising such information systems will also reduce the need to print assembly information on paper which is a positive from a sustainability and environmental standpoint.

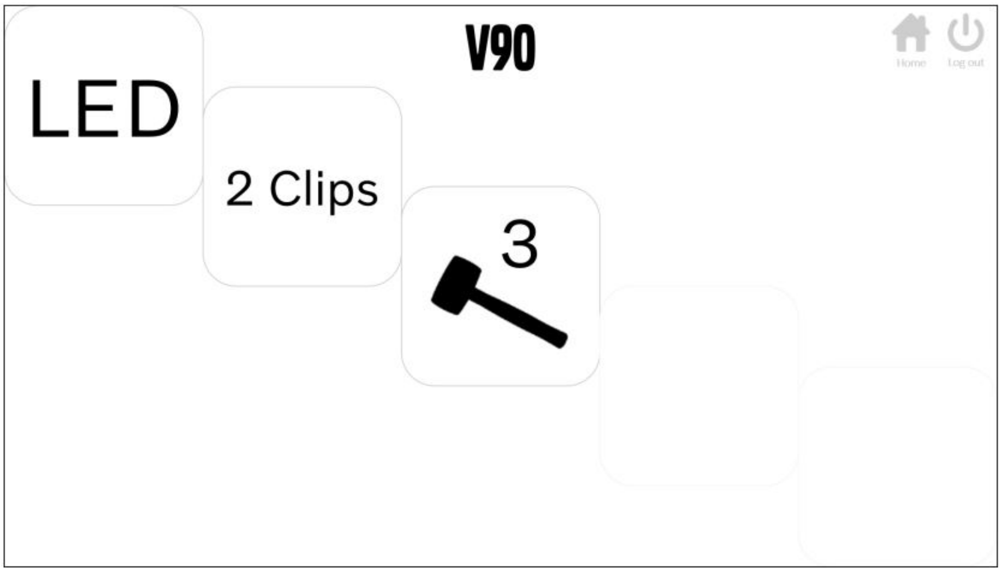
2

Theoretical Frame of Reference

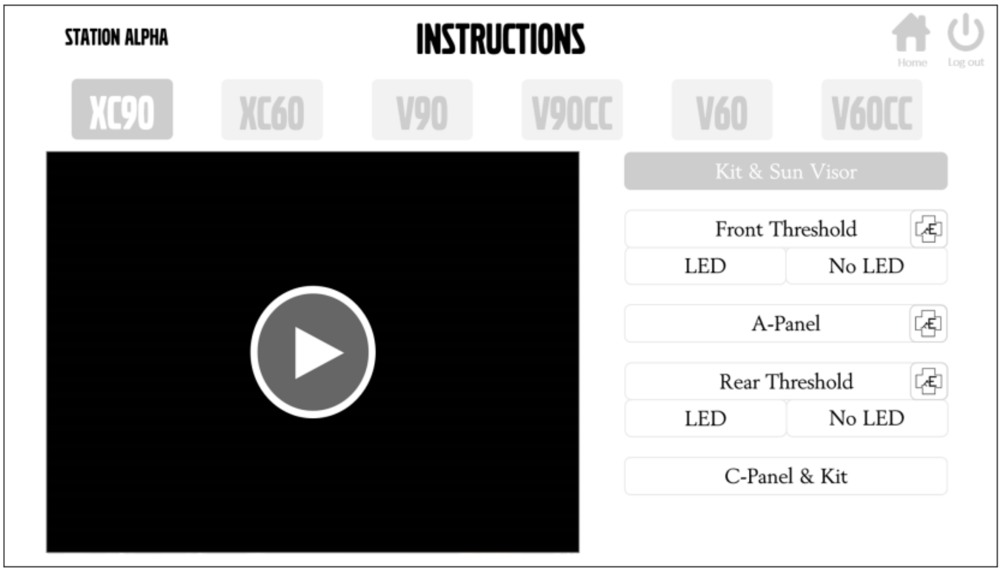
This chapter presents the theoretical frame of reference upon which the thesis is based. Scientific literature and past research within this project's scope have been reviewed and presented. Cognitive Ergonomics within Production, Assembly Information, and Industrial Automation Infrastructures are identified as the key theoretical concepts that will help shape the remainder of this thesis.

2.1 Earlier Research

Earlier research at the case company focused on the concept and development of a system for presenting digital work instructions, which formed a small subset within the larger scope of a digital worker information and support system. In a fast-paced production environment such as a mixed model assembly line, digital work instructions were proven to be an effective means of communicating assembly information (Palmqvist & Vikingsson, 2019). Two research studies had been carried out in this regard. The initial research laid the grounds for the concept of a digital operator support system which included two kinds of digital work instructions - Online work instructions and Offline work instructions. Online instructions corresponded to running or live production information that focused on highlighting variations and important assembly work. These were formatted as symbols for the reason that they were easier to understand, conveying information about the specific assembly operations through their design. For instance, in the figure 2.1 a symbol of a mallet with the number 3 next to it signifies that the assembly operation requires the use of a tool that is to be struck 3 times against the work piece as part of the assembly operations. Offline instructions mainly correspond to assembly information from the perspective of coaching and supporting the learning of assembly work tasks for their station.



(a) Online instructions interface.



(b) Offline instructions interface.

Figure 2.1: A concept for digital work instructions as an assembly information source (Palmqvist & Vikingsson, 2019).

Later research took upon this suggestion for work instruction symbols, developed them for two stations, and provided a baseline validation for their implementation in the industry (Andersson & Trogen, 2020). Digital work instruction symbols as an assembly information source were likely to be effective information disseminators in supporting operators cognitively with their tasks, reducing their work complexity, and possibly improving quality. The benefits of such an implementation could be ascertained from two very similar stations but it was challenging to know for sure whether this implementation would work on stations where digital work instructions are difficult to implement. Recommendations from these studies were in alignment with the aforementioned arguments and to test them in live production.

2.2 Ergonomics within Production

In an industrial setting, Human Factors and Ergonomics (HFE) is a broad term that encompasses both the physical interactions and mental states of humans performing tasks in the workplace. The International Ergonomics Association (IEA) [1] defines ergonomics as,

"The scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimize human well-being and overall system performance."

Ergonomics can be classified into 2 main types - Physical ergonomics, which is concerned with the study of human anatomy, anthropometry, physiological and bio mechanical characteristics when performing physical activities & Cognitive ergonomics, which revolves around studying human mental capabilities and their interactions in a system (Berlin & Adams, 2017). When talking about ergonomics, in general, is important to consider both types. However, for the scope of this thesis, the focus lies more on the cognitive ergonomics aspect because careful consideration must be taken in designing work information systems so as to focus on optimising human well being, efficiency, performance and productivity of work.

2.2.1 Cognitive Ergonomics

This domain of ergonomics mainly deals with the basic human senses (like vision, hearing and touch) and mental faculties (such as memory, perception, attention and reasoning) combined with how these affect human interaction with different systems in their external environment. The overall process for information handling is a combination of both sensory stimuli, namely vision and mental processes like focus, perception and memory that can lead to comprehension and decision making (Berlin & Adams, 2017).

There are several important cognitive processes that contribute to information comprehension in a production environment. Attention refers to the ability to actively keep focus on a specific task and its details. When focusing on multiple information sources at the same time, our ability to process and interpret stimuli and information gets reduced. Another factor that affects attention is the design and frequency of the task. Monotonous tasks fail to stimulate our senses which results in low levels of alertness and a decrease in motivation. Memory allows for the storage of information and is divided into long term and short term working memory. The former allows us to make sense of different relations and patterns observed or experienced over time

[1] https://iea.cc/what-is-ergonomics/

whereas short term memory limits itself to storing of new information and recalling recent events. The rule of thumb with this kind of memory is that we can process and store up to 7 ± 2 entities of information items (Miller, 1956). Perception refers to our comprehension of the surrounding environment and the ability to associate meaning and reasoning with the information gained through this. Finally, mental models are mental how-to's that we develop over time from perceiving information and carrying out certain tasks through our experiences (Berlin & Adams, 2017). From a sensory perspective, vision is the most important cognitive faculty as it is connected with the perception of information, aiding in gathering visual cues from our surroundings and making meaning out of them.

2.2.2 Cognitive Support Functions within Production

In a mixed-model assembly line of short takt times, operators are required to perceive different kinds of information related to their work from different sources whilst simultaneously drawing upon from their memory and past experiences. This can create a significant mental loading and stress which can lead them to deviate from the ideal way of working. Industrial processes are designed to support operator cognitive abilities whilst optimising the performance of assembly systems.

Andon

The concept of Andon serves as an operator support system which empowers the operators to seek support when required and know the status of the plant floor. The main focus of implementing Andon is to help solve problems at its source and secure the build-in quality in the first instance (Berlin & Adams, 2017). This is done by pulling the Andon cord which highlights and alerts the workforce about where and when problems have occurred and line stoppages. As a cognitive support function, this assists operators in the events where their workload is high or potential mistakes/errors can be anticipated, empowering them to stop the line.

Poka Yoke

Poke yoke or mistake proofing is the use of automatic methods or devices that makes errors obvious to the operator when performing a specific task. Poka-yoke helps with performing the task right the first time and this is evident in its intuitive and effective nature of revealing obvious errors immediately (Berlin & Adams, 2017). As a cognitive support function, this helps reduce the mental workload of remembering detailed assembly steps and procedures reinforcing their knowledge of assembling right the first time.

Pick by light & Pick by barcode

Pick by barcode uses barcodes and scanners to facilitate the picking process. It serves as a cost effect picking method in low volume picking environments and cognitively aids the picker by providing the necessary picking information via a handheld screen. Pick by light utilises lights positioned on material racks or shelves to indicate to an operator, information about what item to pick, by lighting up according to a pre-defined sequence (Berlin & Adams, 2017). In this method, an operator confirms the picking of a part by either touching a button, activating the light sensors or pulling a rope. As a cognitive support function, by lighting up against the correct part, it reduces the chances of a miss pick and subsequently errors during assembly. In addition, it reduces picking times and operator's hands are kept free from any devices.

2.3 Quality in the Production

Quality control and cost reduction are considered the most important in any manufacturing industry (Hossain & Sarker, 2016). In manufacturing industries, quality inspection is carried out to make sure the products have no defects, defective items are either sent to the workstation where the defect occurred to fix it or sent to a dedicated rework station (Hossain & Sarker, 2016). In the former case, the rework procedure reduces the line efficiency whereas in the latter case, additional cost is added for rework stations (Hossain & Sarker, 2016). In manufacturing industries, the quality of the product is measured using two factors called FTQ (First Time Quality) and QBR (Quality Buy Rate), where FTQ refers to the ratio of all the jobs processed at the first time and QBR refers to the ratio of the jobs which includes both first time processed jobs and the reworked jobs (J. Li et al., 2006). Deciding if the defective items to be repaired at the workstations or at separate rework stations or should be scrapped, is a concern in many line production systems (Hossain & Sarker, 2016).

2.4 Assembly information

Aehnelt & Bader (2015) details 5 general types of information assistance for operators in complex assembly environments. An assembly operator may desire up-to-the-minute information regarding their work. This ensures that they can align their work tasks in accordance with any deviation that they may have come to know about in advance. As a result, it influences their decision making by making them situationally aware of different assembly scenarios. This kind of information assistance is linked with **raising awareness**. When faced with continuous production, operators require orientation with respect to the current and upcoming tasks. This can be achieved by selectively filtering out information and specific work steps. Breaking down detailed instructions into smaller easy to understand snippets of information and presenting them in advance, reduces the information load and guide them in their work task. This kind of assistance is linked with **guidance**. Information assistance in terms of **monitoring**, supports operators with ongoing tasks by ensuring that the process is kept in check and aids them by avoiding rework. **Documenting** as an assistance supports tracking of deviations, complaints, etc. It provides a way by which operator can track problems and be aware of quality issues. And finally, **Guarding** which is linked with protecting the operator from physical and mental overload. Here, information as an assistance should ensure that it does not overburden the end user either by its level of presentation or by the way it is visualised.

2.4.1 Work Instructions

Work instructions are used to support the assembly operators to perform their various assembly tasks easily and prevent any errors during their work (Pimminger et al., 2020). Work instructions can be presented in different forms to the operators, it can be given either as a simple paper based static instructions but also through augmented reality based instructions (Pimminger et al., 2020). Operators receive their work information through visual, auditory, and tactile cues, where vision is the dominant sense among others, and for that reason the operators should use their central field of view for most important information like work instructions (Pimminger et al., 2020). The trend of mass customisation has increased the assembly complexity of parts and this requires basic technical knowledge (Pimminger et al., 2021). To support the novice assembly operators, proper learning and training environments are required and work instructions play a part in such a setting (Pimminger et al., 2021).

2.4.2 Information Quality Attributes

Poor information quality in industries has adverse effects on the organization's economy and society which includes low customer satisfaction, high operating costs, poor performance and low job satisfaction. (Haug, 2015).

Intrinsic Information Quality
Intrinsic instructional informational quality is linked to individual perception. These are derived by focusing on the relationship between 'needed instructions' and 'given instructions'(Haug, 2015). Based on this, as seen in Figure 2.2, there are six intrinsic instructional information quality criteria's

Deficient Instructions are an instructional quality problem where the needed instructions are not present completely amongst the received instructions. It refers to something that is missing from the necessary instructional information.

Ambiguous Instructions refers to a situation where the provided instructions are vague, requiring additional information about carrying out the task. The lack of information here can cause ambiguity for the end user.

Unneeded Instructions refers to when the received instructions are more than the required instructions. The end user is already aware of this information, and it adds no extra value to complete the task at hand.

Incorrect Instructions is when the given instructions are incorrect. From an instructions informational perspective this falls under the incorrect communication aspect of information.

Repetitive Instructions is another quality dimension where the received instructions include repeated elements of the needed instructions. The repeated repetitive nature may be closely associated with redundancy however, this is different in the fact that only important parts of the instructions are presented to the end user often.

Fitting Instructions is the ideal quality dimension for instructional information. Here, all the needed information intended to carry out the task is provided to the end user.

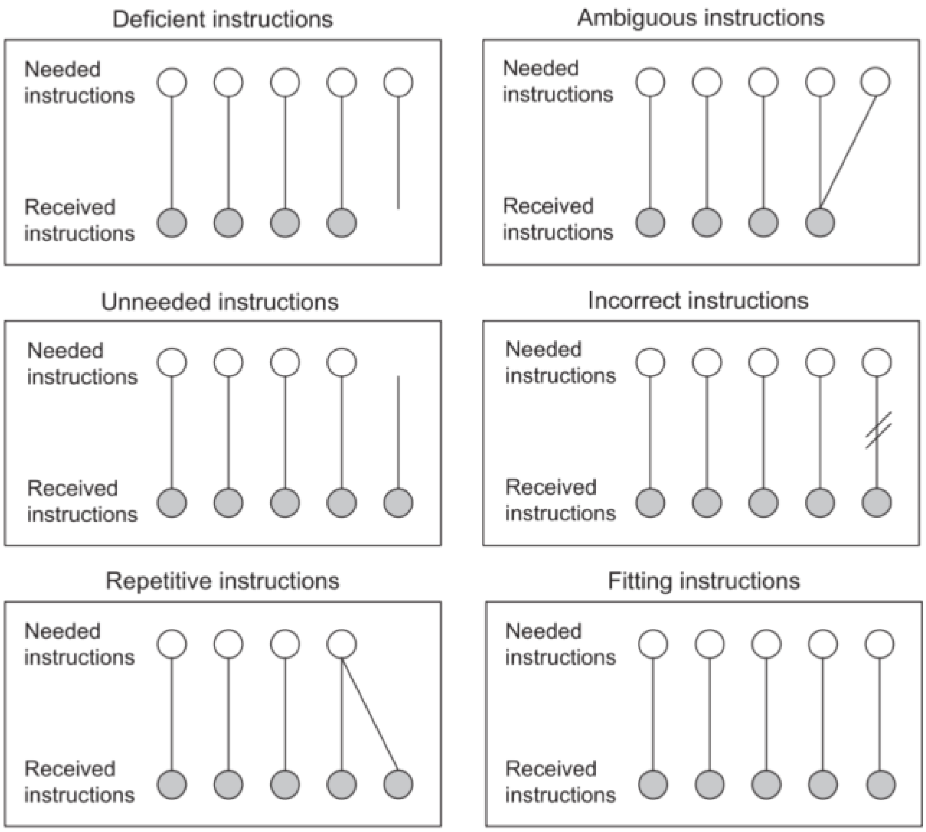


Figure 2.2: Intrinsic dimensions of information quality (Haug, 2015).

Extrinsic Information Quality
An information becomes useless if there is no quality in it and is often described as 'Garbage in garbage out' (GIGO) which means that unless the input information has the quality characteristics, output information from a system will be useless (Kehoe et al., 1992). According to Kehoe et al. (1992) there are six essential qualitative criteria that every information should have, and they are

1. Relevance - information is considered relevant when the users get benefited in making a decision or actions from it.
2. Timeliness - it refers to the timely availability of information that enables in the making of useful decisions and actions.
3. Accuracy - it refers to the level of precision of the information, that is how far it is error free and true.
4. Accessibility - it refers to the degree of availability of information.
5. Comprehensiveness - it refers to how the information is presented briefly but in detail without omitting any important data.
6. Format - it refers to the degree of how well the information is received to make it useful for decision making.

2.5 Industry 4.0

Advances in information technology, communication systems, and computer technology used to automate processes have spurred the manufacturing industry to undergo a new paradigm shift. The rise of cyber-physical systems to link real-world objects and people through data from several information systems via industrial communication networks is believed by many, to be the basis for the fourth industrial revolution (Leitão, 2017).

The term "Industrie 4.0" in 2011, initially represented a high-end industry strategy for the German manufacturing industry, but over the years, the term has expanded to include a wide array of enabling technologies that will transform the present manufacturing landscape (Kagermann et al., 2013). Today, Industry 4.0 is used as an umbrella term to describe several smart supporting technologies (Adaptive robotics, Big data analytics, Cyber-Physical Systems, Digital Twins, Artificial intelligence, Machine Learning, etc.) coupled with real-time communication and networking (Cloud and Edge Computing, Internet of Things & Services, Wireless and Cellular technology) to enable greater flexibility, robustness in overall quality standards, data-driven decision making, and agility in meeting stakeholder requirements across the manufacturing value chain (Cañas et al., 2021; Salkin et al., 2018)

Another aspect of Industry 4.0, is its characteristics of integration across organisational value chains. According to Kagermann et al. (2013), these will include horizontal and vertical integration. Horizontal integration across organisational value networks means integrating various IT systems (used in manufacturing and business processes) within the organisation and between several companies that enable value creation. Vertical integration refers to tying together the logical layers in the manufacturing hierarchy, from shop floor sensors and actuators up to production planning and control systems such as the MES, ERP, etc. Together, this will enable an end-to-end digital integration across the entire manufacturing value chain wherein, with the help of the internet, traditional manufacturing environments can be converted into smart manufacturing environments by involving all value-creating processes from cradle to grave (Kagermann et al., 2013).

Maturity Index for Industry 4.0

Schuh et al. (2020) proposed a maturity framework for organisations to position themselves in their digital transformation journey towards Industry 4.0. This also allows organisations to choose the best business strategy to make this transition based on their current capabilities and available resources (Schuh et al., 2020). The advent of computerisation and connectivity bought about a faster and more efficient means of information sharing and communication. Internet Protocols (IP) became the basis for enabling communication between various discrete manufacturing data/information silos thereby connecting a manufacturing company's core business processes with that on the shop floor. This provided the basis for digitalisation and ultimately Industry 4.0.

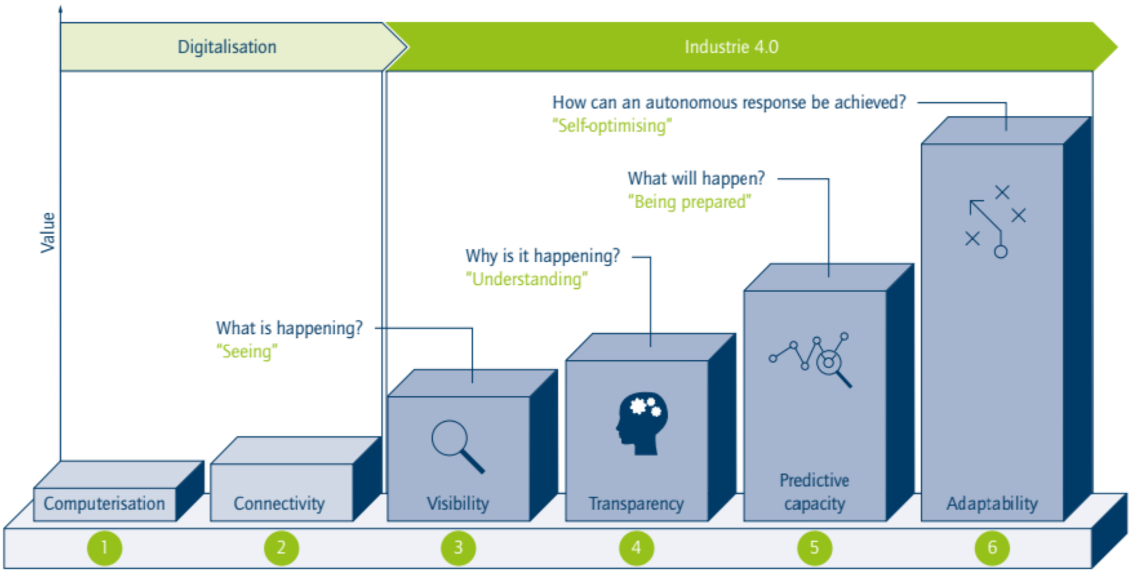


Figure 2.3: Stages towards Industry 4.0 development (Schuh et al., 2020).

