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Digitalization of Work Instructions in Production Plant

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Abstract. Digitization of the manufacturing and assembly sector is important to set up Industry 4.0. In this process, one of the key factors is the channel of sharing and distributing information on the shop floor. This study highlights the implementation of digital work instructions in the manufacturing and assembly sectors and finds the benefits that it could bring to the industry. The study was conducted in a large production plant with over five hundred workers in Malaysia and was carried out for almost a year. Whereas, most of the existing studies have been conducted in a controlled environment with a group of inexperienced workers in manufacturing and assembly tasks. In this article, the benefits and challenges of digital work instructions are studied over paper-based textual representation of assembly instructions. The study was conducted among groups of people with different roles, such as electrical assembly, mechanical assembly, and final quality check. The qualitative analysis is carried out based on the survey conducted among operators with different roles. Results show that digitalization eases the work for the quality inspection group. In contrast, people with other tasks are either neutral or find it more difficult to work with digitalized versions over paper-based instructions. In addition to this, some data-driven facts are presented, which help in improving the plant operations. This includes recording material shortages, optimizing working hours, and having real-time updates on production status which leads to effective production planning. At last, with the collected information, manufacturing plants can also optimize power utilization that impacts the environment in a positive direction.

Keywords. digital work instruction, assembly and manufacturing industry, data-driven decision, production optimization

Introduction

Work instructions are detailed documents that provide step-by-step guidance on completing a set of tasks, widely used in the manufacturing sector, and the way it is presented highly affects the quality and efficiency of the workers [1]. Over the decades, researchers have been conducting experiments with different ways of projecting work instructions, for example, gamification [2], augmented reality [3,4,5], virtual reality [6]. These studies have conducted experiments and collected user experience data to relate the effectiveness and draw the limitations on the mode of sharing information in a simulated and

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real environment. These proposals have intended to offer a better alternative to paper-based instructions, which is considered the primary channel of sharing information with workers.

On this path, a large variety of systems have been invented and numerous patents exist for digitally animated and interactive work instructions rather than relying on hard-copy (paper-based) work instructions, such as technical drawings [7,8,9,10]. Despite such extensive work, the fully digitalized version has not yet been adopted completely by companies and faced setbacks pointing to the limitations. However, as we are focusing on Industry 4.0, digitalization is defined as the primary step for its implementation[11].

In this article, the authors will look into the challenges associated with the paper-based approach and study the benefits that digitization can provide for lean manufacturing by setting up real-time communication between different entities and minimizing communication delays.

Most of the previous research focuses on single assembly tasks, mainly hardware or mechanical assemblies as a job for work instructions. However, it is important to understand the effectiveness and challenges of the format or the medium of sharing instructions in different assemblies such as mechanical, electrical, and others including quality checks. So the main question comes here, is there a single medium of delivering work instructions suitable for all variants of tasks? If not, then what are the challenges encountered? Considering the question that is left unanswered in many studies, this article focuses on the range of tasks and understands from the operator's perspective if digital work instructions are any superior to paper-based representation.

To answer the question, the study was conducted in the production plant, where different tasks are presented in a digitized format to a group of operators.

In contrast to the findings of other research papers [12], not all the groups have one opinion. Where simple mechanical tasks and quality check groups have favored the digital format, electrical, and heavy mechanical assembly found it difficult to follow the process through digital medium.

As we study the benefits of Industry 4.0 [13,14,15]. Another question arises, is it still worth implementing digitization and spending on re-engineering and infrastructure for setting digitization throughout the production units?

This paper is structured as follows: Section 1 introduces the topic which includes related studies on work instructions and its impact on the manufacturing and assembly sector, followed by the literature review, highlighting the previous studies and their outcomes. Section 2 gives a brief background about text-based instructions and the challenges being faced. To overcome the challenges, the steps followed to transfer the current setup towards digitalization and what are the challenges experienced in the process. The transition from text-based to digitalization took place in three stages as explained in Section 3. Section 4 studies the impact of digitalization followed by a survey, that was conducted in the factory to understand the challenges being faced by the workers and the advantages of digital work instructions offered on the shop floor. Quantitative analysis is performed to understand the sentiments of workers in relevance to the usage of digitalization. In the last, Section 5 concludes the paper and discusses future work.

