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Analysis of the effect of using digital instructions on efficiency and cost-effectiveness of the assembly process

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ABSTRACT

Digitisation of processes is one of the important elements of Industry 4.0, which is becoming an increasingly popular form of introducing improvements in production processes. The aim of the article was to study a modern solution aimed at improving the workflow, which is the digitisation of assembly processes. The article raises the issues related to the introduction of digital instructions to the assembly process on the example of pump assembly. The focus was mainly on the comparison of work efficiency by comparing the time of product implementation using traditional paper and digital instructions. The impact of the use of programmable tools on the time of order completion and the achievement of the "zero defects" effect was also examined. The study also allowed determining the economic benefits of introducing digital instructions.

Keywords: digital instruction, assembly process. productivity, digitisation of the assembly, quality control, programmable tool.

INTRODUCTION

Modern manufacturing companies strive to increase the efficiency and flexibility of manufacturing processes by implementing the concept of Industry 4.0. A key element of this transformation is the digitalisation of assembly processes, which allows for reducing errors, increasing precision and improving product quality [1]. Traditional paper instructions are still widely used, but their limitations, such as the lack of immediate updating and high susceptibility to operator errors, encourage companies to implement digital assembly instructions [2].

Shortening the time of order fulfilment [3, 4], lowering production costs [5], or increasing competitiveness on the market by designing products according to individual customer needs [6–8] are just some of the aspects considered by scientists, such as also the goals pursued by existing production companies. In order to achieve them, all production processes must be constantly analysed and improved [9], because every smallest change can decide about the success or failure of a given project, and even the entire enterprise.

Many different factors affect the improvement of the organisation of production. In the assembly process, the key role is often played by employees who have to learn quickly and adapt to changing product variants [1, 10]. An additional problem for enterprises may be the high turnover of production workers and the shortage of qualified workforce. In manufacturing plants, where operators are typically required to undergo mandatory training before actually assembling products, this can lead to production delays and increased costs over time. For this reason, the employees with skills, qualifications and experience began to play an increasingly important role. The constantly dominant method of providing information on the assembly process using static, paper instructions [12] requires the involvement of an experienced employee in the training process and is not very susceptible to any changes, especially in processes with a complex structure [11]. All this resulted in an increased need to develop the solutions and systems to support employees in the assembly process. Undoubtedly, the development of Industry 4.0 contributed to the development of new solutions, using digital technologies such as: augmented and virtual reality, robotisation and automation of production processes, as well as broadly understood cyber-physical systems and digital twins [12–14].

It is observed that the most frequently researched technologies are:

- the use of robots or cobots [8, 15, 16]. However, despite the benefits that these technologies can bring to the assembly process, it is necessary to conduct further research to make the best use of their potential [17];
- use of virtual/augmented reality [18–20]. Owing to the interactive digital assembly instructions, a hands-free worker can control the program using head and eye movements, e.g. holding the gaze works as a substitute for clicking [21]. There is also an interest in visual assembly instructions. Research has been undertaken on the topic of animation of individual operations [22] or in designing tools that enable 3D projections of assembly instructions steps in the employee's field of view, with additional descriptions and animations, using augmented reality [20];
- automation of the assembly process, by using e.g. pick-to-light systems [23];
- digitisation of instructions and creation of process digital twins [24].

Research on digital assembly is used in various industries, especially in the automotive industry, but there are also examples of implementations in the consumer electronics sector, the production of household appliances and in the machine industry [13]. In the aviation industry, digital instructions are used in technical service and maintenance, which allows for increased precision and safety of operations [18]. In the electronics sector, interactive assembly instructions reduce the number of operator errors, which is particularly important in the production of highly miniaturised devices [24].

Despite examples of the analysis of the assembly process and its digitalisation in the literature, a lack of studies comparing the use of paper and digital instructions and their impact on the efficiency and cost of production can be noticed. There is also a lack of detailed analyses regarding the impact of the use of programmable tools on the efficiency of the process.

The aim of the conducted research was to analyse the impact of using digital instructions on improving the efficiency of the production process and reducing costs. For this purpose, the following research problems were defined:

1. How does the use of digital instructions and programmable tool affect the order execution time?
2. What is the impact of using digital instructions and programmable tools on the current control of critical operations?
3. Will the use of digital instructions and a programmable tool reduce production costs?