From figure 2.3, stages 3 to 6 represent the core of what Industry 4.0 brings in terms of value creation. Visibility through the act of real-time data collection via sensors can help one get a complete picture of the system at any given point in time. Transparency allows for an understanding of why things are happening by taking advantage of big data and determining the root cause of the problem. Predictive capacity allows the organisation to simulate different possibilities with the help of available data points and identify potential process pitfalls and development opportunities. Finally, with adaptability an organisation can make full use of data to make strategic decisions that will enable them to adapt their operations & processes to changing market scenarios in the shortest time possible whilst implementing appropriate countermeasures.

2.6 Industrial Automation Infrastructures

The traditional manufacturing landscape comprises of different kinds of automation of integrated devices and technologies at different hierarchical levels within a factory. The International Society of Automation (ISA) has defined a standard for communication (IEC 62264) that defines how various automation levels between the control level communicate with the manufacturing and enterprise levels. Figure 2.4 depicts the 5-level automation stack defined by ISA.

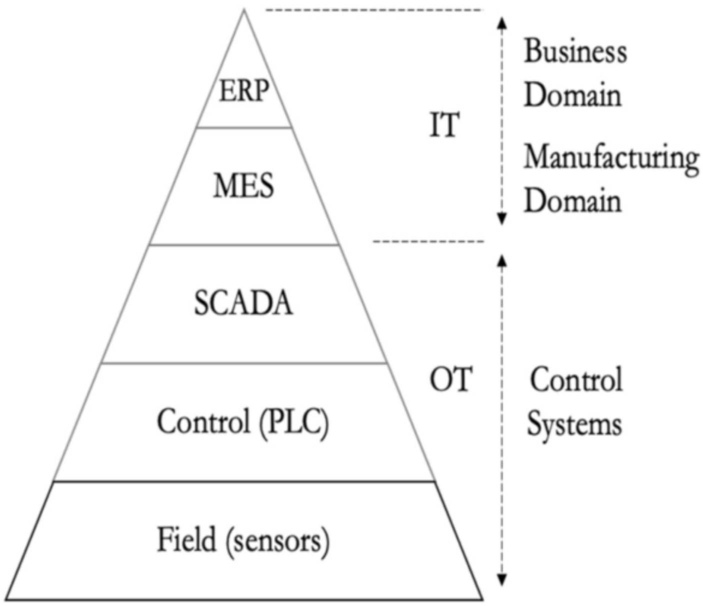


Figure 2.4: ISA 95 model, also called Automation Stack (Apilioğulları, 2022).

Level 0 or the field level, is representative of the production floor, consisting of all actuatory and sensory devices and technologies that are used to enable and measure processes and systems respectively.

Level 1 is the control or programmable logic controller (PLC) layer which consists of technologies that are used to exhibit a level of control over field-level devices. They receive input from sensors and actuators and process these inputs to create an output that controls various production processes.

Level 2 is the supervisory control and data acquisition or SCADA/HMI layer. This layer is responsible for the monitoring of multiple processes from levels 1 & 2 through user interfaces and data stored in various databases within the enterprise.

Level 3 corresponds to the planning level for manufacturing. This layer mainly consists of the manufacturing execution systems (MES) which are primarily responsible for monitoring the entire manufacturing process based on real-time data acquired from production level control systems within the factory.

Level 4 is the enterprise or management level which caters to managing and controlling operations (manufacturing, sales, purchasing, finance, etc.) on an enterprise level. This layer ensures up keeping of efficiency and transparency within an organisation.

Levels 0 to 2, i.e., all control systems together make up the operational technology while levels 3 and 4, i.e., the manufacturing and business domains together form the information technology side. Traditionally, the communication between these layers was hierarchical, requiring several discrete application programming interfaces (APIs) to be established in order to integrate new systems within an existing legacy dominant infrastructure; making scalability and modularity of the industrial monolith (5 levels of the automation stack) complex (Apilioğulları, 2022).

To overcome this, horizontal integration via Internet of Things (IoT) platforms (also called API gateways or middlewares[2]) as suggested by Åkerman et al. (2018), of future systems can decouple the traditional automation hierarchy, decentralising individual systems thereby enabling easier networked communication, scalability and modularity. Such a solution provides a foundation for building a system-of-systems (SoSs) architecture, wherein diverse systems(or services) hosted locally or on a cloud may be added on to form a single entity, whilst each system (or service) contributes, operates, and is maintained independently (Cuesta et al., 2016).

2.6.1 Service-Oriented architecture (SOA)

Within the context of the Industrial Internet of Things paradigm, service-oriented architecture (SOA) enables the characteristics of Industry 4.0 such as interoperability, scalability, flexibility, modularity, etc., through cloud-based approaches (Xu et al., 2014; Siqueira & Davis, 2021). A service-oriented architecture (SOA) is essentially a method deployed in IT to create programs using services [3] that interact between different systems and domains (Haorongbam et al., 2022). As an architectural concept, SOA yields benefits such as increased agility & efficiency, interoperability, modularity, and loose coupling (minimal dependencies) whilst breaking down each business process into smaller functions such as services (Niknejad et al., 2020). Various processes in a system can be interacted through a loosely coupled mechanism of SOA to share any information and manage the operations (Haorongbam et al., 2022). SOA aids the businesses to communicate between the applications easily and possibilities to expand the current systems at lower costs (Haorongbam et al., 2022).

[2]https://www.ibm.com/cloud/learn/middleware

[3]https://www.mulesoft.com/resources/esb/services-in-soa

One of the benefits of using SOA is the improved business agility. The advantage of building an application from disposable service APIs allows the programmers and developers to respond to a new possibility much more rapidly compared to the conventional methodology (Haorongbam et al., 2022). SOA enables increased scalability by allowing the applications to operate through many different hosts. Since the SOA uses the common network protocols, businesses can limit the communication between consumers and services (Haorongbam et al., 2022). Another key benefit of using SOA is lowered costs. Implementing SOA enables the business to reuse the existing applications and functions, decrease the cost and time spent during the deployment of an application which results in reduction of operational costs (Niknejad et al., 2020).

2.6.2 Micro services and Micro Front-End

Micro services have been growing in recent years especially in an academic field and also in the industrial field where many organizations are shifting from their monolithic single-application back-end architecture to the trending microservices architectures (Peltonen et al., 2021).

The traditional single page applications (SPA) have many modules which are tightly coupled together and have dependencies between different components, where making some changes in one part of the application results in the situation where the entire project needs to be redeployed which is a highly time-consuming process (Peltonen et al., 2021).

Microservices are a subset of service-oriented architecture in which the applications are built as a group of loosely coupled services or functional components in a modular way where each component can communicate through language independent APIs (Peltonen et al., 2021). Since these functional components or services are based on single responsibility which can be developed and deployed independently, it enables the development teams to work on the applications in parallel without any dependency (Peltonen et al., 2021).

Micro Front ends are similar to Microservices but for the front-end side of an application. Micro front-ends are becoming more popular and are used by many large companies today, in which the monolithic front-ends which are based on singe code application architecture are broken down into independent smaller micro front end applications where each of these mini applications can be created and deployed independently (Peltonen et al., 2021).

As seen in figure 2.5 the whole application is divided vertically between different business sub domain teams and each team will handle only one domain and built completely from the bottom to up, that is, each team handles database, backend and front end compared to the monolith front ends where the separate team will

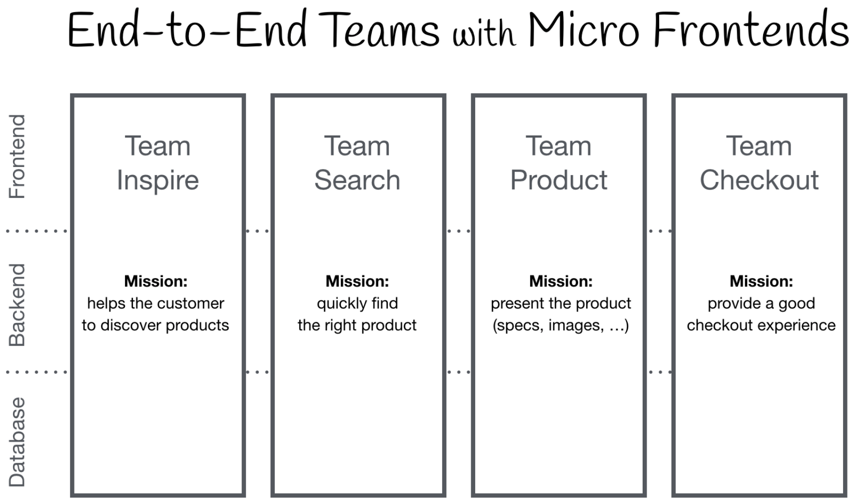


Figure 2.5: Micro front-end architecture (Peltonen et al., 2021).

handle the front end (Peltonen et al., 2021).

This approach brings several benefits to an organization. They are simple and codebase is decoupled, meaning the micro frontend applications have less dependency on the code and less complex compared to monolith front end (Tran, 2022). Since each micro frontend is maintained by single team and has their own delivery pipeline which enables them to develop and deploy the application independent of other micro frontends without affecting each other (Tran, 2022). In terms of handling larger applications in monolith front ends, there might be teams handling different functionalities such as styling and validation for all the domains, whereas, in the micro front end each domain is handled by separate team which enable the development and deployment process quicker and effective (Tran, 2022).

3

Methodology

This chapter presents the methods employed throughout this thesis. The chapter begins with an overview of the applied research approach followed by an in-depth description and motivation behind carrying out each stage of this research project.

3.1 Applied Research Approach

This thesis proceeded with the following stages, as depicted in figure 3.1. The first stage was to understand the scope and formulate the aim of the thesis. This was followed by an initial literature review to gain foundational knowledge over relevant topics within the project's scope. Initial state analysis of information support and quality systems was then carried out which consisted of concurrently carrying out qualitative and quantitative research methods. Simultaneously, a more in-depth literature review was done to gain a deeper understanding of the topic. To co-create the final solution, iterative brainstorming sessions were held with operators whilst refining the conceptual mock-up adaptable to the end user's requirements. Finally, the results of the adapted concept were validated with relevant stakeholders at the case company.

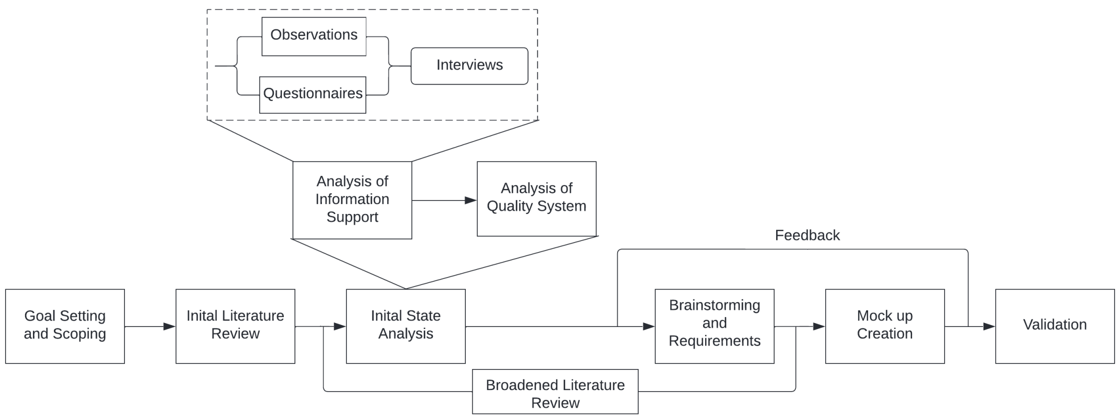


Figure 3.1: Applied research approach.

A mixed-method approach was chosen as part of the research which involved both qualitative and quantitative methods. The integration of these methods gives a better understanding of the study and is useful when either of the approaches is inadequate for understanding a problem (Creswell, 2014). The review of scientific literature was based on themes perceived from the given problem description and those found within past research that fell under a similar scope.

3.2 Initial state analysis of Production system

The initial state analysis focuses on studying two aspects within the case company, one that is concerned with the available information support for operators and the quality system tasked with giving operators quality feedback.

3.2.1 Analysis of Information Support

3.2.1.1 Observations

An observational study is a qualitative research approach wherein a researcher observes and takes notes of certain activities at the research site (Creswell, 2014). The type of observational study can vary between systematic observations and participant observations. The former is carried out using an observational schedule to note the frequency of events or activities of people based on a checklist whereas, in participant observation, the observer remains discreet but observes, questions, and takes notes about the daily life of participants at the research site and the activities being carried out (Denscombe, 2010).

From an ethical standpoint, as operators were being observed, considerations (like privacy, confidentiality, etc.) and required permissions were sought from production superintendents and team leaders prior to making observations. Additionally, operators were made aware of the intention of the study and permission to observe them during their work was also sought.

The goal of the observational study is summarised by the following focus areas

- How information is provided to the operators?
- How do operators perceive information during their work?
- How they interact with support functions (Poka-yoke, Andon, etc.)?

The observation study comprised of several guided and unguided production walks throughout the research period. This combined with a combination of systematic and participant observations was used; allowing for flexibility and adaptability while making field observations. The guided production walks were mainly carried out with the team leaders who assisted in providing insight into different operations carried out on the selected line and what challenges they currently faced from perceiving information. Unguided production walks allowed for more general observations of several assembly lines within the facility. The purpose here was to understand how the different production operations were set up and how information was relayed to operators within these assembly environments. This approach presented the opportunity to ask operators unstructured questions regarding their work, the kind of information they need, current challenges regarding information presentation, and thoughts about future digital solutions.

3.2.1.2 Questionnaires

Questionnaires are used to survey to get a quantitative explanation and opinions from the population on whom the research is done (Creswell, 2014). The questionnaires should collect two kinds of information from the operators, factual information and opinions (Denscombe, 2010). Factual information is that which does not require any judgmental opinions and requires only simple information like their age, sex (Denscombe, 2010). Opinions are those which tend to express the respondent's attitude, feeling, views, beliefs, and preferences (Denscombe, 2010).

Planning the questionnaires is essential, as it should be done right the first time because asking the respondents to answer the questions a second time will not be feasible (Denscombe, 2010). When preparing the questionnaire, five aspects should be considered: the cost, preparation time, organization, schedule, and permission (Denscombe, 2010). There was no cost involved in preparing this questionnaire as they were created using Microsoft forms. Around 2 weeks were spent preparing the questions which were framed based on the observations and research requirements. The whole process was well organized by maintaining a separate excel sheet which contained the responses and was later used for analysis purposes. There was no schedule prepared for the questionnaires as it was an online form, and operators were allowed to answer the survey whenever they were available. Before sending the questionnaires to the operators, relevant permission from the shop floor superintendents and supervisors was sought. The questionnaires, as seen in appendix A, consisted of demographics questions and questions based on four focus areas -

1. Work situation
2. Work instructions
3. Quality feedback
4. Future concepts

To collect qualitative data from the questionnaires, 2 open-ended questions were asked towards the end of the questionnaire. Web-based questionnaires (Microsoft Forms) were used in our research. This method has two advantages, first is that the respondents may find the questionnaires attractive as the questionnaires will be colourful and contain graphics (Denscombe, 2010). It is much easier to fill the questionnaires as it contains predefined answers and respondents just have to select and submit them (Denscombe, 2010). The second advantage is that the responses can be transferred to a spreadsheet which makes the data collection process faster and more accurate (Denscombe, 2010). The disadvantage is that it needs technical skills to create the questionnaires and is difficult to access by the participants (Denscombe, 2010). The questionnaire was sent to the operators in Swedish as most of their native language was Swedish which makes it easier for them to understand the content and answer them right. After collecting the responses, it was then translated into English for analysis purpose. A 4-point Likert scale with options – Strongly Disagree, Disagree, Agree, Strongly Agree, were used. 4-point Likert scale was selected because it forces the participants to select a side rather than being neutral. The benefit is that it makes the data analysis for the researcher easier (Denscombe, 2010).

3.2.1.3 Interviews

Interviews are used to collect the qualitative data to understand the participants' experiences, and know how they describe their experiences (Castillo-Montoya, 2016). Interviews are used to support and clarify unexpected responses from questionnaires. Semi-structured interviews were carried out in our thesis, the reason being that it enables the interviewer to be flexible and is not necessary to ask the questions in the same order as planned, allowing the interviewee to open up more widely on the questions asked (Denscombe, 2010).

The interview questions were framed based on three focus questions which align with the aim and the research questions. The three focus questions were:

1. What are the current information support systems available to an assembly operator today?
2. What kind of personalized information can support operators in the faultless execution of assembly tasks?
3. How should the system be designed to enable information personalization and implemented to gain operator acceptance?

An interview protocol, as seen in appendix B, was prepared and reviewed using the four-phase process (Castillo-Montoya, 2016). The interview protocol framework consists of:

Phase 1 - Ensuring interview questions align with research questions: An interview protocol matrix was created to make sure every question aligns with the research questions (Castillo-Montoya, 2016).

Phase 2 - Constructing an inquiry-based conversation: The interview protocol consisted of inquiry-based questions and at the same time acting as an instrument to develop a conversation. It consisted of four types of questions - introductory questions, transition questions, key questions, closing questions (Castillo-Montoya, 2016).

Phase 3 - Receiving feedback on interview protocols: Once the interview protocol had been drafted, it was reviewed by the research members to get feedback to check if the participants can understand the questions and if their understanding is close to the researcher's expectations (Castillo-Montoya, 2016).

Phase 4 - Piloting the interview protocol: As the last step, the interview protocol was given a trial run by interviewing a team leader, who has the same characteristics as an operator. This was done to check on how the interview will go, how long it would take, if the participant can answer the questions, get their feedback, and make a final version of the interview protocol (Castillo-Montoya, 2016).

From the trial run, it was estimated that an interview will last up to 30 minutes. Since the operators could not spend that much time during the production running, the interviews were conducted only during the production stops. Required permission from the shift supervisor was obtained. In total 10 interviewees participated in the Interviews, which included personnel from different roles within the production, as seen in table 3.1. To get different perspectives, interviews were held with the participants from both morning and evening shifts.

Table 3.1: Number of interviewees.

	Operators	Team Leaders	Process Technicians
Interviewees	4	4	2

3.2.2 Analysis of Quality System

ATACQ, or Answers to all car questions, is the quality system managed at the case company. This system is used to log all errors and quality concerns present on a car during/after it has been assembled and the data is stored until the car is sent out to the customer. As part of the initial state analysis, several transactions within the quality system were reviewed to understand what kinds of quality-related data were recorded, how these were being currently registered to operators and tracked on cars. Since this study involves the generation of personalised alerts, a particular team that had electronic rotation cards implemented were chosen for the analysis. 3 weeks' worth of quality error history was collected. The main intention here was to review the different kinds of mistakes and discuss the reasons for their occurrence during the assembly process. The report was printed and reviewed with the team leaders from the chosen team of the morning and evening shifts, respectively. Furthermore, review of internal documents of the quality system and unstructured interviews with the system owner gave an in-depth understanding of the system.

3.3 Brainstorming and Requirements

Brainstorming is a problem-solving method and creativity technique that is used for generations of group ideas (Adams, 1979). It is qualitative in nature and the concept revolves around inspiring people to use their creativity and bring out novel ideas over a topic of discussion. Brainstorming discussions are unstructured and open allowing participants to think outside the box when bringing forward new ideas.

A general brainstorming session consists of 3 phases (Osborn, 1963). Prior to brainstorming, it is important to prepare the group by inviting participants and giving them background about the session in advance. A clear problem statement should be provided along with a list of questions that stimulates idea generation. The environment within which the session is conducted should also facilitate the spirit of brainstorming.