1. Related Work

As the demand for products and services has changed exponentially over the last decade, small and medium enterprises (SMEs) need effective ways to tackle the challenges [16]. The authors [17] highlight the challenges of implementing digitized solutions in small and medium-sized enterprises. As we talk about digital twin, Augmentation, and much more, the ground reality breaks at an industrial implementation level [18], where the implementation cost, along with various challenges of adaptation and distribution of solutions across the production line, makes the solution impractical.

One study shows that combining digital and paper-based instructions does not yield any advantage over digital work instructions and concluded that paper-based work instructions would be phased out in the future [12]. The study was conducted with three groups: one had access to paper-based instruction, another was given digital, and the last batch had access to both variants. However, the conclusion was drawn on the basis of single product assembly, which may not be adequate proof to obsolete the paper-based instructions. In this paper, we have accounted for different sets of operations ranging from wire connections to handling heavy metal sheets to conjecture the advantages and limitations of digital instructions.

Another study investigates the benefits of dynamic work instructions over static instructions that incorporate display animations. The experimentation found that the animated instructions were successful for first-time assembly, however, as the operator gets the steps to be followed, the usefulness of animation disappeared and was found to be of no advantage over textual instructions [19].

In the above experiments, the authors have either assessed the results with a limited set of instructions restricted to one set of assemblies or included the candidates with short or no experience in the assembly tasks. On the other hand, in this article a study was conducted with operators who are already trained and have been operating for more than three months and the data was collected from the group of operators handling different sets of instructions with a wide range of tasks.

2. Work Instruction

As per the authors' view, humans have been interacting with work instructions since childhood in the form of board games that come with a set of documented instructions that take us step-by-step to assemble links and joints and make a desired shape out of it. There are different ways of sharing work instructions, such as paper-based and digital formats, and with the recent advancement in augmented and virtual reality, there has been ongoing research on the benefits and limitations of using a 3D environment for projecting work instructions.

2.1. Paper-based Work Instructions

Paper or text-based instructions have been used as a primary medium for knowledge transfer or sharing. As information bulks up or gets complicated, it becomes harder for the users to relate the images to the textual information printed on the paper.

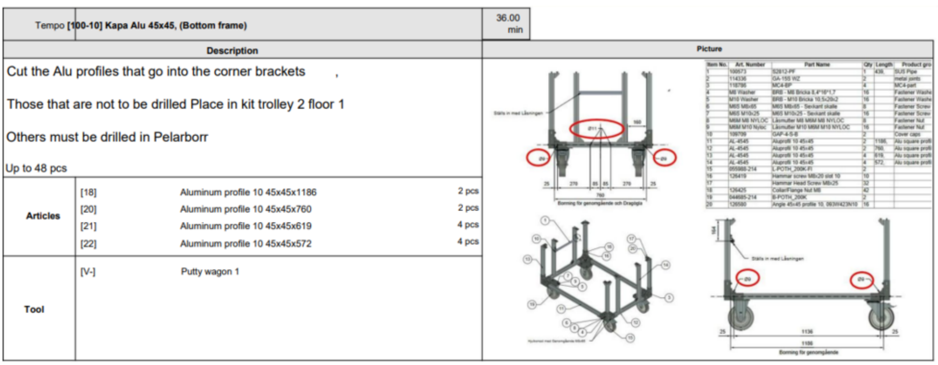
During discussions with clients from the manufacturing sector, some of the challenges of paper-based instructions have been listed:

- **Writing clear and concise instructions**: One of the biggest challenges is creating instructions that are easy to understand and follow. It can be difficult to convey complex information in a way that is clear and concise, and if the instructions are confusing or unclear, they may be ignored or misunderstood.
- **Keeping instructions up to date**: Work instructions need to be updated regularly to reflect changes in the process or technology. If the instructions are not updated, they may become outdated and no longer relevant, which can lead to errors and inconsistencies.
- **Ensuring compliance**: It can be a challenge to ensure that everyone is following the instructions correctly and consistently. Without proper oversight and training, employees may deviate from the instructions, leading to errors and inconsistencies.