The authors, wishing to examine the impact of using digital instructions on the production order execution time, conducted experimental studies using digital and traditional assembly instructions. An additional research problem analysed in the article is the impact of modern programmable power tools and "pick to light" systems on increasing the efficiency of the assembly process.

The article has been divided into three sections. The first section presents the tools, methods and research materials used. In the second section, an experimental study was conducted to compare the impact of digital and traditional assembly instructions on employee work efficiency, profitability and order completion times. The third section presents a summary of the research findings and final thoughts.

Digitalisation in modern manufacturing is not merely about converting paper-based processes to digital formats; it is about creating a seamlessly connected network where every component communicates in real time. Through high-speed connectivity, IoT sensors embedded in machinery provide continuous data on equipment performance and environmental conditions, enabling predictive maintenance and reducing unplanned downtime. Simultaneously, AI-driven analytics process vast amounts of data to identify patterns and optimise workflows, ensuring that production processes are both agile and resilient. This level of integration facilitates a dynamic feedback loop between machines and operators, where real-time insights drive continuous improvement in efficiency, quality, and responsiveness to market demands. Ultimately, this interconnected approach not only elevates operational performance but also positions manufacturers to better anticipate future challenges and opportunities in an increasingly competitive environment.

Test stand and methods

To test the impact of the use of digital instructions on the efficiency and cost-effectiveness of assembly, a test stand (Figure 1) consisting of the following elements was used:
- a table on which the pump assembly process is performed,
- shelves on which rack boxes containing individual parts of the pump are placed,
- slats, mounted above each shelf, containing a pick-to-light system in two variants: manual confirmation of picking parts for the upper slat (button) and a motion sensor for the lower slat.
- monitor on which the digital instruction is displayed and on which the administrator panel is available,
- power tools – manual and programmable screwdrivers.
- barcode reader.

The stand was equipped with Smart Factory Assembly ELAM software. The software consists of three modules (Figure 2): Administration, Assistant and Analysis.

The Administration module is used to manage users, job structure, product and workflow. User management largely consists in creating employee profiles to which a given product can be assigned. Employee profiles are also important during the analysis, as they allow examining parameters such as performance for each employee separately. Site structure management is used to set up the entire bench, devices, and other features such as the pick-to-light system, so it is important that everything is set up correctly. Product management allows adding individual parts and create correlations between them. However, when it comes to workflow, block diagrams are created here, which are then used in the Assistant panel when assembling components.

The Assistant module is dedicated to the work of employees of the assembly station. It allows registering orders and running a digital manual. The start form allows entering the name of the order and selecting the product variant, entering the serial number or the name of the position. It is also possible to add other fields to the start form, such as employee selection.

Selection of the order and product variant results in displaying a screen with digital assembly instructions (Figure 3). At this stage in the examined pump assembly process, one must choose whether to display a detailed step-by-step assembly manual or go to the abbreviated