During the session, 4 essential criteria should be kept in mind (Adams, 1979). Firstly, the primary purpose of brainstorming is to create as many original ideas as possible that are related to the discussion topic. For this reason, criticism and judgement of ideas are prohibited during the session and must be deferred to later stages. Secondly, participants must be allowed to think out of the box and share ideas irrespective of how practical they may be. This spurs their thinking process and aids in the idea generation process. Ideas that are repetitive and seem far-fetched can be filtered out easily at later stages. Next, quantity over quality ensures the likelihood of good and useful ideas coming through several suggestions. Lastly, participants must not be restricted to their own ideas, rather communication and improvements should be sought by allowing them to build on other's ideas. After the brainstorming session, it is important to probe for afterthoughts i.e., for additional ideas and obtain feedback. Separate sessions may be called for at later stages to evaluate and validate the ideas generated.

However, during brainstorming sessions, there are potential barriers such as the emergence of judgements during idea generation, members giving up midway through the session, and inadequate interaction leading to a decrease in the effectiveness to gather new ideas (Isaksen & Gaulin, 2005). Use of technology (interactive pictures, videos, displays, etc.) to keep participants engaged in the session and facilitators may be used to overcome these barriers (Isaksen & Gaulin, 2005).

The brainstorming process was carried out mainly with operators and team leaders. In total there were 3 rounds of brainstorming sessions carried out during production stops. Sessions consisted of a group of 5 operators and the team leader. Each session started by conveying the purpose of the brainstorming activity, which was to generate ideas about what kind of information & functionalities would benefit their use case and how this could be visualised from a user interface perspective. Operators were then encouraged to talk about what kind of information they thought would be helpful to them if it were presented on a digital screen. Next, they were asked to focus on the visualisation of this information. A4 sheets of paper were handed out to each of the participants, and they were asked to draw their version of such an interface. These papers were representative of the future digital screens that would convey this information to them. Operators were encouraged to collaborate and freely discuss with one another during this stage to bring out more ideas. After this, they were asked to share some insight and thoughts on their visualisation of the user interface. Next, a discussion for alerts and feedback was taken up and the procedure was repeated.

Based on the review of scientific literature, initial state analysis, interview with various stakeholders, and brainstorming sessions, a list of requirements from operators and various stakeholders were drafted. This was done to capture both the operational end users and management requirements for realising a digital worker information system capable of supporting operators on a moving line. The requirements were reviewed and finalised based on feasibility. This ultimately served as a basis for the next process which involved the creation of the mock-up.

3.4 Prototype

3.4.1 System Interface - Front End

A prototype is defined as a visual representation of an interactive system created during the design process which aids the designers in choosing the best final solution (Beaudouin-Lafon & E. Mackay, 2007). Based on the requirements from various stakeholders and the brainstorming sessions with operators, guidelines for information content and visualisation were drawn up as seen in table 3.2. Based on these guidelines and the first brainstorming session, the first iteration of the mock-up was created, as seen in appendix C.1 to show the required information content and how it can be visualised on a digital screen. In a similar way, consecutive iterations, as seen in appendix C.2 & appendix C.3, of the mock-up were generated based on feedback and ideas, given by the operators during subsequent brainstorming sessions.

Table 3.2: Guidelines for prototype front-end.

Information Content and Functionalities	Visualization
Simple and focused Instructions	As simple as possible
Information Feedback	Text over symbols
Quality Alerts - Online and Offline	Vibrant colours for alert messages
Ability to flag car	Generated alert should not block main instructions
Ability to view instructions	

3.4.2 System Interface - Back End

After creating the mock-up for the information content and visualisation, the next step was to map different information sources and draw up the back-end logic for the system to generate the required information content. Self-study of various IT systems, internal IT documentation, and conducting open-ended interviews with various system owners were carried out to understand the information flow between the different systems. Based on this understanding, a preliminary system mapping and logic was created to show the information flow for the information content created in the previous step.

3.5 Validation

The validation of the concept was carried out through open-ended qualitative interviews. These were primarily carried out after each brainstorming session to validate whether the designed mock-ups met the conceptual requirements and needs from an information perspective for the end user and associated company stakeholders. The process involved showing the mock-up and explaining how the end user would potentially interact with such a system. Based on the iterations created, table 3.3 detail the number of stakeholders each iteration was validated with.

Table 3.3: Design iterations and stakeholder validation.

Mock Up Design	Involved Stakeholder		
	Operators	Process Technicians	Higher Engineering Roles
Iteration 1	2		
Iteration 2	3	2	
Iteration 3	3		3

The criteria for validation were selected based on relevant themes found in literature, understanding of the assembly situation and statements made by stakeholders during interviews. Table 3.4, detail the themes and their associated questions which encompass the main project scope i.e., information presentation and cognitive support. The inputs from this served to answer research questions 1, *How can assembly operators be supported through effective information presentation displayed digitally during assembly work tasks?*.

Table 3.4: Validation themes and questions.

Themes	Questions
Information Support	1. Is the level of Information sufficient? 2. Does suggesting the WES for repeated mistakes support you? 3. Does showing quality feedback during the log-in improve your work?
Information Presentation	1. Is the information presented in a simple and easy to understand way? 2. Is the quality alert presented in an easy to understand way? 3. Do you think text is better to read and understand?
Functionality Assistance	1. Is it easy to access information through such a presentation? 2. Does flagging option support your work and keep you focused? 3. Do you think alerts shown during production can support you?

Validation of the back-end systems involved interviewing stakeholders connected with each system and the IT department to understand whether such kind of a mapping would be feasible. Additionally, a review of internal documents linked with individual systems also served to validate the potential system. Moreover, this helped gain insight into answering research question 2, *How can personalised alerts be generated to aid operators in performing assembly tasks accurately?*.

4

Results

This chapter presents the results obtained from the chosen methodology, providing insights that help answer the two research questions. The chapter begins with the results from the initial state analysis, followed by specifying the requirements of stakeholders, the development of a conceptual model based on the scope and finally a prototype detailing the front end and back end of such a system.

4.1 Initial State Analysis

The results from the initial state analysis were obtained through two stages - Analysis of Information Support and Analysis of the Quality System. The former is carried out in three stages - conducting observations, carrying out questionnaires and having operator interviews. These were done to understanding how operators currently work with the available assembly information and how they seek support from their work environment. Analysis of the quality system was carried out to understand the types of quality errors made; and how they were registered and tracked within the organisation.

4.1.1 Analysis of Information Support

4.1.1.1 Observations

General Information and Operator support systems

At the case company, the production line chosen for the observational study carried out final assembly tasks on the cars. Assembly operators on this line relied upon several information sources placed within the vicinity of their workstation. General information sharing is done through meetings with team leaders before the start of shifts. Operators and team leaders discuss the team's performances in terms of quality, delivery, and safety during their previous shifts, daily production targets, updates pertaining to new assembly instructions and/or procedures, and are also intimated about ongoing problems and issues found during other shifts (day, evening or night) that might directly or indirectly affect their work.

Whiteboards present by the line side detail information outside production such as names of operators working during each shift, competence matrices, performance metrics in terms of cost, quality, and delivery from all shifts for that workweek, information about ongoing assembly problems faced by operators of that team from other shifts and information about line fundamentals i.e., best practice to be followed on the assembly line. Every station has its own Operator Instruction Sheet (OIS), detailing the important work elements for each kind of assembly and the respective work order for that station. In addition, Work Element Sheets (WES) are also present which describe the why and how details behind the OIS content. These are present in paper format within binders and are either referred to before shift starts or during production stops, for operators to refresh their memory on the work instructions for different cars and their variants.

During assembly operations, operators are supported by classical support installations – Poka Yoke, pick by light, pick by barcode and electronic nut runners, as seen in figure 4.1. These are steered by the organisation's IT and production PLC systems. Poka-yoke as support is integrated into the operator's work in two ways – one via the assembly itself through the design of assembling (DFA) principles (for example: operators look for a certain colour of a connector module to know whether the car is of a certain variant – electric or hybrid) and second, as equipment which lights up and requires operator interaction as feedback to the system that he/she did not miss the assembly step. Pick by lights systems placed on the material racks assists the operators in knowing which part to pick when a car enters their station. Barcode scanning serves as another measure for information support to ensure that the right part is picked before assembly. Information from the electronic nut runners also relays information to the operators about the number of screws to tighten on the current car.

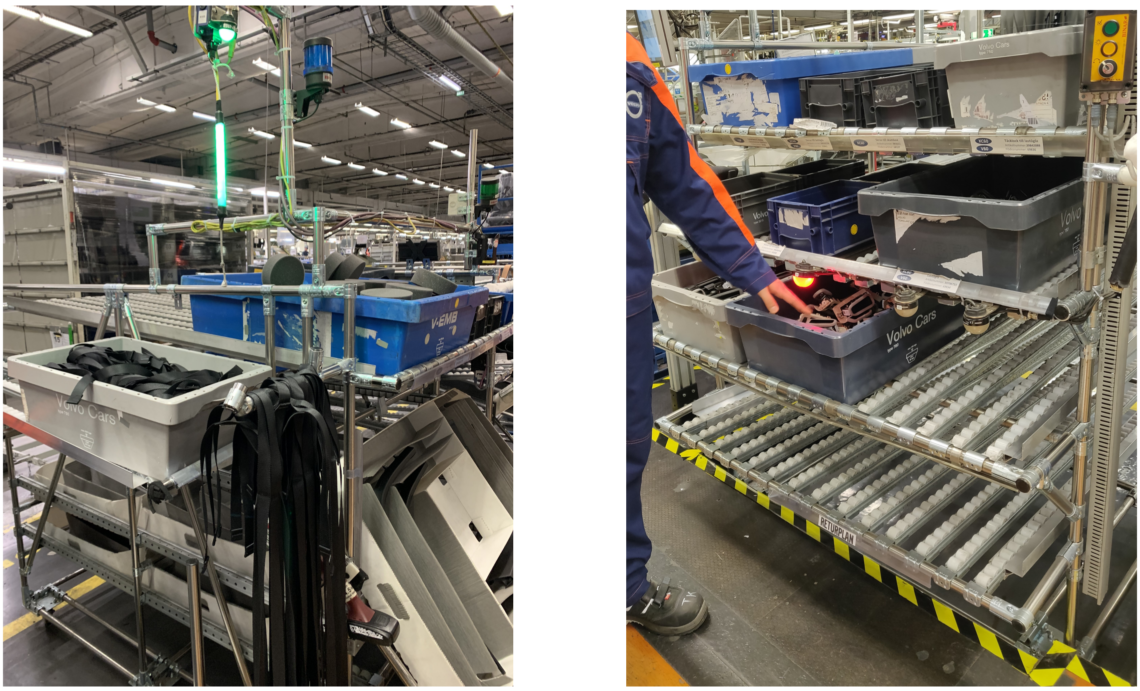


Figure 4.1: Poke Yoke and Pick by Light support systems.

Another support function is the andon rope that runs along the length of the station. When an operator faces a problem either while assembling a certain part, difficulty with using tools, encounters material shortage or is unable to complete the assembly within the specified takt time, he/she pulls the andon rope signalling to the team leader which station requires his assistance.

Assembly information sources

Information pertaining to the assembly of the cars is in the form of instructions and is of two categories - simplified station instructions (SSI) that are common to all cars and specifications to a particular car variant or variant-specific information.

The simplified station instructions, as seen in figure 4.2, are presented along the line side at all stations. These are extremely basic and simplified assembly instructions detailing to the operator the common operations to be performed on all car types. Depending on work performed at the station, these instruction sheets also contain pictures of recommended tools to be used during assembly and special symbols informing the operator to be aware of actions (safety, ergonomics, quality, critical operation, error proofing, etc.) during certain assembly steps. To ensure assembly quality, there also exist images to instruct and support operators to be mindful of certain aspects of assembly, for example, images depicting OK and NOK situations while assembling. In addition to these, illustrations detailing the workload for each car model and information on following good ergonomics and associated risks are also present for the operators.

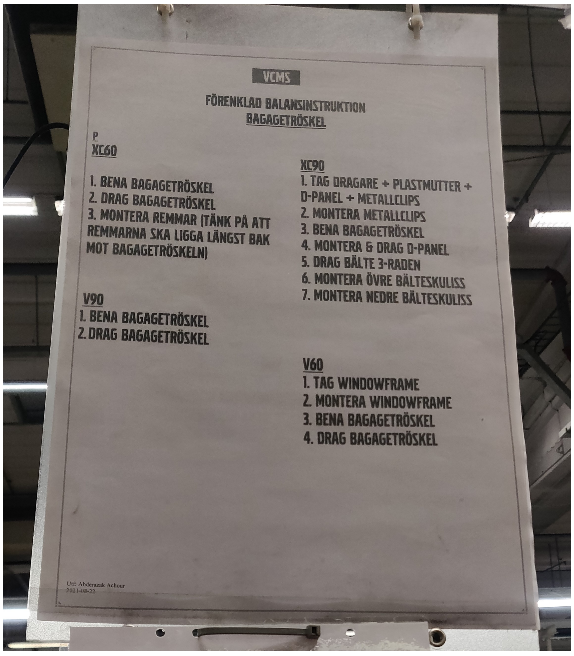


Figure 4.2: Station specific instructions

On the line, operators predominantly rely on variant-specific information which is largely paper-based today. These are attached to the car body and follow the car as it makes its way around the factory. Two sets of such specification sheets are present - one at the front of the car (hanging under the hood) and another on the backside. As the car moves around the factory and is gradually built, operators tear off these sheets after a certain set of assemblies have been carried out to access or reveal the information relevant for their work or the next station or line. Currently, these sheets detail information such as car model, its make, sequence number, engine type, colour, and variant parts specification. The layout of the specification sheet of the observed line contained assembly information for the previous line as well making the contents on the sheet quite crowded. In addition, to save space and present as much information as possible on the sheet, the size of text for part numbers is quite small. In addition to this, the rear specification sheet was found to be dislodged from its hanging position and placed on the floor of the car; causing operators to handle and reposition these sheets to access the rear building information in the car.

Information seeking patterns

During assembly, as seen in figure 4.3, the operator begins assembling parts from the front of the car and makes his/her way towards the back of the car. As they come towards the end of the current assembly, a common observation was that operators have a glance at the upcoming specification sheet to know what car model, its variant and if any unique parts are needed. Support equipment such as the poka-yoke, electronic nut runners and pick by lights/ barcode systems further provided information about the correct parts to pick and assembly operations to carry out.

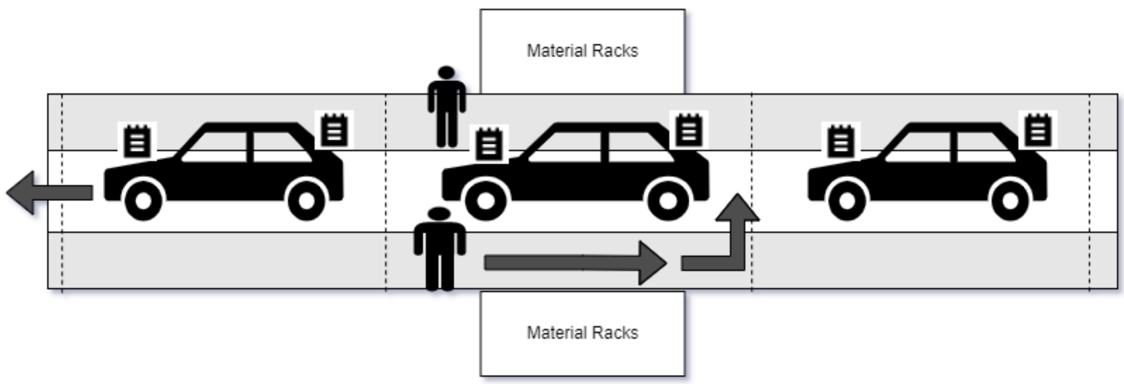


Figure 4.3: Current state of information seeking pattern by operators on moving line.

4.1.1.2 Questionnaires

This section presents the most interesting results obtained from the questionnaires. The survey inputs have been presented in accordance with the questionnaires format in appendix A.

Demographic Questions

Figure 4.4 depicts the general demographic of participants that answered the questionnaires. Overall, a significant number of operators that answered the survey were well experienced with assembly tasks at the chosen line and within this manufacturing facility.

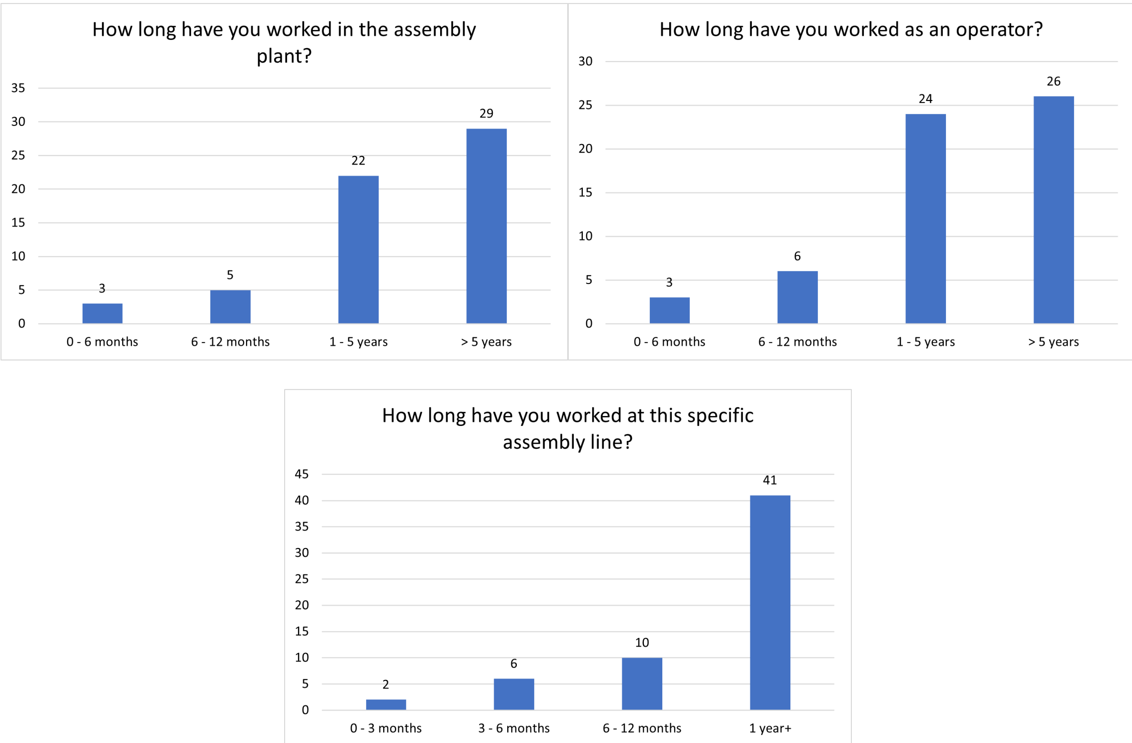


Figure 4.4: Experience of the surveyed demographic at assembly work.

Work Situation Questions

Figure 4.5 shows the work situation of the current state. Operators are expected to perform a variety of task on different car variants within 1-minute takt time. This demands operators to seek and rely on a variety of information sources throughout the assembly process.

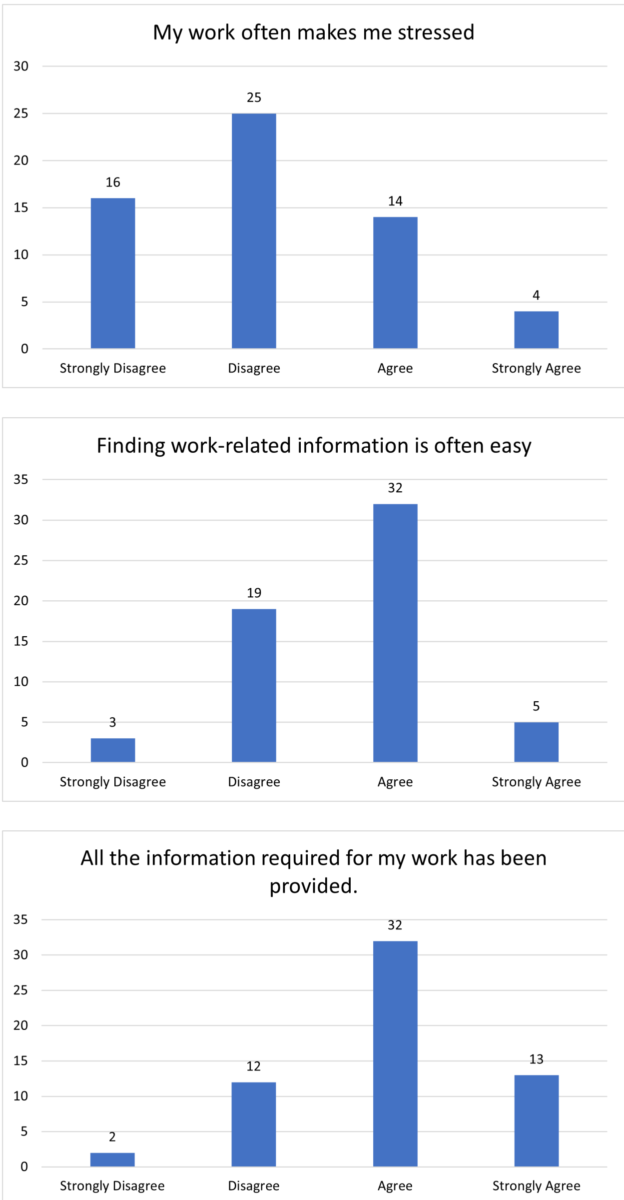


Figure 4.5: Understanding current work situation of the operators.