2.2. *Implementation of Digital Work Instructions (DWIs)*

The solution implementation started by studying the shop floor operations. The operators responsible for assembly tasks were following a set of instructions documented on the printed papers and followed by the quality check team. The quality check team runs the tests and records the results in a spreadsheet. The recorded values and inspection results were communicated back to the production floor which is necessary to make the decision if the product can be dispatched or needs to be reworked. In this cycle, one of the major problems was the accumulated time to convey information from the production floor to the quality check team and production management team. The delay or the time gap between each communication channel showed an effect on quality approval, logistics, and production planning. Thus the main reason to change to digitization is to maintain transparency throughout the production unit.

The first step towards creating DWIs is to extract images and individual assembly steps along with part numbers and quantity details from PDF files and represent the same on multiple pages in digital format. The question that comes here is why we need to do this step, if a person can upload the PDF on a tablet it could work as well. The answer lies in how we can manage the work instruction in digital format and what functionalities are bound at the backend of each page or instruction.



Tempo [100-10] Kapa Alu 45x45, (Bottom frame)				36.00 min
Description				Picture
Cut the Alu profiles that go into the corner brackets Those that are not to be drilled Place in kit trolley 2 floor 1 Others must be drilled in Pelarborr Up to 48 pcs				
Articles	[18]	Aluminum profile 10 45x45x1186	2 pcs	
	[20]	Aluminum profile 10 45x45x760	2 pcs	
	[21]	Aluminum profile 10 45x45x619	4 pcs	
	[22]	Aluminum profile 10 45x45x572	4 pcs	
Tool	[V-]	Putty wagon 1		

Figure 1. PDF Version of Work Instructions

Figure 1 shows the snippet of work instructions taken from a Swedish company that works in the manufacturing and assembly domain. Figure 1, shows a subsection of the trolley to be assembled. The PDF snippet shows the part description along with the quantity needed to complete the assembly along with the picture. The image in the work instruction is marked with arrows pointing to the numbers where components fit into the frame.

2.3. Digital Version of the Paper-based Work Instruction

The work instructions were created by extracting images and text separately. The image and text are reconfigured in digital applications along with additional functionalities coded in the background. Figure 2 shows the digital representation of work instructions, the additional functions that are added to this version are *Image Zooming*, operation marking like Article-1 finished/produced, and shortage of material. While capturing the data on production, the additional information that was saved was time stamping behind each operation, and notification was generated on encountering a shortage of material.

Report Shortage

Article-1

Article-2

Article-3

Article-4

Description

Cut the Alu profiles that go into corner brackets
Those that are not to be drilled place in kit trolley 2 floor 1
Others must be drilled in Pillar

Article Number	Part	Quantity
18	Aluminum Profile 10 45x45x1186	2 pcs
20	Aluminum Profile 10 45x45x760	2 pcs
21	Aluminum Profile 10 45x45x619	4 pcs
22	Aluminum Profile 10 45x45x572	4 pcs

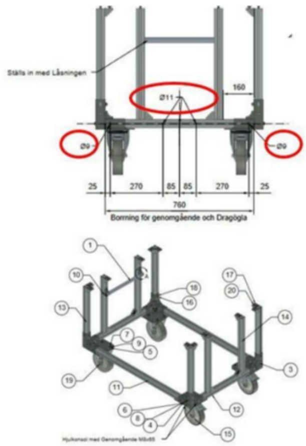
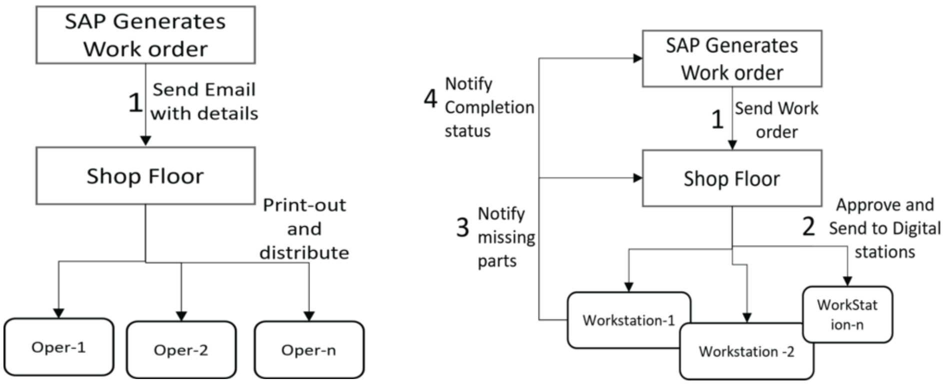