Work Instructions Questions

Figure 4.6 shows how current work instructions OIS/WES are being used by the operators; it can be seen from the graph that most of the operators do not use the OIS/WES during their assembly work. Most operators were not involved in the creation of their instructions, meaning they cannot influence the instructions presented to them in anyway.

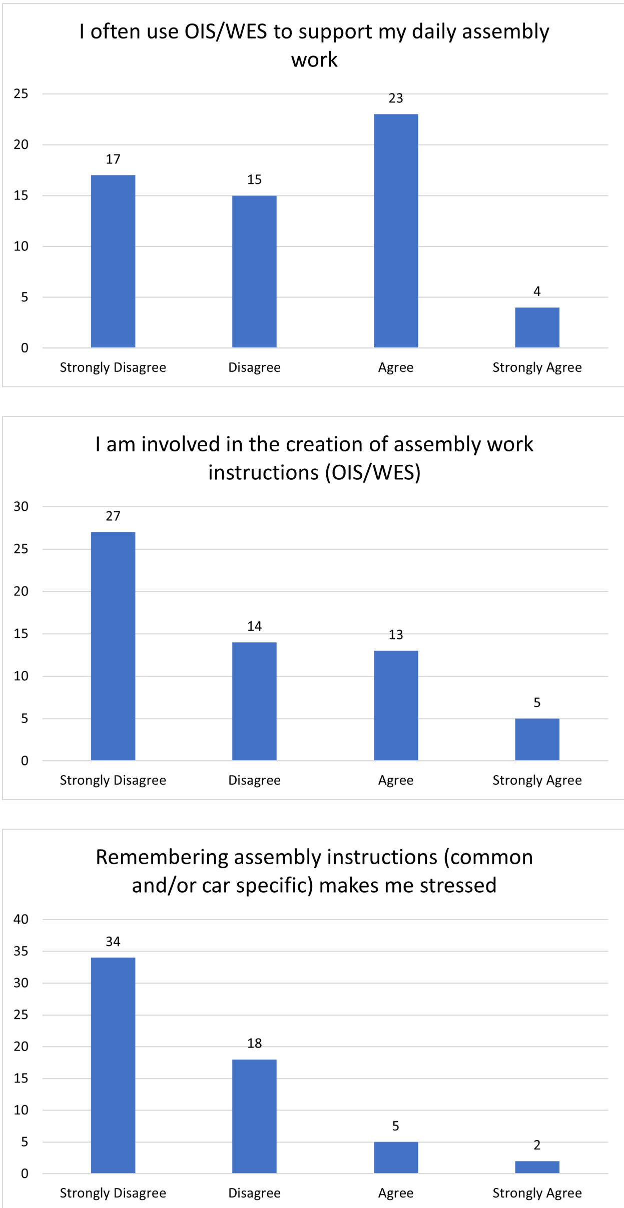


Figure 4.6: Understanding how operators interact with the available information.

Quality Feedback Questions

Figure 4.7 show the operators opinions towards the currently implemented quality system. Several operators find it easy to communicate quality errors found during assembly and are informed about the mistakes they make. However, when it comes to assembly mistakes made at other lines, nearly half of the participants mentioned that they are not informed about those mistakes.

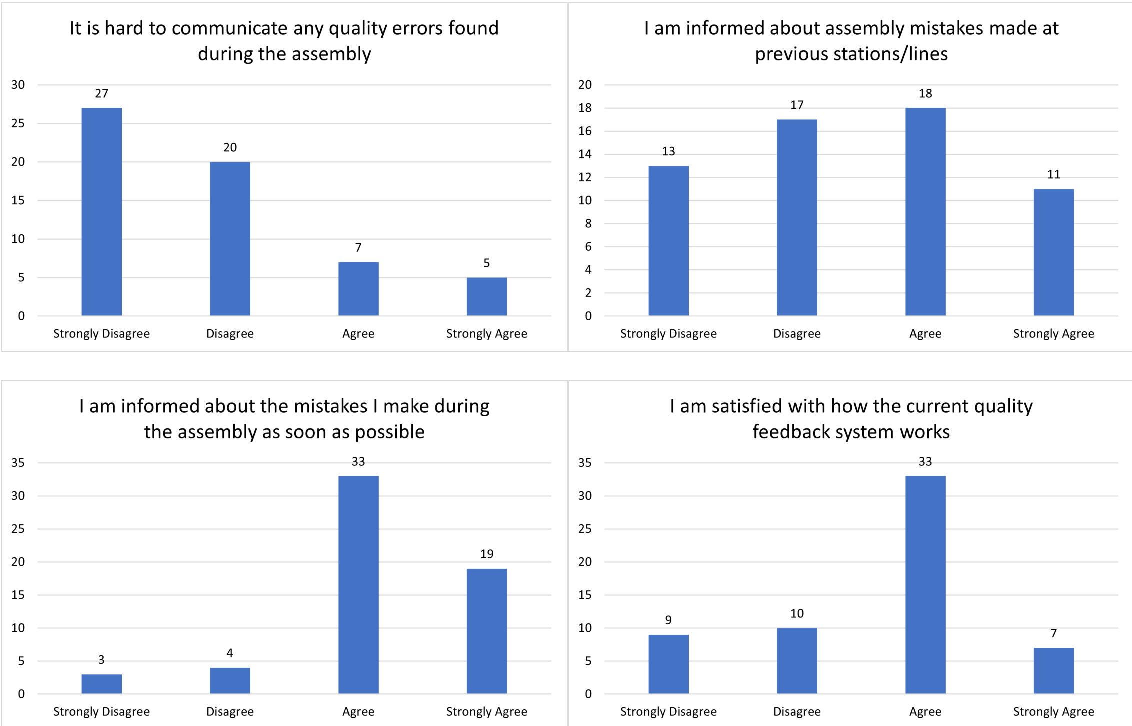


Figure 4.7: Understanding how the current quality feedback system works.

Future Concept Questions

Figure 4.8 shows the operators acceptance towards digitalised and personalised information. Several operators claimed their liking towards the idea of information personalised based on their work experience.

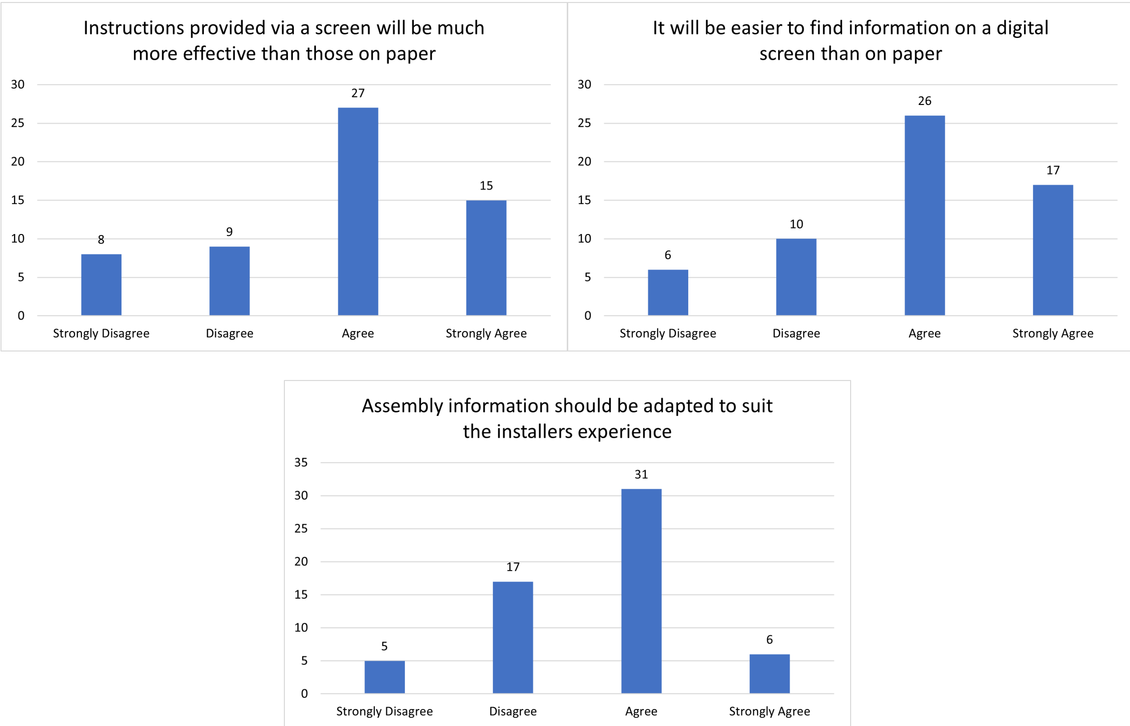


Figure 4.8: Operators opinions towards future concepts.

Qualitative Data

The questionnaires allowed for the collection of some qualitative data from the respondents. 2 open ended questions connected to what important assembly information operators desired to see on a digital screen and recommendations to consider for the study were put forward. Out of 59 respondents, 41 of them answered these question.

Codifying the received answers, ten respondents suggested about receiving information in advance, this could be either in the form of incoming assembly errors or material shortages for cars, general production information, or even quality feedback.

From an instruction's perspective, seven respondents suggested being able to view variant specification in the form of a picture or video of the assembly, digitalised version of the OIS and WES documents, tips and tricks for specific assemblies that will help them conform to the standardised way of working. From a support perspective, several respondents suggested showing variations for particular assemblies, personal quality feedback as a complement to the team leader instructing them about their mistakes, tips to overcome the most common errors you make as an operator. From a system functionality perspective, one respondent suggested having an alarm button to alert the team leader about errors or write off a cars build responsibility in case they require a break.

From a visualisation perspective, several respondents suggested that the information be clear, simple, and easy to understand. Essential information like the quality feedback and incoming faults should be easy to grasp and presented in a timely manner so that they can be mindful of them during their work. In addition, be concise in their delivery due to assembly time constraints.

18 respondents neither answered the questions nor know what to suggest for the study. Suggestions regarding the system technicalities like logging in and logging out were categorised as irrelevant and therefore not considered.

4.1.1.3 Interviews

Amongst the interviewees, operators, and team leaders stated that from an information support perspective there is a high reliance on the variant specifications that hang on the cars today. Cars essentially have two kinds of assemblies – the standard assemblies, performed on every car and then the variations, which are the more important assemblies based on the specification and differ for each car. The variations are quite subtle and are hard to know by just looking at the car which is when the specification comes in handy. For instance, one of the operators stated that two parts for a certain assembly may look identical but, in reality, they are not because they differed by the article number for each car as stated on the specification sheet. From a support perspective, the sheet also acted as a way to secure the quality of assembly operations in the event of technical issues concerning the poka-yoke and pick by lights systems. The interviewees stated that the car model, variant, the mix number, and specifications specific to their workstations were the only pieces of information required from the sheets. The OIS and WES were other sources of information the interviewees referred to in times of problems with certain assemblies or when they felt the need to refresh their memory of the standard assembly instructions. However, most operators stated that as an aid it is only looked into once, during the time of their training.

Some of the operators argued that the information they perceive on the line today was sufficient and enough to support their work while others argued that there was too much information to perceive from their work environment. As one operator said, *"With so much information on the line today we tend to care a little less for each thing and sometimes you may not know what to focus on. So, we only want to see the essentials."*

The current specification sheet is shared with the previous line and contains information from that line as well. Operators claimed that the presentation of information on the specification sheet is optimised as per the entire line's requirements and were content from a layout point perspective. However, constructing the layout of the general line requirements makes it quite messy, leading to the non-use of most instructions at a given workstation. For an experienced operator reading this sheet, it's quite easy to look up information for your work but for someone who has started working on the line, the sheet can be quite confusing, and it takes time before you get a good grasp over where to find relevant information for your work.

Moreover, several interviewees stated their disapproval over the amount of paper-based information on the line today. Team leaders mainly stated that the current challenge with this is that if there were any updates to the specification then they would have to manually update or notify all operators involved with assemblies using that specification sheet. Another drawback was the accessibility of information. As one of the interviewees stated, *"I would like to seek out information myself and think about the work I do because otherwise, it's a lot of physical work and not as much of a mental stimulant."*

If an operator required specific information regarding an assembly process or information that was not on the variant sheet, OIS or WES, he/she would have to depend on the team leader or a process technician to access this information for them. The centralised locations of the OIS and WES, coupled with the time constraints for assembly make it hard for operators to access them.

Some interviewees stated that the manner of obtaining quality information and feedback today is not very good. Team leaders stated that on some lines, individual quality feedback is done manually where building information must first be retrieved from each station, entered into a computer, printed, and then taken to each person on the line, for them to acknowledge. From his perspective, this is a lot of work and not an efficient way of sharing quality information. As one operator stated, *"We build several cars in a day, and it is hard to remember what we did wrong on a particular car. If we get quality feedback at a later time, it is hard for us to remember what fault and which car it was on. If we receive this feedback faster, then it will help us remember better the occurrence of the fault and we can avoid it in the future."*

It would be easier if the error feedback could be sent directly to respective operators as feedback. Another instance described by one of the operators was that during production if an error is found, team leaders convey usually this information to us right away. However, because they are so involved in their work, operators tend to not take this feedback seriously enough. Hence, not paying attention to it. Several interviewees agreed that faster quality feedback would be desirable as it would allow them to be more mindful of certain assemblies.

The concept and thought of personalising assembly information were very new to all participants. Several interviewees stated that if the information were to be personalised it would be good to see it from a quality feedback aspect. The reason for this was that operators are always curious about their quality performance. Knowledge about their own mistakes gives them a sense of ownership of the work they make errors on and can then focus on not repeating them. Personalisation from an experience perspective was also quite new. There was a consensus among operators and team leaders that such kind of information would be nice to see however there is an associated risk of moving away from the standardised way of working because different operators would interpret this information differently.

Process technicians stated that this would lead to the creation of multiple versions of the same information resulting in additional work and frequent updates. The personalisation could be done based on the work content for a particular station instead. This way operators would only have to deal with station-specific information.

4.1.2 Analysis of Quality System

The quality system, ATACQ, captures all quality problems on the production line at the case company. This is mainly done at the quality control stations, or standard inspection process (SIP) stations which are located at the end of the line. Quality problems/ mistakes found here are linked to the specific team in order to address erroneous assembly activities of the team responsible. At the case company this is done once every hour as a batch process where all quality errors made at the line are compared and linked with the appropriate operator's login details at a station. The data is stored within a separate transaction within the ATACQ system, called overview of cause of concerns. Here 3 weeks' worth of quality history is retrievable.

Analysing the data from this transaction with the team leaders helped learn more about the most occurring mistakes caused by the chosen team. Some of the most occurring mistakes involved lower and side panels being wrongly assembled, side panels being loosely attached, missing clips, incorrect mounting of parts leading to gaps in flush between mating parts and dirt on interior surfaces.

The most common mistakes that were linked to this team were that of dirt on interior surfaces and the parts being assembly wrongly. Quality issues related to dirt on interior surfaces were mainly identified on the next line when operators from that line entered the car to perform assembly tasks. However, quality concerns are always linked to the original team that assembled these parts. The main reason for this as well as the other mistakes revolved around the operators either forgetting to perform certain assembly steps, handling parts incorrectly, or working in a non-standardized way to keep up with production pace.

4.2 List of Requirements

4.2.1 Management Requirements

Based on the interviews with various stakeholders, a future concept of a worker information system should consist of following:

- Real-time feedback
- Personalised information to the operator
- Focused information to the operators
- Wireless solution
- Visualise quality concerns
- Take pictures to document any issues
- Material Call function
- Updates made to OIS/WES should be sent to the information system
- Information based on operator's competency

4.2.2 Operator Requirements

According to the operators, a future concept of a digital worker information system should be able to provide the following information and functionalities:

- Information - Simplified instructions
- Information - Variant specific instructions
- Information - Latest statistics on errors
- Information - Quality error feedback during log in
- Information - A video of the assembly
- Functionalities - Able to View OIS/WES instructions
- Functionalities - Flag the car which has issues
- Functionalities - Quality alerts during running production
- Functionalities - No delay in the quality feedback

4.3 Brainstorming and Mock-up creation

4.3.1 Preliminary brainstorming session

The operators that participated in the preliminary brainstorming session mentioned that if a digital assembly information system were to be implemented for a moving line, the most important information visualization is the specifications sheet. For instance, participants mentioned that the most important specification they look for when a car enters their station is the car model, mix number, and the variant of the car because this information combination differentiates assemblies for the same kinds of cars. From an instructions perspective, the specifications for that station. Since participants belonged to different stations their inputs varied based on what they deemed appropriate from the specification sheet. When it came to the visualisation, operators stated that the text on the current specification sheet was the standard on the line today but the drawback was that some of this text was quite small, making it hard to read from the specifications. If the digital solution were to display specifications, then the text must be displayed larger in size. Reminders could be a part of the instructions page, but they should not take up too much space. One of the operators suggested that the language of the reminder should be operator friendly and not too technical, as then it would increase the likelihood of them taking notice and acting to correct the mistake. From a functionalities perspective, all the participants suggested that there must be a way for which they could log errors on the current car. An option to flag the car was recommended which meant transferring the building responsibility of the current car from themselves to the team leader. Another functionality was the ability for them to access the particular WES and OIS documents for that car. From a user interface perspective, operators suggested that a simple and clear user interface where they can access information within a few swipes would be desirable. This resulted in 13 ideas as seen in figure 4.9.

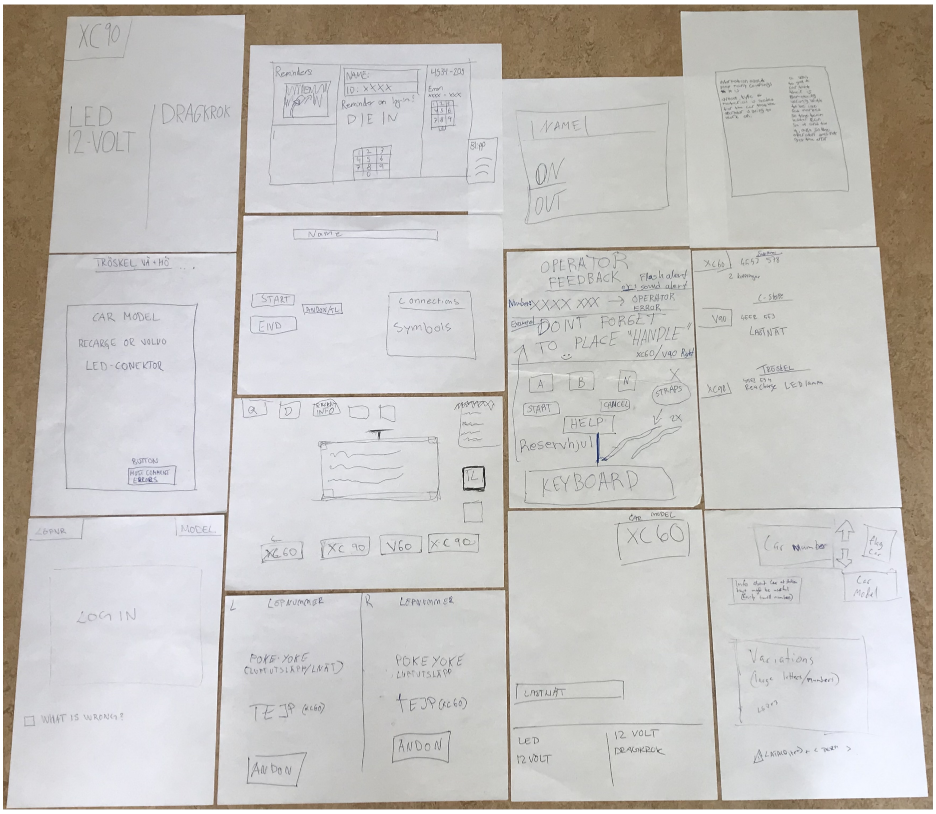


Figure 4.9: Brainstorming inputs by operators.

4.3.1.1 Design iteration 1

Based on the inputs from the preliminary brainstorming, 4 different pages, as seen in appendix C.1 were designed, login page for the operators to log into the system, a quality feedback page which would detail the personal and common mistakes operators made at a station, instructions page which detailed information related to the station, and the alert page, visualising incoming alerts. The mock up screen was split into 4 sections which corresponds to different kinds of information. The header section, sub header section, instructions section and the footer section. The header section would include basic information like the operator's name and small messages like a welcome note. The sub header section would detail information specific to the station and operator, such as the line number, station number the operator is working on, and information about the car model which he/she is working on. The instructions section which the middle part, displays the main information content like the instructions, variant specifications, reminders, and alerts. This would make it easy for the operator to seek and grasp relevant building information. The footer section was the designated spot for displaying interactive support functions such as mater call, flagging of the car, and other functionalities that could be added in the future.

4.3.2 Second brainstorming session

In the second brainstorming session, the operator's feedback from an information content perspective mentioned that they would like to see the car details such as the model and the mix numbers of the previous car and the upcoming car in addition to that of the current car. From a visualisation perspective, operators also wanted to see if the upcoming car variant had any kind of alerts, this would pre-alert them about upcoming issues as a notification. Regarding the quality alert screen, while showing the alert notification, operators wanted to visualise the mix number of the car on which they made the mistake which caused the alert notification. From a functionalities perspective, operators were satisfied with flagging the car option but they suggested against mentioning the causes for flagging. Another suggestion was made to separate the messages window from the instructions page.

4.3.2.1 Design iteration 2

Based on inputs from the second brainstorming session the mock-up designs were changed, as seen in appendix C.2. The same layout as mentioned in design iteration 1 was used, except for the main page, wherein the header section, the information about the operator was replaced with the information of mix numbers of 3 consecutive cars shown in three different colour codes to denote the completed car, currently working car and upcoming car with an alert or no alert. The font size was made larger than the previous iteration. From a support functionalities perspective, in addition to the flagging option two more functions were added - material call button and an option to read WES/OIS. No major change was made in the quality feedback screen except for visual changes like changing the font colour to red for the personal mistakes denoting that the operator has made that particular mistake several times. In the design iteration 1, the alert was visualised in a red colour box, which was changed to a yellow car in this iteration because red colour seemed to be a bit harsh on the operators. The mix number of the car on which the operator made the mistake was mentioned in the yellow alert box.

4.3.3 Final Brainstorming session

In the third and final brainstorming session, operators suggested that on some stations operators may seek information from both the front and back specification sheets. The digital display needs to incorporate this information. From a user interface perspective, the interface does not have to be colourful, rather black text on white background, similar to the specification sheets today is desirable. On the line, two standard colours are used red, indicating not ok and green indicating okay. One participant suggested that cars which are currently being worked on in a station blink green on the existing nut runner displays and this could be incorporated as well. Displaying the reminder as a blinking red box surrounding a particular specification is preferable as it conveys the intent of the alert and there is a reduced likelihood that we miss the other specifications being displayed.

4.3.3.1 Design iteration 3

Based on inputs from the final brainstorming, the instructions page was adapted to fit essential information both from the front and back specifications, as seen in appendix C.7. The layout also takes into consideration assemblies that are meant for the left and right-hand sides of the car for respective specification sheets. The online alerts, seen in appendix C.8 was altered to highlight the boundary of that specification linked with the error, mentioning the error group and mix number on which it was caused.

4.4 Prototype

4.4.1 System Interface - Front End

The front end of the conceptual worker information system is essentially divided into three parts - a login terminal, a home page, and the online instructions page. The purpose of the prototype is to visualise the user interface and contents on the screen of such a system, for the assembly use case of short cycle times. The preferred method of login will be via RFID cards which operators currently possess. Alternatively, a choice for logging in via manual entering of details is also present.

Upon login at a particular station, operators are first taken to the home page where they can see their quality feedback. The quality feedback is presented to operators in the form of alerts. These alerts are of two kinds - offline alerts and online alerts. Offline alerts correspond to those which an operator sees at the time of login while online alerts are the real-time running production alerts. Personalisation of information begins at the time of login at the station. The quality alerts at the time of login are personalised to the operator, based on his previous rotations at the currently logged in station. Additionally, the operator can view quality alerts, irrespective of shifts and personnel, that are the most occurring at that station. The structure of these alerts is to be concise and to the point so as to provide maximum information about their past mistakes. The general structure of these alerts details the car they previously worked on, the description of the error location and what reason for the cause. Here, the top 3 alerts are chosen based on the previous day's quality data and their severity. If a particular mistake is repeated several times, the system suggested to the operator the WES corresponding to that mistake. Additionally, the home screen consists of a message button which represents internal communication from team leaders or supervisors directly to the operator.

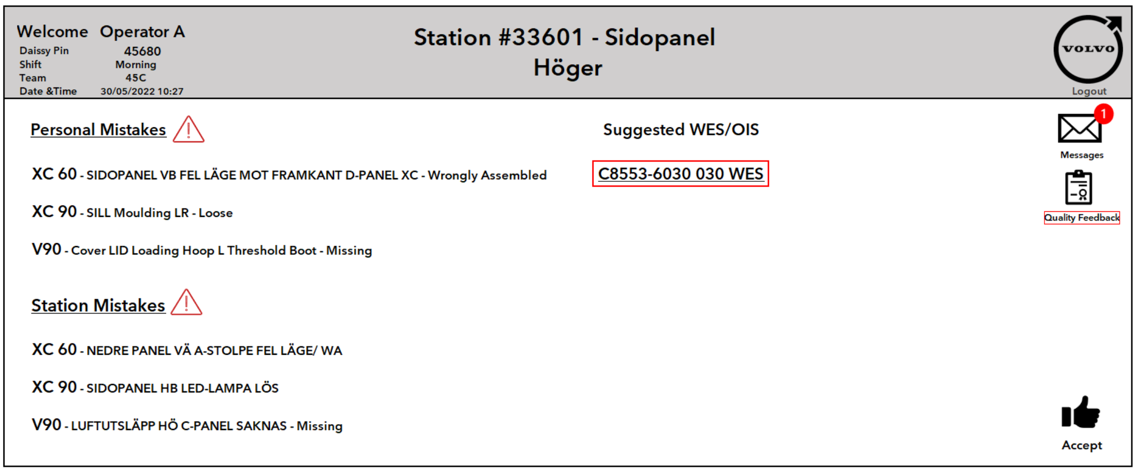


Figure 4.10: Offline alerts at the time of login.

The operator can either choose to view the WES, else must acknowledge the feedback in order for the screen to update. Upon confirmation, the screen updates to present variant-specific instructions for their station, as seen in figure 4.11. The layout of the screen is divided into 3 parts. The header section of the screen details information about the currently logged-in operator. Under this section is the information about the car model and its sequence number. At any instant, the operator can view building information about the present car at the station, cars they previously built, and incoming cars to their station. The middle section displays the variant specifications and instructions for their station.

From a functionality perspective, there exist 3 buttons - WES/OIS information, flag car option and a material call option. The WES/OIS information allows the operator to access the building instructions for the car at their station. The material call button is used to order material and notifies the team leader that a station requires material when activated. The flag car option permits the operator to hand over the responsibility of the car to the team leader when the operator encounters a problem during their assembly or notices mistakes that affects their work.

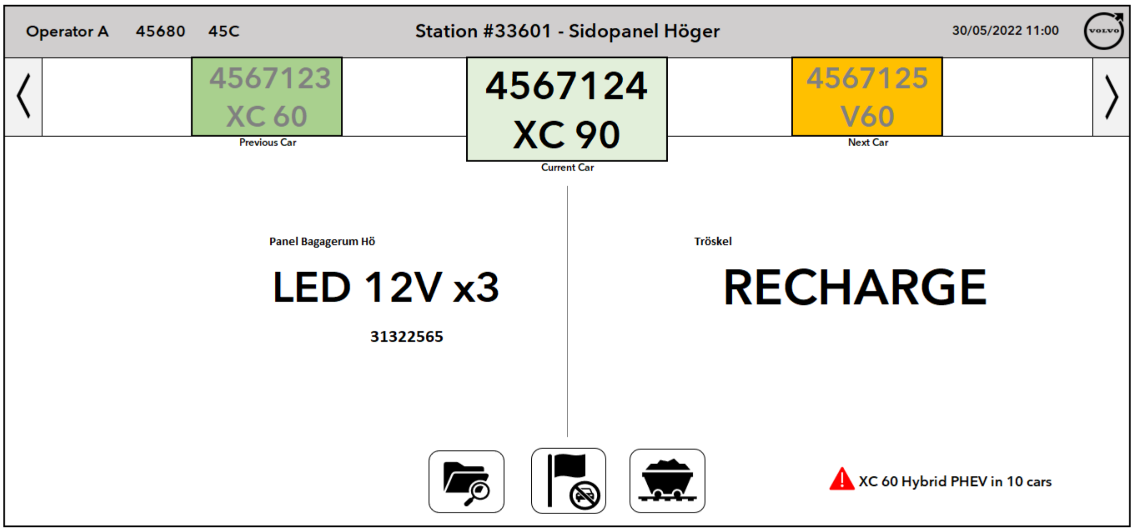


Figure 4.11: Instructions page upon offline feedback confirmation.

4.4.2 System Interface - Back End

The back end of the conceptual worker information system details the different production information systems that relay information and communicate between the systems. Based on the information to be displayed on the screen and the functionalities described, figure 4.12 depicts the communication and data flow from a systems perspective.

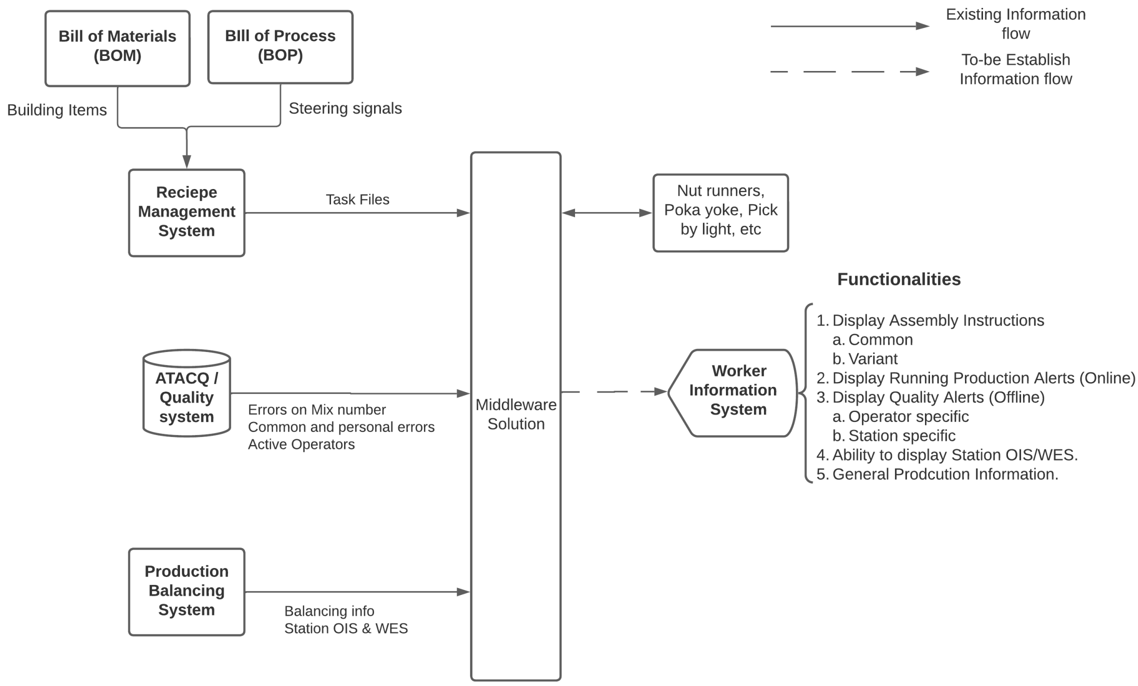


Figure 4.12: Systems overview for a digital worker information system.

The conceptual worker information system will be tasked with receiving information from a variety of sources. Firstly, upper production steering systems (BOM & BOP) will be responsible for sending building information about incoming cars when line events are triggered i.e., a car enters the assembly line for example. The building information consists of the part numbers and variant specifications. Based on the variant entering the line, a recipe generation system matches the appropriate instructions with the incoming car type. This also steers building signals to the shop floor tools to indicate this information. The quality system is used to obtain information regarding faults created by an operator, log common and personal mistakes, and track faults made at a workstation. The production balancing system will be responsible for transferring all information regarding the station OIS and WES linked with each variant.

Alert Generation

A - Offline Alerts

Offline alerts are generated at the time of login which works by first storing the operator's login data i.e., their name, operator ID, team, and shift details within the system. This information also gets logged into a transaction within the quality system that deals with real time rotation data of all operators. Another transaction within the quality system logs all concerns made by an operator at a workstation. From this, for the logged in operator, the system retrieves quality data (item description and family groups) based on the faults made by him at the workstation. Once this information is available, the system checks the online rotation card for the 1st occurrence of login of the operator ID for the shift. If it is the first occurrence of login for that shift, then the system checks for past quality concerns linked with the logged in operator. If the logged-in operator ID contains any quality items associated with it for the current workstation then the personal quality alert is generated and displayed by taking the car type, the quality error description, and the error class to which the mistake belongs. Similarly, common quality mistakes made at the same workstation (irrespective of operator and shift) are consolidated and displayed, as seen in figure 4.13.

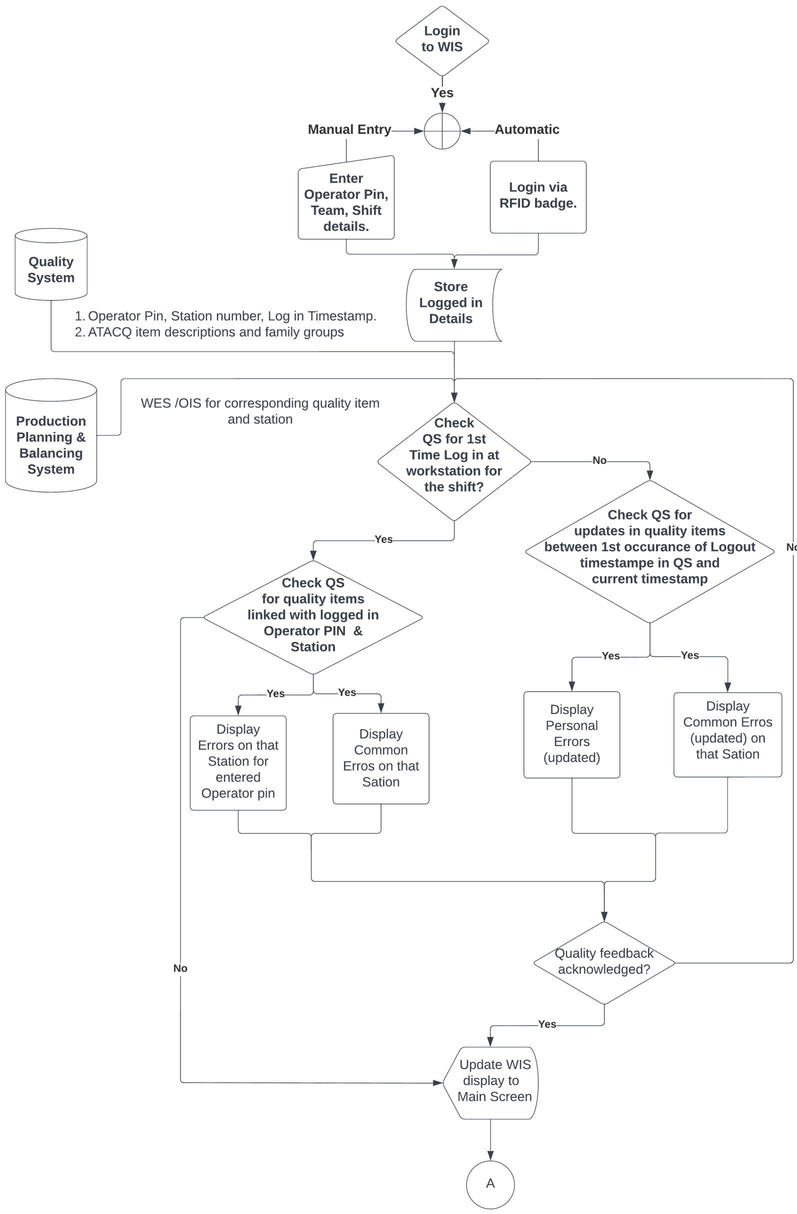


Figure 4.13: Generation of offline alerts.

An operator would likely return to a particular workstation during a typical work shift. In this case, the operator would need to receive an updated quality feedback when they come back to that station. In this case, the operator logs in for the second time, and the data gets updated in the system and within the quality system. A check is made amongst the overview of cause of concerns for updates in quality items for the logged in details. This search for updates in the quality system are done between the period of when the operator first logged out (1st rotation) and the current login (2nd rotation at the station). If new quality entries are found, then following the similar logic as explained previously, the updated personal quality feedback and common station errors are displayed to the operator. The operator acknowledges the feedback and the WIS updates to the main instructions page.

B - Online Alerts

The online alerts are real-time alerts displayed during production and figure 4.14 details how these are generated. These stem from the time a car (of a particular variant) enters the quality control (QC) station. Quality errors found at this station get entered into the ATACQ database and are always linked to their source. Details such as the car model, the ATACQ item, description of the mistake, which family group they belong to, car engine type, the graphical point could (if available), timestamp of linkage as well as the causing workstation. Details of when it was closed and by whom are also recorded.

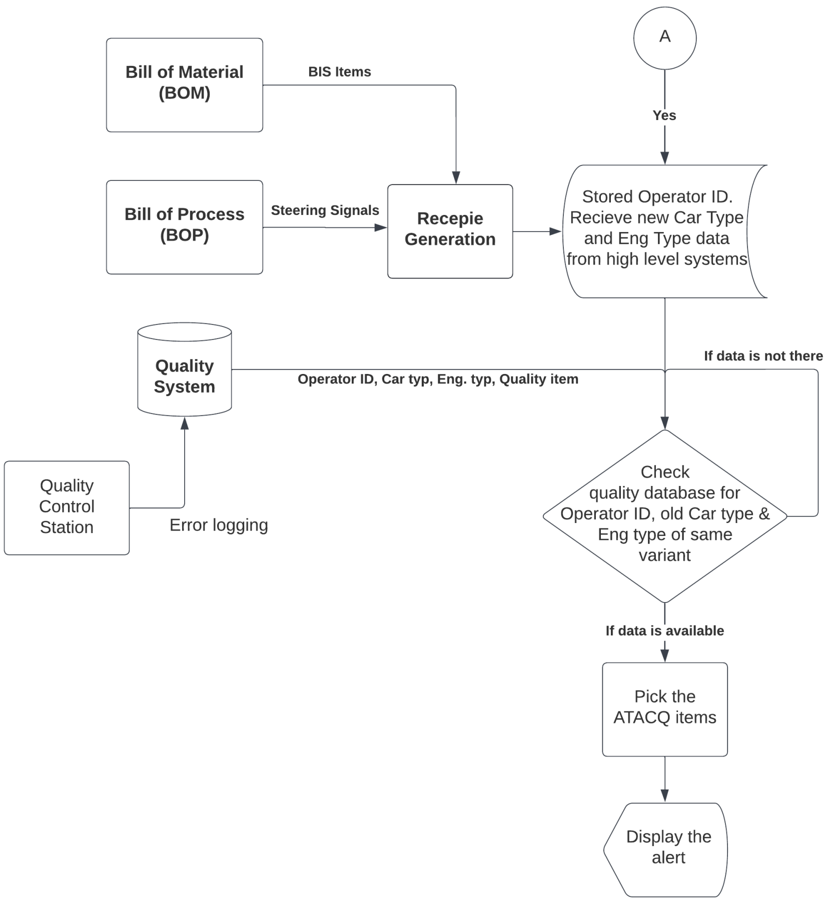


Figure 4.14: Generation of online alerts.

At the workstation side during production, the location of the operator is retrievable via a transaction in the quality database that stores online rotation data. When a car enters the workstation, upstream information systems send building information to the worker information system about the upcoming car model and its engine type. This information is compared with those that have already been entered into the ATACQ at the quality control (QC) station and with the operator pin at the logged in workstation.