Figure 2. DWIs with Additional Functionalities

These additional functions make multi-channel communication possible and establish the real-time data pipeline in a production plant. The figure shows the flow of information in the formal case, where the work order is being generated by SAP and sent to the shop floor via email. The instructions associated with the work order are being printed and used as a reference. On the other hand, in digital work instruction, a network is created to establish communication inside an organization, such as material shortage notification to the responsible team, and time stamp capturing which can be helpful in logistics and production planning.

When we asked if using digital work instructions has caused some delays or disruption to their assigned work. All groups seem to be aligned on the negative side, but the team that supports is the FQC workstation. So, we discussed further to understand the problems faced by the majority of the team, the main reason that was given was flexi-



(a) Data Flow in Paper Based Instructions

(b) Data Flow in Digital Based Instructions

Figure 3. Flow of information in the shop floor

bility. If work instructions are given in digital format, in this case, a tablet is the hardware device used, because, after each and every assembly task, they have to move back to the workstation to confirm that a particular step is done. Whereas, in the case of a paper-based approach there is no such feedback mechanism and they can simply carry it where they want. The second main reason given by them was flexibility in choosing the operation. If they have limited components with them, they can easily switch tasks and do multiple assemblies partially, whereas, in the case of digital format, the production team wants the assembly to be done in sequential steps rather than random assemblies.

Contrary to the above challenges, the FQC team found it useful irrespective of the challenge of moving back and forth between the workstation and the test station. They found it easy to share the Quality Inspection data. Not only this, each product has different threshold values and testing criteria, for experienced team members it was easy as they have been doing it over and over many times, but it becomes really useful for new operators when they can get this information along with the work orders.

3. Methodology

The main focus of the studies is to understand the benefits of digital work instructions in manufacturing, which consists of different assemblies. So the groups were divided into three assembly sections mechanical, electrical, and final quality checks. In addition to this, to make sure that it is well adapted by the workers who are from different backgrounds and have different paces of learning. The complete adaptation of digital instruction is divided into three key phases: *Training*; *Active Support* and *Passive Support*.

Training Phase: Training is conducted in small groups with 15-20 people in each unit, as there are a total of one hundred nineteen workers on the shop floor, including Line leaders, Manufacturing Execution Engineers, and the production head. During training, the users are provided with hands-on exposure to various functionalities and usage of digital versions.

Active Support: The assembly unit operates 24 hours, with two shifts. In each shift, at least two people from the development team are available on the shop floor continuously monitoring the operators and assisting in solving doubts.

However, due to the first cycle of deployment, a few errors and bugs are captured and rectified to ensure smooth operation.

Passive Support: After, two months of on-shop floor support, the team moved to passive support. During this phase, the doubts and errors are handled through a ticketing system, and queries are answered over telephonic support.

The initial deployment started in the middle of 2022 and operations were observed for ten months to resolve errors and doubts, where users with different operations such as mechanical assembly, electrical assembly, and quality inspection worked on their designated applications. After actively observing the shop floor activities, and ensuring the bugs were resolved completely. We started capturing the data from the shop floor and analyzed it to monitor productivity, material tracking, and scrap. Additionally, a survey was conducted at the end of active support to look into the level of acceptance in all the assembly tasks and understand the challenges and benefits brought to the shop floor with digitalization for individual operations and operators.

4. Survey

The survey was conducted on the shop floor of the assembly unit, the floor accommodates multiple assembly sections such as electrical, mechanical, pipe fitting, and final quality check. The participants in the survey are from various regions of China, India, and Malaysia. The survey is divided into three groups; *new users*, *experienced operators*, and the *management team*. The management team includes the production head and plant head members. Figure 4 shows the distribution of groups among different workstations, where most of the workstations have two groups with four to five participants in each group, whereas Final Quality Check (FQC) had only one group with 3 participants.