If there exists an ATACQ item linked with the logged-in operator pin which matches with the incoming car model and engine type and historical data of the same car model and engineer type (entered at the QC station) then the screen updates the instructions to display the alert, as shown in figure 4.15 and also in appendix C.3. The visualisation of the alert is a blinking red box displaying the error group and the mix number on which it was found. Here, it is important that the alert only notifies the operator by catching his attention but does not interfere in the process of information seeking. This text lasts for a duration of 2-3 seconds before it disappears, leaving the specification highlighted by the red box.

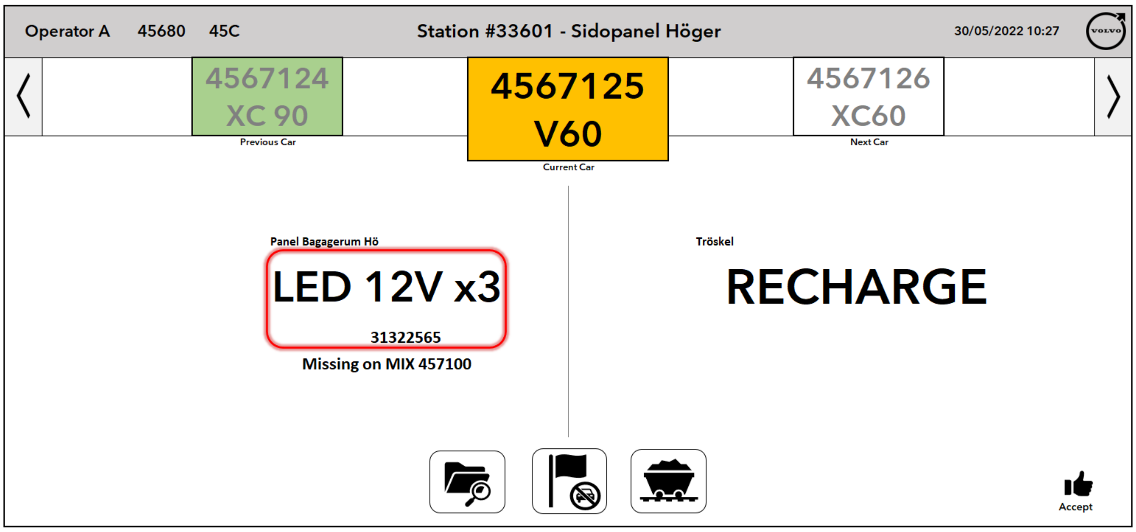


Figure 4.15: Running production alert.

4.5 Validation

The validation of the designed front end was performed in tandem with the brainstorming sessions and while seeking feedback over each iteration. The comments from these session were categorised based on themes that supported the aim of the research study.

Information Presentation
The overall impression for information presentation was quite positive over the 3 design iterations. Several operators that participated expressed their satisfaction over the way information was presented through the front end mock-ups. From their perspective, the general layout was simple and easy to understand. Featuring instructions specific to the station would benefit operators for that station however, there may be certain station on a line that depends on the specification of a previous workstation. In this case the screen would have to display a lot more information to support the operators work. These kinds of dependencies make it hard to have fully individualised information according to participants from higher engineering roles.

From a team leader perspective, it would be useful to them to know the kind of mistake or part number of the fault. The solution presented seems to focus more towards operators and not team leaders. According to participants from higher engineering roles, role-based information presentation would greatly benefit team leaders and operators respectively as then the information would be more personalised.

Information Visualisation
From a visualisation perspective, design iteration 1 & 2 had static text alerts - would be like reading another text of a screen and would likely not bring much value in terms of conveying the information to the operator. The proposed visualisation of a flashing red box in design iteration 3 would likely capture the operator's attention to the screen, prompting them to take notice of it.

Most of the operators felt that the information visualization of the alerts was good as it helps them know about potential assembly mistakes that they had made in the past. Operators were satisfied with the amount of text-based information been shown during running production through such a concept. With the screen updating the informational content automatically, they stated that they can rely on the information from the screen without it affecting their work. Moreover, this would also reduce the interactions with assembly information during assembly.

A common question that arose during each of the feedback session were where this conceptual system was to be placed. The solution of having it run from the screen of the material rack seemed to be the most fitting option. However, this solution would not fit every workstation because each station is different in terms of its setup meaning that the screens would have to be placed in a way that the operator would be able to perceive this information irrespective of his position.

Functionality Support
As a support function, operators mentioned that this kind of a digital solution would definitely benefit them during their work tasks. However, none of the participants were able to comment on the intended effects it would have on themselves. According to the participants, this kind of a digital solution would mainly assist from a communication perspective. It would make sure operators would not get stressed or irritated about not having the required information, for instance, errors on upcoming cars. Moreover, by having the functionality of inputting which errors through the flag option, operators on subsequent assembly station would have readily have this information, making them prepared for the task at hand. Operators mentioned that from a factory perspective this would also help improve the quality but were unsure whether it would benefit at a workstation level, as it would then depend on how well the operator is following the standard.

Displaying common & personal quality issues during time of login and running production was another beneficial addition in the concept. Both operators and process technicians mentioned that this kind of conceptual real time feedback would aid operators in their assembly situation and increase their awareness towards certain issues. On a more personal level, getting to know their own quality issues prior to the start of work at their station would help them know where to improve in their work. Operators suggested that alongside presenting the quality feedback, displaying a graphical image of where the fault was made would help them be mindful of their actions next time.

5

Discussions

This chapter discusses the results of the formulated research questions and the employed research approach. The implications for the industry are touched upon and finally how this work can be further taken forward within research is suggested.

5.1 Research Question 1

"How can assembly operators be supported through effective information presentation displayed digitally during assembly work tasks?"

Assembly information, be it assembly work instructions or general assembly information, plays a significant role in aiding operators in their day-to-day tasks. Scenarios where cycle times are short and assembly complexity & variations are high, demand a higher level of operator cognition to perform work tasks accurately, which is especially the case in final assembly. The way information is presented here can affect how operators perceive and approach the task at hand.

Analysis of the current state of information support at the case company revealed several potentials to digitise current assembly information and support functions, via an assistive information system. The current specification sheets contains the required information for the operators on the line, however, its presentation with other irrelevant information causes operators to search for their information. This is especially true for novice operators that are new to the line and still learning every balance. Presenting only the station-specific instructions to the operators in a digital screen makes the information more focused and personalised to their relevant station. This kind of information presentation falls within the extrinsic dimensions of information presentation proposed by Haug (2015), ensuring that the operators receive only a concise and appropriate number of specifications relevant for their work.

Given the short cycle time and time constraints of reading the information, to adequately support operator's cognitive processes, accessibility to the information is key. This is enabled through the designed concept allowing operators to toggle between cars to retrieve building information within a limited number of touches. As Osvalder & Ulfvengren (2009) state, information that is often used and required in an assembly situation should be accessible with ease. Both operators and process technicians acknowledged this as an essential feature when it comes to designing digital information displays, as they should be able to quickly retrieve essential information during assemblies.

From support perspective, the data from interviews and questionnaires shows that the quality feedback are provided to the operators the next day for the mistakes made on the current day. This delay in receiving the quality feedback makes it hard for the operators to reflect on what was the mistake and on which car it was made. Providing the quality feedback at the real time supports the operator to reflect on the mistake and act quickly to avoid the same mistake again (Gewohn, Usländer, et al., 2018). The feedback is given during both offline (summary of errors shown during the login) and online (alerts during running production) which helps the operators to be aware of their mistakes and avoid it in the future.

Presenting assembly information personalised to the operator's station entails filtering out unnecessary information and displaying only the relevant building specifications. This kind of information presentation is in itself a form assistance, particularly in the form of guidance by presenting work specific information and guarding, i.e., against cognitive overload via level of presentation and visualisation (Aehnelt & Bader, 2015). Similarly, displaying assistive personalised alerts in a concise and focused structure can enable the operator to grasp the full intent of the fault. This also falls within the information attribute category of comprehensiveness (Kehoe et al., 1992).

Operators' content over the existing text-based presentation and the success of the previous pilot studies conducted by higher management within the same scope gives credence for the proposed concept to comply with the existing presentation of assembly information, but in a digital format. Integrating both the front and rear specifications provide a means for operators to capture simultaneously the required specifications for a particular car mix. Moreover, the proposed layout being designed to incorporate left- and right-hand side assemblies in accordance with the cars orientation on the line raises potential intuitiveness of such a layout for information presentation. The benefit lies in the fact that the presentation is consistent with that of reality, thereby enabling operators to link mental models in understanding the information presented (Söderberg et al., 2017).

5.2 Research Question 2

"How can personalised alerts be generated to aid operators in performing assembly tasks accurately?"

This thesis portrays a concept for the generation of personalised alerts in a worker information system. The personalization of assembly information in this regard focuses more on the operator's quality mistakes. Providing quality alerts prior to the start of production or their shift is beneficial from a cognitive point of view. This could enhance their assembly awareness and increasing their preparedness for the

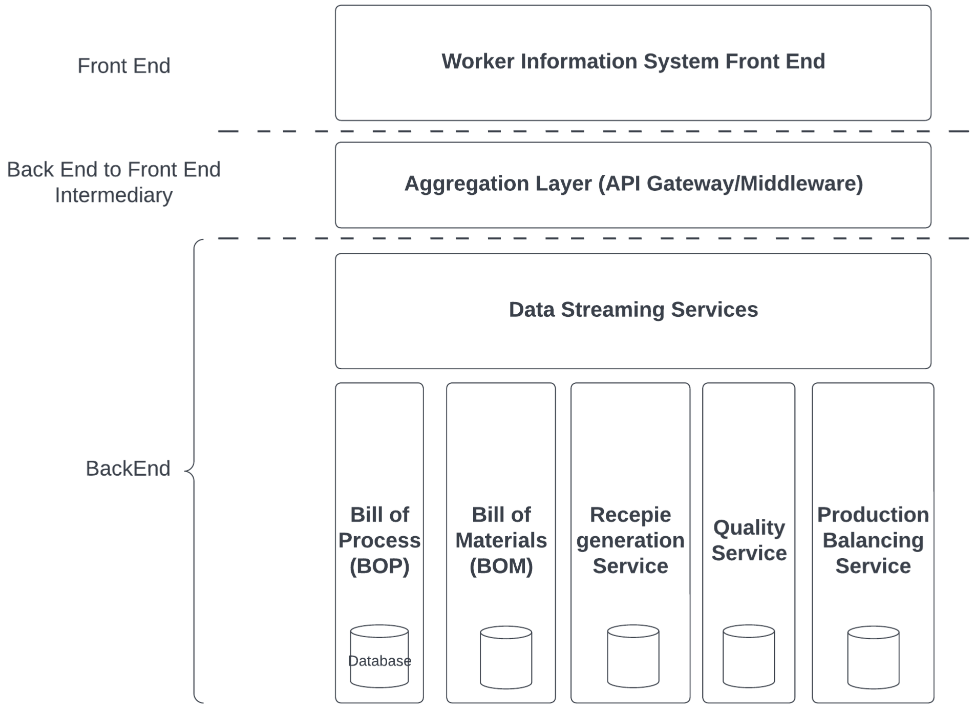


Figure 5.1: Microservice based system architecture for personalised alert generation.

work tasks that lie ahead. Moreover, the concise structure and language of the alert conveys the required information regarding their errors which from an information quality perspective matches criteria such as relevance and comprehensiveness (Kehoe et al., 1992). The proposed visualisation of the alert, extends from the perspective of information modality, extending its value as an information trigger. As Thorvald et al. (2008) states, using flashing lights to highlight information, increases its range of delivery. This enables the operator to move away from the information source and still receive the same information.

From an IT systems perspective, the generation of assistive alerts would involve gathering data from several manufacturing systems within the organisation. Generalising this kind of solution using a suitable system architecture such as a microservices architectural style, as seen in figure 5.1 can potentially bring about personalised alerts. This will be based on events triggered simultaneously from systems that lie within the information technology (Bill of process, Bill of materials, recipe management systems) and operational technology (shift registers, line and data PLCs, powered tools, poke yoke, etc.) realms.

Employing industrial data streaming services such as Apache Kafka[1], Amazon Kinses[2], or Google Cloud Data Flow [3] among others, alongside event-driven microservice architectures can enable front end services to subscribe to notifications/alerts published when back end systems(services) change state when events are hit, for instance, when an operator logs into a station or when a specific car variant with a similar fault (that was made in the past) enters a particular workstation. The use of an aggregation layer, which in this case is an API gateway/middleware solution, streamlines the communication between several back-end systems and the front end of the proposed worker information system. Thereby updating information in accordance with the assembly situation as prompted by events occurring on the assembly line. In addition, the real-time data streaming capabilities of such services ensure that operators on the line/at respective workstations will receive information in a timely manner thereby aiding the operator's cognitive processes (attention, perception, etc.) during assembly work tasks.

5.3 Quality of Research

The focus of this research study has been within the automotive industry, primarily within final assembly where the variations and complexity of assembly tasks are generally high. The main purpose of this study was to investigate how assembly operators can be supported through the presentation of personalised information and assistive alerts that are to be visualised digitally. To realise the intended aim, this research adopted a mixed method style with the intention of keeping the overall approach as operator centric as possible. The benefit of this kind of approach is that the collection of both qualitative and quantitative data allows for a deeper understanding of the given problem statement Denscombe (2010). Reference to scientific literature alongside the applied research approach reinforced the understanding as the research progressed. This kind of triangulation helped in ascertaining the findings, linked with answering the research questions thereby increasing the credibility of the stated claims.

The observation study that was carried out allowed for general observation of assembly information sources operators rely upon and perceive for their work. The benefit of having unguided production walks as part of this allowed for open questioning with operators regarding potential solutions. However, a more systemic approach could have been adopted wherein observational checklists could have been used to document how operators interact with information sources in different scenarios based on the complexity of the workstation and work content. Nonetheless, the observational study was deemed sufficient when a saturation amongst the observations made and inputs from the production walks was achieved.

[1] https://www.redhat.com/en/topics/integration/what-is-apache-kafka
[2] https://aws.amazon.com/kinesis/
[3] https://cloud.google.com/dataflow

Analyzing the results from the questionnaires revealed that certain results were skewed in favour of the case company. This caused some ambiguity with the inputs received during unguided production walks. A plausible explanation is that the questionnaire was officially sent out through production area superintendents and shift supervisors, potentially causing an inherent fear amongst operators that the survey was from upper management. To counter this, interviews provided a way to capture the operators needs and difficulties accurately, diving deeper into certain questions that felt skewed. This helped preserve the truthfulness of the findings and consequently the trustworthiness of the overall approach for the initial state.

Operator availability was a major limitation, leading to interviews being conducted only during production stops. This caused significant delays in carrying out certain steps of the intended research methodology. To compensate for the lost time, group interviews were carried out. Only people from the morning and evening shifts were prioritised for the interviews and brainstorming. More inputs could have been acquired if the night shift were involved in these stages, but the answers obtained were deemed sufficient from this sample to carry on with the study.

The brainstorming approach with the operators to come up with a suitable front-end aligned with the conventional user-centric design approach thereby preserving the novelty of the conceptual solution. 13 ideas resulted from the first brainstorming sessions with the operators. Although this may come across as limited in number, it can be backed by the fact that there was a fairly quick consensus amongst the participants regarding the information to display and the support functionalities. No external sources such as a brainstorming facilitator or ideation material (images/videos of a digital worker information front end), were used to stimulate new ideas amongst the participants and keep them engaged during the sessions. As Isaksen & Gaulin (2005) states, the use of technology or facilitators could be used to overcome these barriers. The lack of such an approach may have been the reason for so few results. To compensate for the lack of inputs and to strengthen our own design, a front-end mock-up created by the case company served as valuable input and a source of inspiration in this case. Overall, the fairly quick consensus of the designed solution and its verification with the case company mock-up & operators, serves to generalise the way information should be presented for a larger sample of operators working on moving lines in the case company.

The adopted research methodology did not include a separate validation phase. Rather, the brainstorming feedback sessions allowed for a qualitative validation wherein open-ended questions were put forwards to stakeholders during the mock-up reviews. Moreover, as the front end for information presentation was created by the operators, it can be said that the design is self-validated with regards to how operators deem information to be presented to them digitally.

Since they are the ones well versed with processes and its associated information presentation. Involving stakeholders from higher engineering roles during informal feedback sessions meant capturing their inputs as well which further strengthens the trustworthiness of the concept. In hindsight, for a more detailed and insightful validation, building a scenario-based validation and including stakeholders from academia could potentially have resulted in richer insights.

5.4 Implications for the Case Company/Industry

Whilst this study has provided insight into how focused information and assistive alerts should be presented and visualised to aid operators' cognition, as a concept, it has revealed several implications that are of interest, both at the case company and the industry.

In highly complexity assembly environments, different assembly situations may call for varying amounts of information required to support operators in their assembly tasks. Presenting focused information via digital worker information and support systems brings about several benefits from a process and cognitive aspect. Displaying focused information enables the operator to receive only information relevant to them thereby aiding their cognitive faculties, namely attention, and perception of information (Osvalder & Ulfvengren, 2009). The benefits can be ascertained from two perspectives, for newer operators focused information would ease the mental pressure linked with information seeking and for more experienced operators, the reduced information content and alerts serve as reminders nudging them towards the standardized way of working (Palmqvist & Vikingsson, 2019).

The study initially set out to investigate how assembly information could be personalised based on operators' work experience. However, the ambition to have a fully individualised set of assembly instructions may be hard to realise, especially in the case of moving line scenarios. Different operators perceive information in different ways and adapting the specifications according to each's preferences may be too much work for those who create the instructions, and ultimately risk going against the standardised way of working.

Another implication revolves around the process side. Being a digital solution that aims to replace conventional paper-based information will change the way operators daily work with such solutions. As an information support function, operators may desire to seek their quality profile, upcoming car details or general information through the system. This will lead to increased interactions with a digital screen alongside their assembly work. As suggested by process technicians and higher stakeholders within the company, from a process perspective, given the short cycle time, the ambition is to dedicate all the available cycle time to building the car. Integrating such a digital solution can be challenging however, it would be interesting to research how future digital technologies should be integrated into such situations.

Within the Industry 4.0 paradigm and from a systems perspective, developing the back-end systems based on popular architectural styles such as service-oriented architectures or microservices deviate from the traditional hierarchical monolith presented by the ISA 95 model. This allows for the overall system to be scaled horizontally, integrating newer modules from various other information sources thereby enhancing overall operator support. From a front-end development perspective, micro front ends being an extension of microservices on the front-end side allows for the development of single page applications (SPA). The benefits are ascertained from an information seeking and visualisation perspective, as SPA front ends don't have to refresh as much when user interacts with the screen, dynamically and instantaneously rendering visualisations based on information requests from associated back-end services (Peltonen et al., 2021). This fits well within short takt time environments to support operators seeking critical work information.

Finally, from a social sustainability aspect, such a digital solution can have a positive impact on the way operators perceive information through this system. By involving operators throughout the entire process of designing the visualisation of the assistive system, it aligns with supporting human behaviour and the overall process, as opposed to using technology to dictate these aspects (Thorvald et al., 2008). This ensures the likeability and usability of such a concept. This would also result in an increased motivation to use the system more thereby allowing for its continuous development by the case company. Presenting personalised quality information may further brings about a feeling of individuality for the operator and increases the likelihood of them wanting to improve their quality profile, thereby aligning their mindset with the continuous improvement aspect of the lean manufacturing philosophy. On the flip side, collecting and presenting quality data can poses a concern especially from an ethical standpoint as it contains sensitive operator data (name, team and shift details). Although it can be used to motivate and support operators, there are chances that this data can be handled unethically and be used against the operators to blame or fire someone.

5.5 Recommendations for Future Research and Implementation

This thesis focused on developing the front end of a conceptual worker information system. An interesting comparison to have would be to develop similar front ends for different kinds of stations like preassembly and kitting stations where cycle times are comparatively longer than a moving line. Understanding the level of digital information support from those perspectives can give a more holistic understanding towards the theme of personalised information support.

As a conceptual digital technology catered towards operators, studying the associated processes at a workstation level, and suggesting suitable guidelines and strategies as to how organisations can implement digital support solutions for short takt times can prove beneficial for industries in their digital transformation journey. Finally, another research potential lies within the domain of a suitable hardware option to implement such a concept. A common question during the presentation of this concept at the case company was regarding what the best hardware solution would be in case of short takt times. Several inputs suggested at wireless solutions such as a tablet or handheld devices like industrial PDA's or smartwatches. However, this raises questions over the amount of interaction times with such devices and the information displayed. Different assembly situations may call for different information carriers whose effectiveness in disseminating information can be ascertained. As the choice of information carrier plays a crucial role in supporting operators (Thorvald et al., 2013), looking into this area would take this kind of a concept one step further towards realising a fully personalised worker information system.

6
Conclusion

The increased complexity and variation as a result of the mass customisation trend within the automotive sector has spurred the need to provide adequate support for operators on the line today. Operators will encounter different assembly situations during their work, wherein presenting an appropriate level of information can enable cognitive support, aiding them in performing tasks error-free. Today, with several support system streaming real-time shop-floor data and information to the operator, it opens possibilities to develop smart solutions that augment data and information to support assembly operators digitally.

This thesis focuses on investigating a concept for a digital worker information and support system that aids operators with presenting personalised assembly information and assistive quality alerts suitable for short takt time environments. The personalisation aspect of assembly information is based on presenting variant-specific information for an operator logged in to his or her workstation. Being a digital display showcasing this information, the design, presentation, and access to critical information should be quick, enabling the operator to capture all relevant pieces of information at a glance. Similarly, providing personalised support in terms of quality feedback, both prior to beginning their work and during running production can potentially assist operators by increasing situational awareness. As this will predominantly be presented as text-based information, the design and visualisation highlighting critical information extend the range of information as a trigger, thereby supporting the operator's cognition - attention and perception during work tasks.

To realise such a concept, real-time data from several key manufacturing systems need to be made accessible via suitable system architectures. Developing the system to be more horizontal spread through the use of intelligent middleware solutions allows for scaling up of such a system thereby opening potential to develop smart operator support solutions whilst enabling key characteristics of Industry 4.0.

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A

Questionnaire Template

Hello!

Thank you for taking the time to fill out this questionnaire. We are two final year master students studying Production Engineering from Chalmers University of Technology. We are working here at Volvo Cars on our Master thesis – Digitalisation concept for personalised assembly information.

Our thesis aims at investigating how operators can be better supported on today's assembly line through better information presentation via digital assembly information support systems. The idea is to study the need for a kind of digital personal assistant that can support you with any information and help you during your work tasks on an assembly line.

To create the best solution, we need to gain insight into what it is like to be an operator and understand how you perceive assembly related information today. We are interested in what kinds of solutions you would like to see for future implementation and would like to get your input on how best we can create an appropriate solution that will fit your work situation.The questionnaire takes approximately 15 minutes and is completely anonymous. However, you are free to skip a question if you do not feel like answering it. Feel free to contact us if you have any questions or thoughts.

We look forward to your input!

Best Regards,
Puranjay & Pravin.

Demographic Questions

The purpose of this section is to help us understand who is working at the TC assembly plant so that we can better adapt our solution to fit as many operators as possible. If you do not want to answer a particular question, it is okay to skip it.

1. How old are you?
   (a) $<$ 25 years (b) 26 years - 35 years (c) 35 years - 45 years (d) 45years +

2. What is your gender?
(a) Man (b) Woman (c) Other (d) I prefer not to say

3. What is your experience at the TC plant?
(a) 0 - 6 months (b) 6 months - 1 year (c) 1 year - 5 years (d) 5 years +

4. How many years have you worked as an operator?
(a) 0 - 6 months (b) 6 months - 1 year (c) 1 year - 5 years (d) 5 years +

5. Do you/have you worked on multiple assembly lines?
(a) Yes (b) No

6. The work I do on different assembly lines differs greatly.
( ) Strongly disagree ( ) Disagree ( ) Agree ( ) Strongly agree

7. How long have you worked at this specific assembly line?
(a) 0 - 3 months (b) 3 months - 6 months (c) 6 months - 1 year (d) 1 years +

8. What shift are you currently working in?
(a) Morning (b) Evening (c) Night

Work Situation

The purpose of this section is to help us understand how you currently perceive general information in your daily work and how it affects you.

1. My work expects me to perform many different tasks.
( ) Strongly disagree ( ) Disagree ( ) Agree ( ) Strongly agree

2. I find assembly work tasks complicated.
( ) Strongly disagree ( ) Disagree ( ) Agree ( ) Strongly agree

3. It takes a long time for a new operator to learn my work.
( ) Strongly disagree ( ) Disagree ( ) Agree ( ) Strongly agree

4. My work often makes me stressed.
( ) Strongly disagree ( ) Disagree ( ) Agree ( ) Strongly agree

5. Finding work-related information is often easy.
( ) Strongly disagree ( ) Disagree ( ) Agree ( ) Strongly agree

6. All the information required for my work has been provided.
( ) Strongly disagree ( ) Disagree ( ) Agree ( ) Strongly agree

Work Instructions

The purpose of this part of the questionnaire is to help us understand how you today receive information regarding work instructions in the assembly factory.

1. I often use OIS/WES to support my daily assembly work.
   ( ) Strongly disagree ( ) Disagree ( ) Agree ( ) Strongly agree
2. I am notified about updates made to OIS/WES.
   ( ) Strongly disagree ( ) Disagree ( ) Agree ( ) Strongly agree
3. I am involved in the creation of assembly work instructions (OIS/WES).
   ( ) Strongly disagree ( ) Disagree ( ) Agree ( ) Strongly agree
4. I can find information on the balances quickly.
   ( ) Strongly disagree ( ) Disagree ( ) Agree ( ) Strongly agree
5. Information on the balances is printed clearly every time.
   ( ) Strongly disagree ( ) Disagree ( ) Agree ( ) Strongly agree
6. Information on the balances is presented in a logical assembly sequence.
   ( ) Strongly disagree ( ) Disagree ( ) Agree ( ) Strongly agree
7. Information on the balances contains relevant assembly information to my Station/Line.
   ( ) Strongly disagree ( ) Disagree ( ) Agree ( ) Strongly agree
8. It is easy to communicate the mistakes in the instructions to the supervisor.
   ( ) Strongly disagree ( ) Disagree ( ) Agree ( ) Strongly agree
9. Remembering assembly instructions (common and/or car specific) makes me stressed.
   ( ) Strongly disagree ( ) Disagree ( ) Agree ( ) Strongly agree

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Quality feedback

The purpose of this part of the questionnaire is to help us understand how you obtain quality information at present.

1. It is hard to communicate any quality errors found during the assembly.
   ( ) Strongly disagree ( ) Disagree ( ) Agree ( ) Strongly agree
2. I am informed about assembly mistakes made at previous stations/lines.
   ( ) Strongly disagree ( ) Disagree ( ) Agree ( ) Strongly agree

3. I am informed about the mistakes I make during the assembly as soon as possible.
   ( ) Strongly disagree ( ) Disagree ( ) Agree ( ) Strongly agree

4. I am satisfied with how the current quality feedback system works.
   ( ) Strongly disagree ( ) Disagree ( ) Agree ( ) Strongly agree

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Future Concepts

The purpose of this section is to understand what solutions and recommendations you would like to see implemented in a digital assembly information and support system. Feel free to think big or small over potential solutions. Your input here would greatly help us.

1. Instructions provided via a screen will be much more effective than those on paper.
   ( ) Strongly disagree ( ) Disagree ( ) Agree ( ) Strongly agree

2. It will be easier to find information on a digital screen than on paper.
   ( ) Strongly disagree ( ) Disagree ( ) Agree ( ) Strongly agree

3. Assembly information should be adapted to suit the installer's experience.
   ( ) Strongly disagree ( ) Disagree ( ) Agree ( ) Strongly agree

4. What kind of information would you like to be able to see if a digital solution was implemented at your assembly station?
   (What do you think is important to display? What kind of personalised content would you like to see that will help you with your work? How would you like them designed and displayed? Feel free to think big or small over potential solutions. Your input here would greatly help us.)

5. Do you have any recommendations or suggestions we should consider for our study?

B

Interview Protocol

Hello and Welcome! Thank you for taking the time off your work to participate in this short interview that relates to our master's thesis. We are two graduate students from Chalmers University of Technology in our final year studying Production Engineering. We are now working here at Volvo Cars on our Master thesis – Digitalization of Assembly Instructions.

The aim of our study is to investigate how operators can be better supported on today's assembly line through better information presentation via digital information support systems. The idea is to have a kind of digital personal assistant that can support you with any information you require and help you during assembly work.

The interview will take approximately 30 minutes and is structured as per follows – Interviewee background, Current State difficulties, Information Needs Future concepts, Operator acceptance and finally summarising questions.

Do you have any questions before we start?

Consent and Confidentiality – Interviewee Background

Before we begin, we would like to let you know that this interview is confidential and in no way can you as an interviewee be traced back. Your input from this interview will be documented as anonymous in our report. In addition, we require your consent to voice record this meeting. This is so that we can understand your input and reflect upon it at a later stage. The data will be held with us until the end of our study and will be deleted, at the latest, by 20th June 2022.

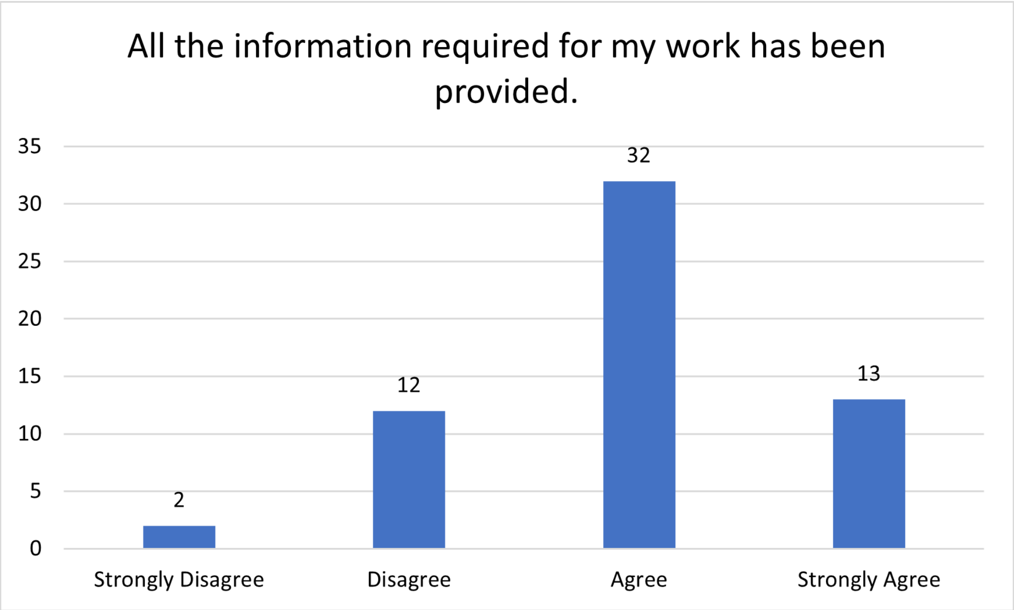
1. What is your role at the TC assembly plant?
2. How long have you worked at this facility?
3. How long have you worked as an operator?
4. During a typical work shift how many stations do you work in?

Current State & Difficulties - Information Presentation.

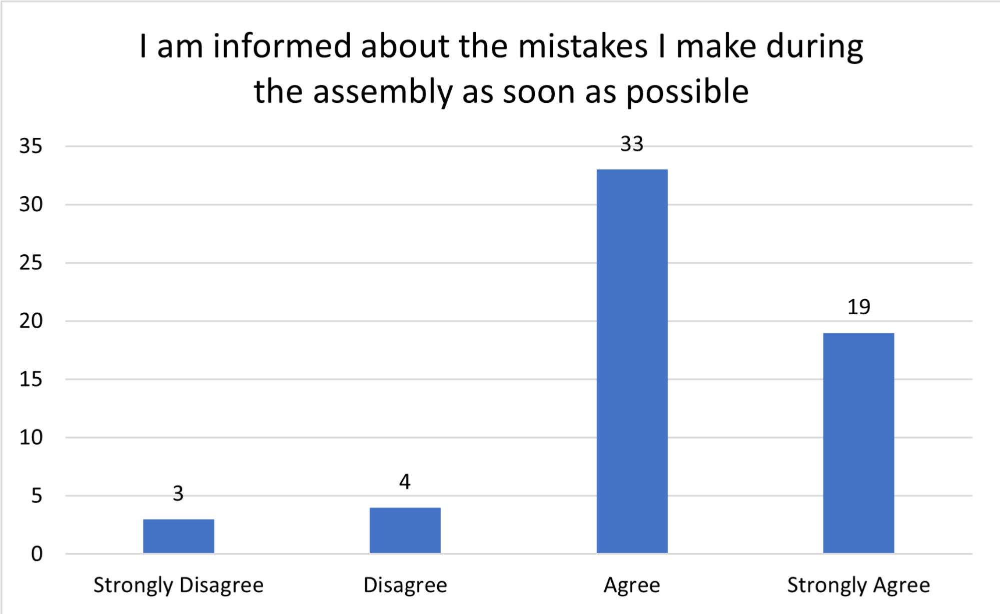
We would like to know your thoughts on how assembly information is presented to operators and what your thoughts are about it.

1. What kind of information do you rely upon during your work as an operator?
    (a) What is essential to you, as an operator?

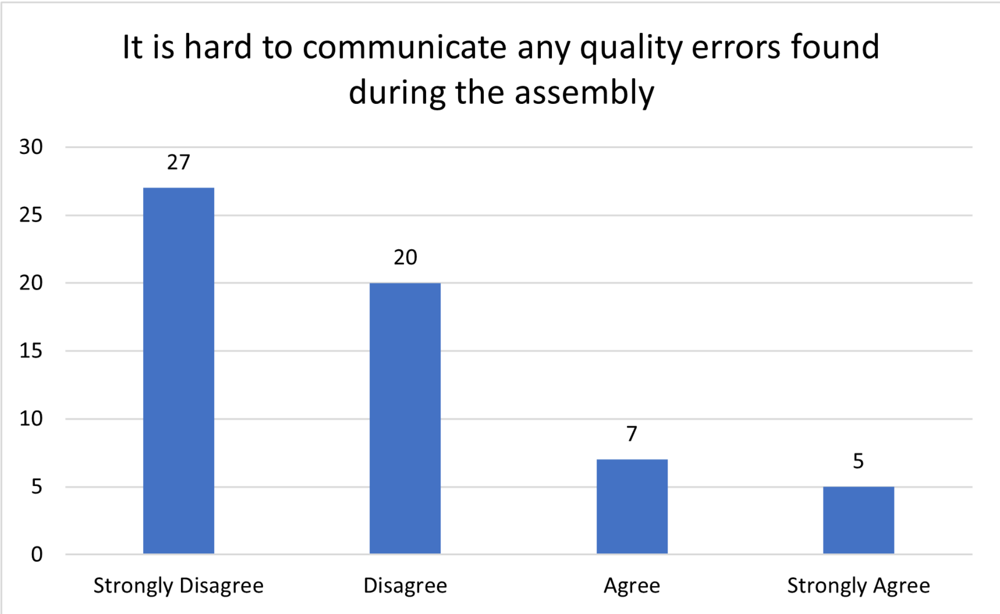
2. Where do you get this information from and in what form?
3. How and when do you refer to the WES/OIS?
4. Do you feel that the information present in the instructions or specification sheet is enough to carry out your tasks?
   (a) If yes, in what way is it enough? Which information do you think is enough?
   (b) If not, what more info do you need?
5. The general response from operators has been that all information required for their work today is provided. Do you agree with this?
   (a) If yes - Can you, please elaborate.
   (b) If not – Why do you think so? What information is missing that could help you in your work?



6. When and how do you seek support during work?
   (a) Is it easy to get the support on time?
   (b) If not, how do you think it can be done better?
7. Do you like the way information is presented to you today?
   (a) If yes – In what way?
   (b) If not – Why do you think so?
8. What kind of mistakes do you often make? Why do you think these mistake are repeating?
9. Do you get feedback from your supervisor about the mistakes you make?
   (a) If yes - When and how do they inform you?
   (b) Is the feedback detailed enough to make sure you do not do that again?
10. What do you think of this result in the graph below? Do you agree with it?



11. Do you agree with the results shown in the graph below?



Operator Needs and Future Concepts

We would like to know what your needs are to overcome the above-mentioned difficulties if a digital solution was implemented.

1. What comes to mind when we use the term personalization? (SWE - personalisering)
2. In the questionnaires, we asked if the information you receive should be adapted to suit an installer's experience. Why or how do you think this should be?
3. What kind of personalized information do you think will benefit you in your work?

4. How do you want personalized information to be displayed to you during running production? (Do you want to see it as symbols/text/pictures/videos/-some kind of sound/ flashing messages)
5. What kind of alerts or reminders do you think will support your work?
6. SV/TL - What features would you like to see that can help you with better information support?

Solution Acceptance

We would like to know how such a solution could be implemented to gain acceptance among the operators.

1. How do you think people in production respond to changes in work methods?
2. What should be considered when implementing this digital solution to be acceptable by the operators?

We are now coming towards the end of this interview. Is there anything you would like to add which you think is important to consider for this topic? Are you available to have a follow-up meeting if required?

Thanks a lot for your time and patience, this interview has helped us a lot to support our thesis work. Bye!!

C

Front End Design Iterations

C.1 Design Iteration 1

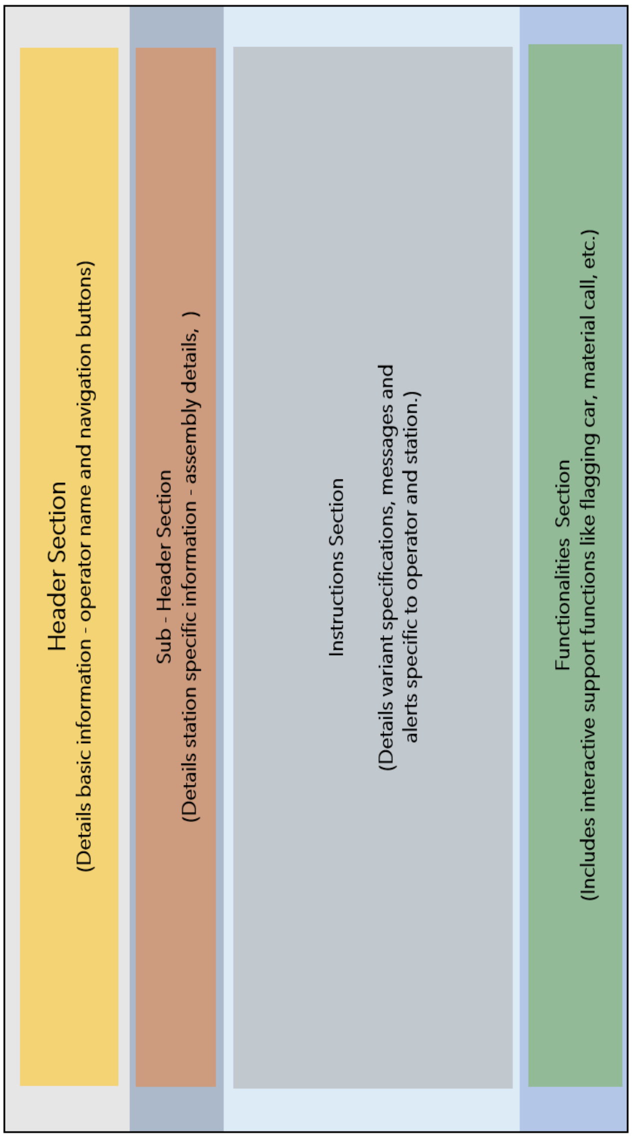


Figure C.1: Design layout.