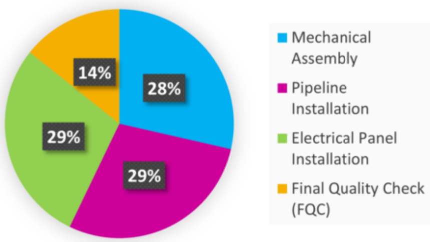


Figure 4. Groups participated in the survey

One primary objective of introducing digitalization is to simplify tasks on the shop floor. However, survey results indicate that opinions on this are mixed referring to figures5 and 6

When we asked if using digital work instructions has caused some delays or disruption to their assigned work. All groups seem to be aligned on the negative side, but the team that supports is the FQC workstation. So, we discussed further to understand the problems faced by the majority of the team, the main reason that was given was flexi-

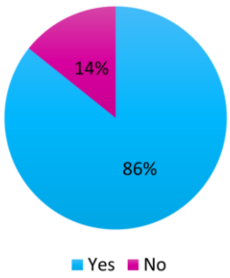


Figure 5. Have digital work instructions caused any delay?

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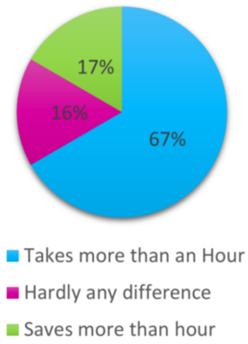

Figure 6. How much time have you been able to save?

Contrary to the above challenges, the FQC team found it useful irrespective of the challenge of moving back and forth between the workstation and the test station. They found it easy to share the Quality Inspection data. Not only this, each product has different threshold values and testing criteria, for experienced team members it was easy as they have been doing it over and over many times, but it becomes really useful for new operators when they can get this information along with the work orders. In addition to this, after looking into the information from production planning and manufacturing engineers, there have been improvements in the production line as discussed in table 1

As table 1 show the data related to reporting of missing components for the assembly operation was 20-30 components per week, and this figure increased drastically after the implementation of digitalization. The data may indicate a negative result here, but as we look into the average backlog which is reduced to more than half. The reason behind this

Observations	Before Digitization	After Digitization
Components missing reported/week	approx 20- 30 units	approx 50-80 units
average backlog / planned production	5-10 per month	2-4 per month
Data recording to SAP	After every shift (12 hours usually)	immediate/ instantaneously
Time for Call for support	Uncertain	max 30 min
Errors in Quality Check	approx 20%	Almost dropped to zero

Table 1. Observations and comparison between before and after digitization

was that the missing components were not reported in time, which resulted mismatch in the monthly production target. However, with timely reports of missing parts and components, the actual production was inside the window of planned production.

5. Conclusion and Future Work

The study was carried out in a Malaysian production plant and focused on the advantages of digital work instructions over traditional paper-based methods. Starting with the challenges being faced by the manufacturing sector, which leads to the development of the digital version of the instructions with additional functionalities on the front end such as clearer images with zooming options, step-by-step guide to follow assembly instructions with part numbers, and tools along with the backend functions such as reporting of missing components, capturing cycle time.

The incorporation of digital work instructions has shown the potential to restructure the shop floor operations by offering a centralized, easily accessible, and up-to-date source of information. These digital platforms promise faster updates, better tracking, and integration with other digital systems like quality management and inventory control. However, the challenges being faced by the shop floor operators cannot be neglected.

Transitioning from traditional paper-based instructions to digital ones is not without its setbacks. As we've observed, the physical robustness of the hardware is a major concern. Besides the noted damage to tablets, there are also concerns about their battery life, especially during extended shifts. Operators found themselves with a dead tablet, thus lacking access to critical assembly instructions.

From an organizational standpoint, the challenge extends beyond hardware robustness. It is important to ensure that the digital instructions are user-friendly. The modular approach to work instructions, as mentioned, by re-engineering instructions to be less linear, operators can proceed with other tasks even if a specific component is unavailable temporarily. This not only ensures better productivity but also instills a sense of flexibility and adaptability among the operators.

Therefore, while the digital transformation of work instructions on the shop floor is promising, a holistic approach—addressing hardware, software, and operator adaptability—is essential to harness its full potential and ensure smooth operations.

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