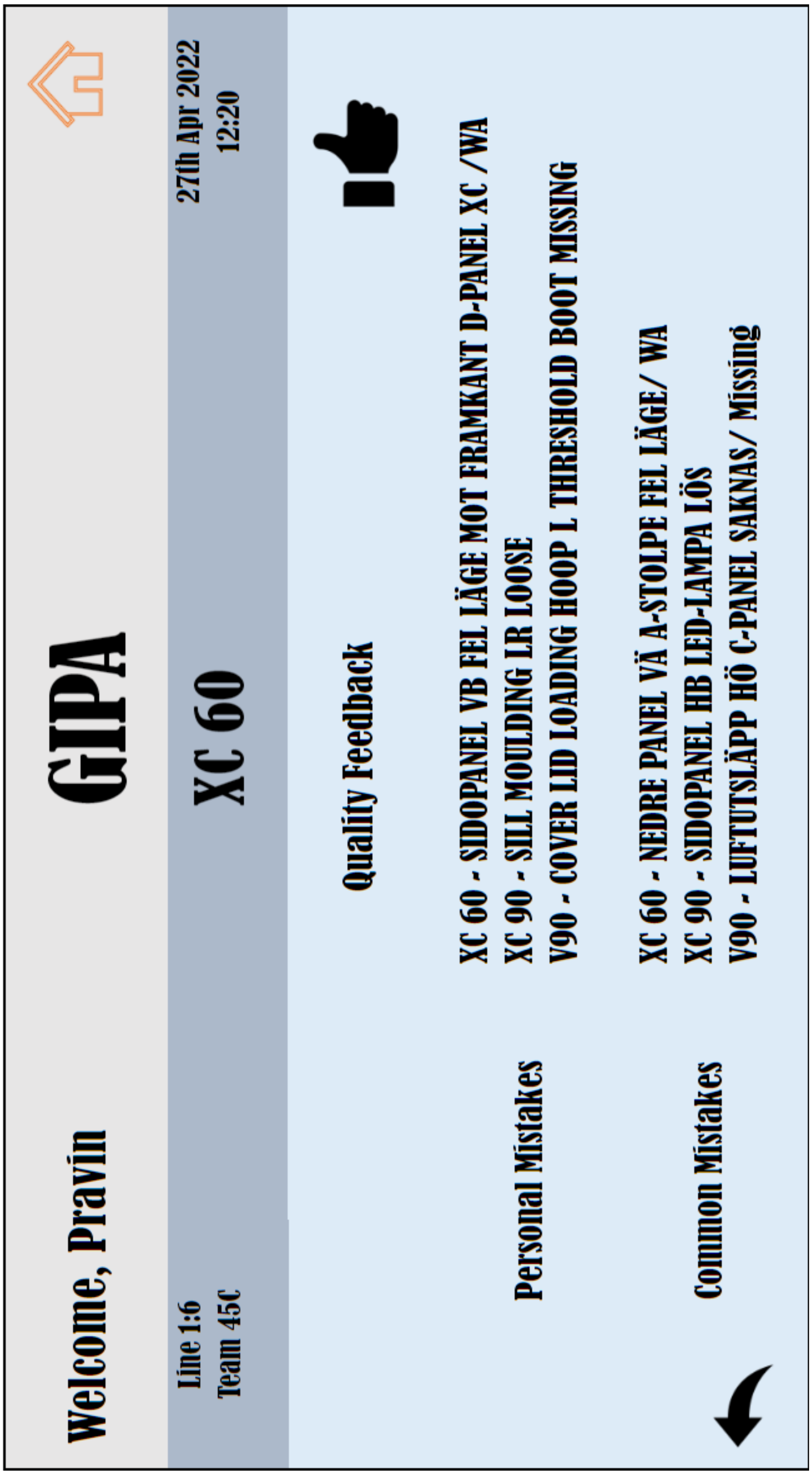


Figure C.2: Quality feedback page.

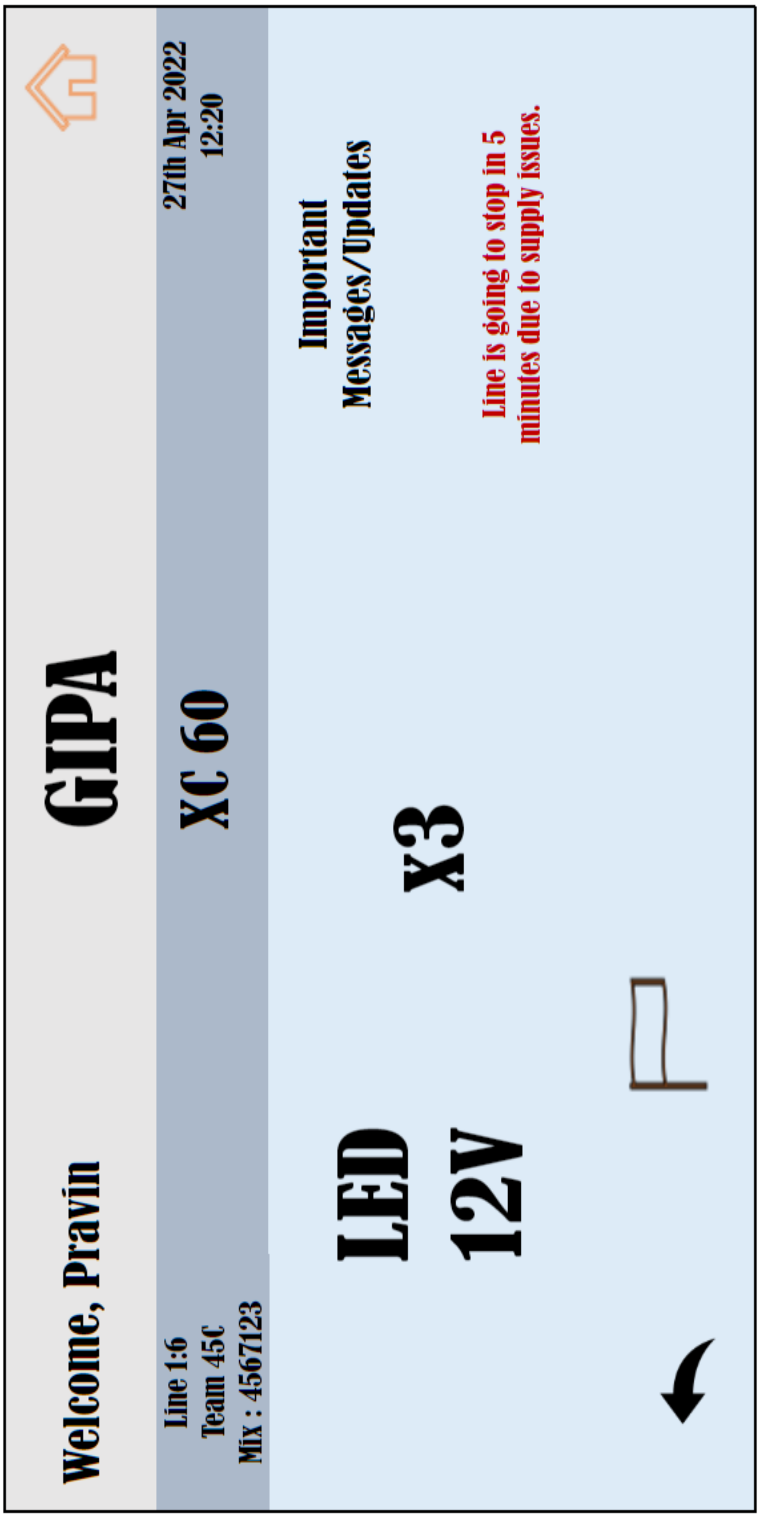


Figure C.3: Main page.

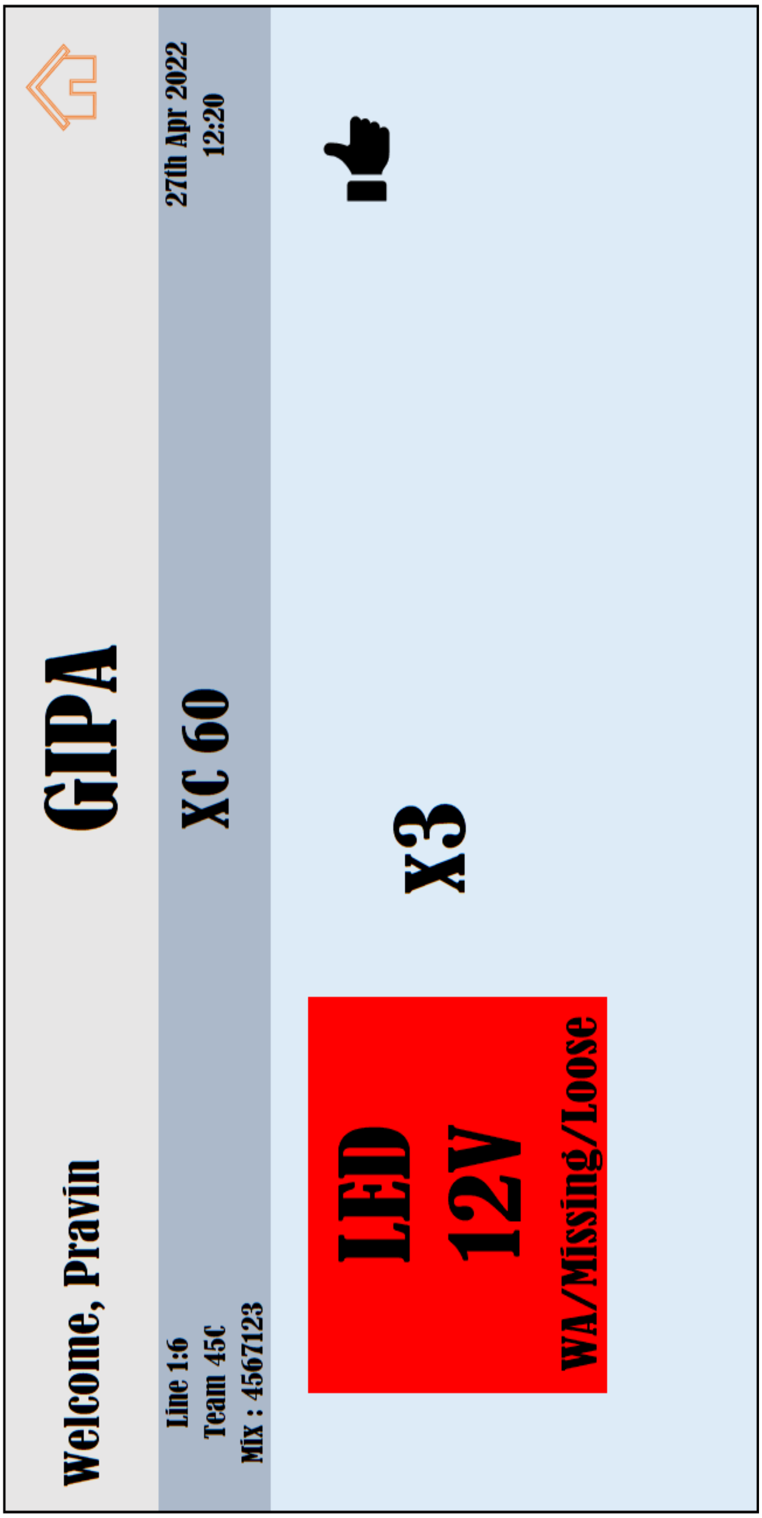


Figure C.4: Alert page.

C.2 Design Iteration 2

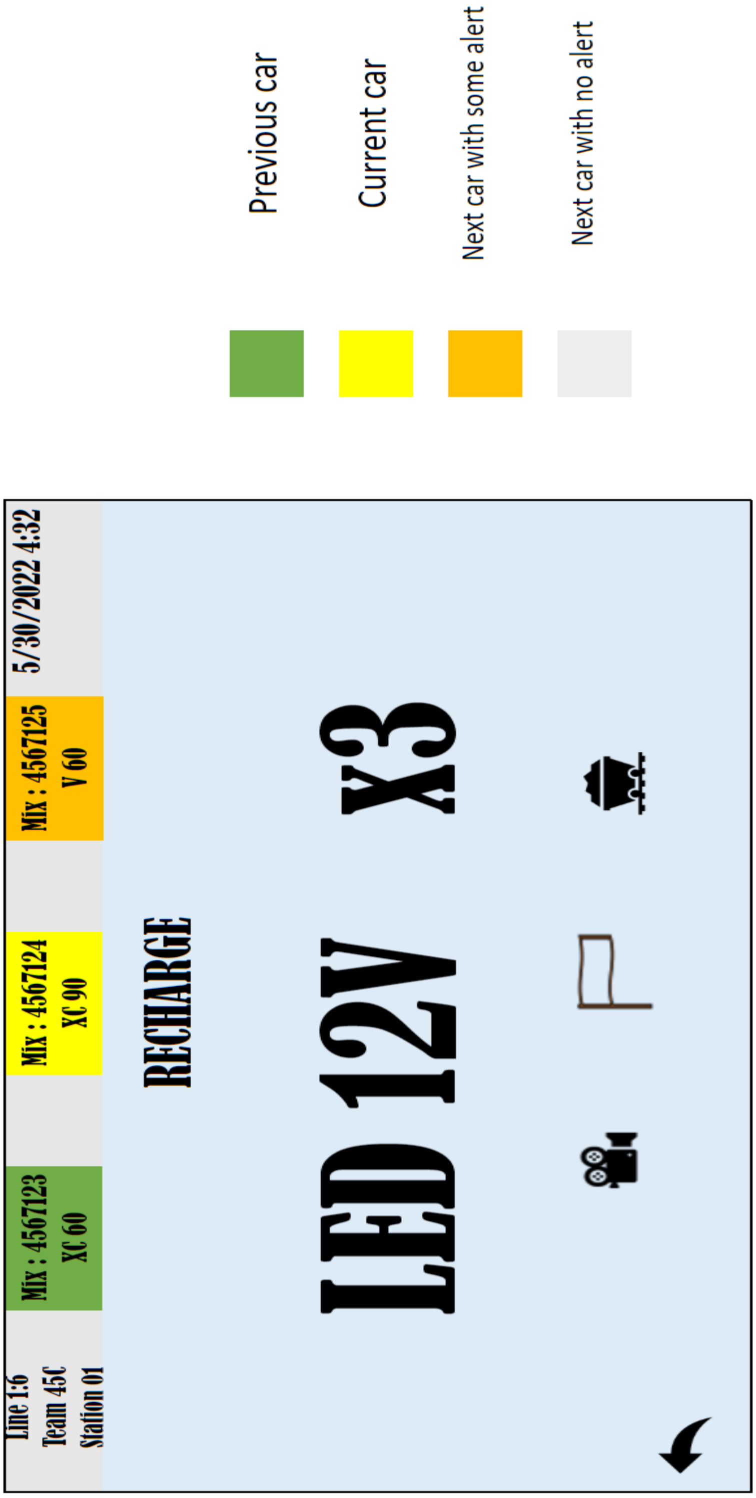


Figure C.5: Main page.

Figure C.6: Alert page.

C.3 Design Iteration 3

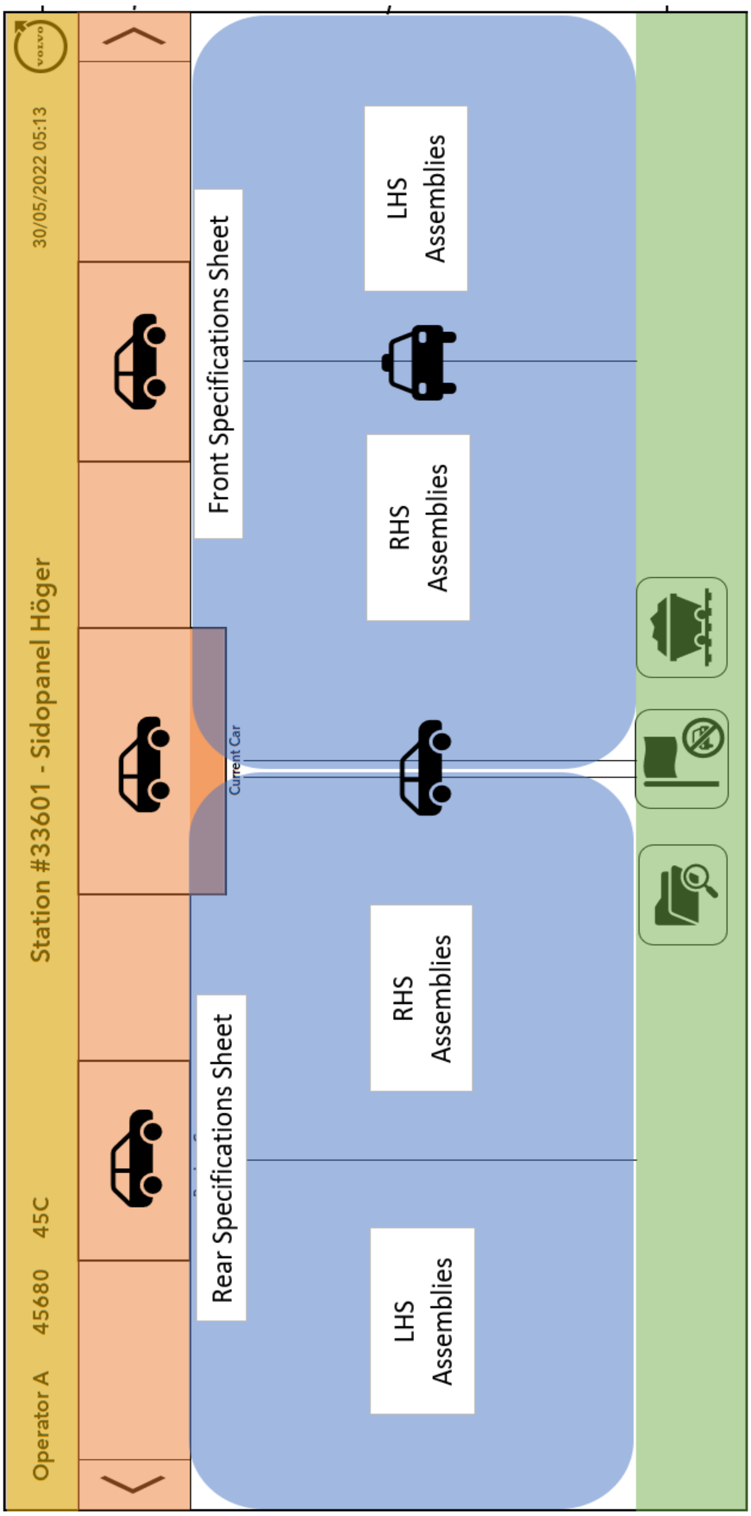


Figure C.7: Design layout for adapted WIS screen.

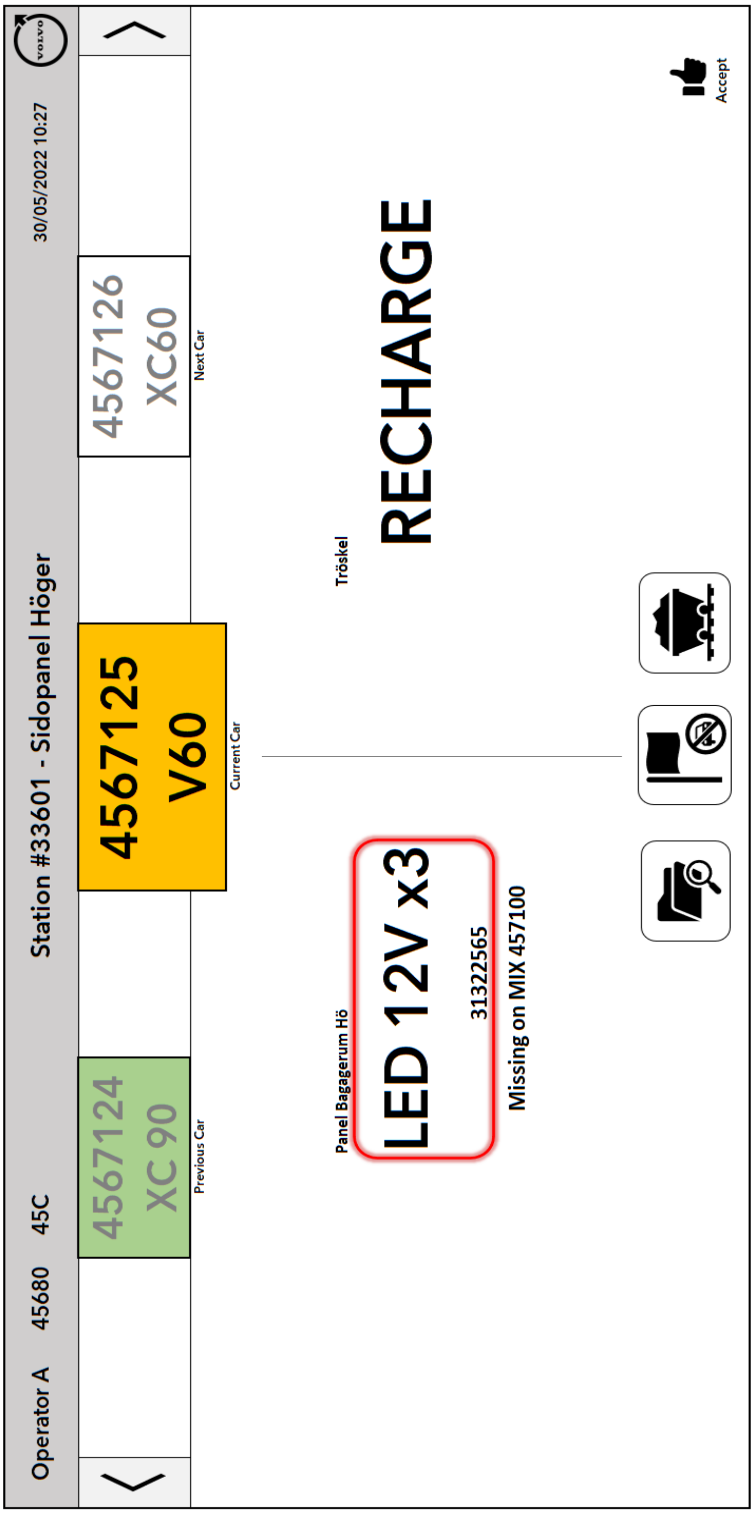


Figure C.8: Redesigned alert page for adapted WIS screen.

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