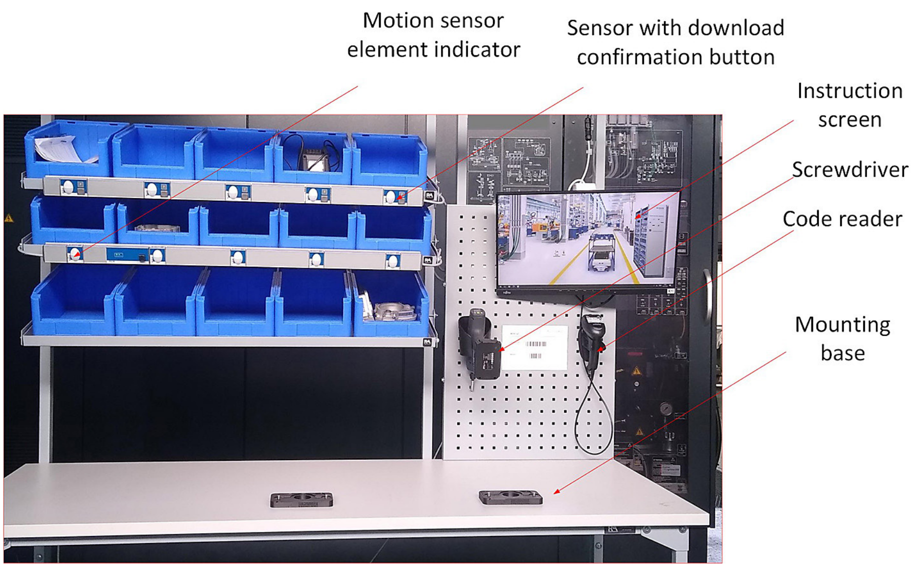

Figure 1. Research stand

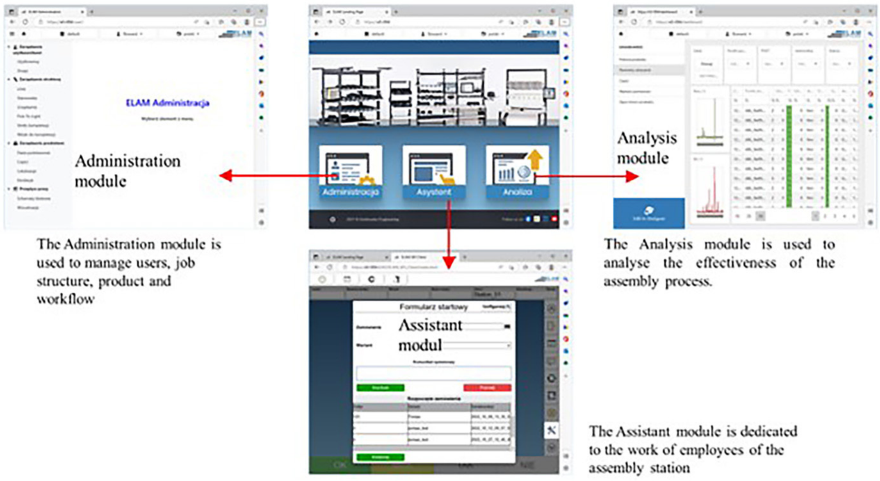

Figure 2. ELAM program

version. It can be seen that the panel of each operation consists of a tool, a command and a status. At the bottom of the panel there are options that allow going a step further after performing the operation, if it was set in the administration panel. On the side there are functions such as a list of all operations, repeat operation or settings. The instructions contain detailed information on what the employee should pay attention to and a photo of the item being downloaded.

The analysis module is used to analyse the effectiveness of the assembly process, where one can download a set of results such as order execution times and individual operations. A product in the form of a vacuum pump was selected for assembly. The assembly instruction consists of 11 operations, shown in Figure 4.

One of the studies that has been carried out so far on this topic has been a comparison of two digital assembly instructions – one more detailed and the other more comprehensive, generated by the worker support system. It turned out that better results regarding assembly time, quality of finished products and the feeling of the surveyed workers during assembly were recorded when using more detailed instructions. This means that

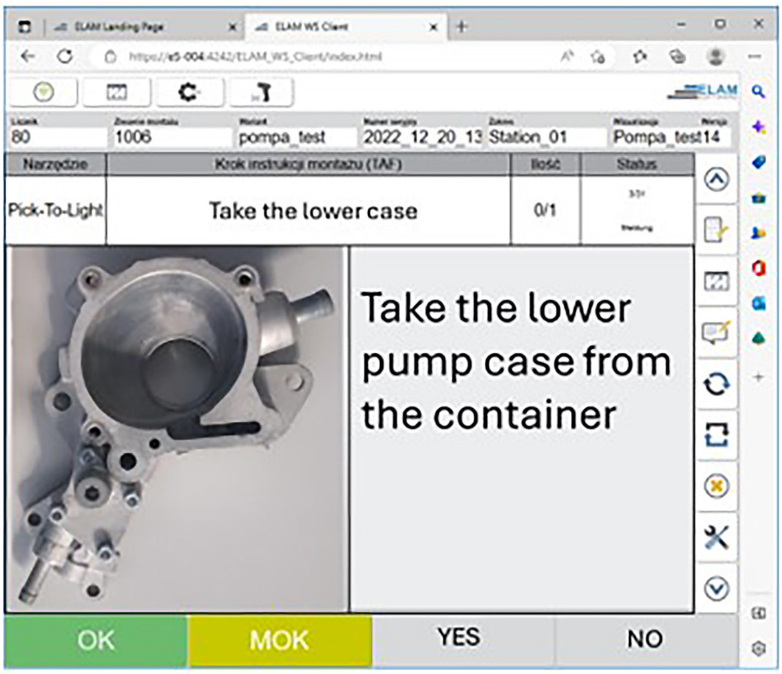

Figure 3. Digital manual, assembly operation screens

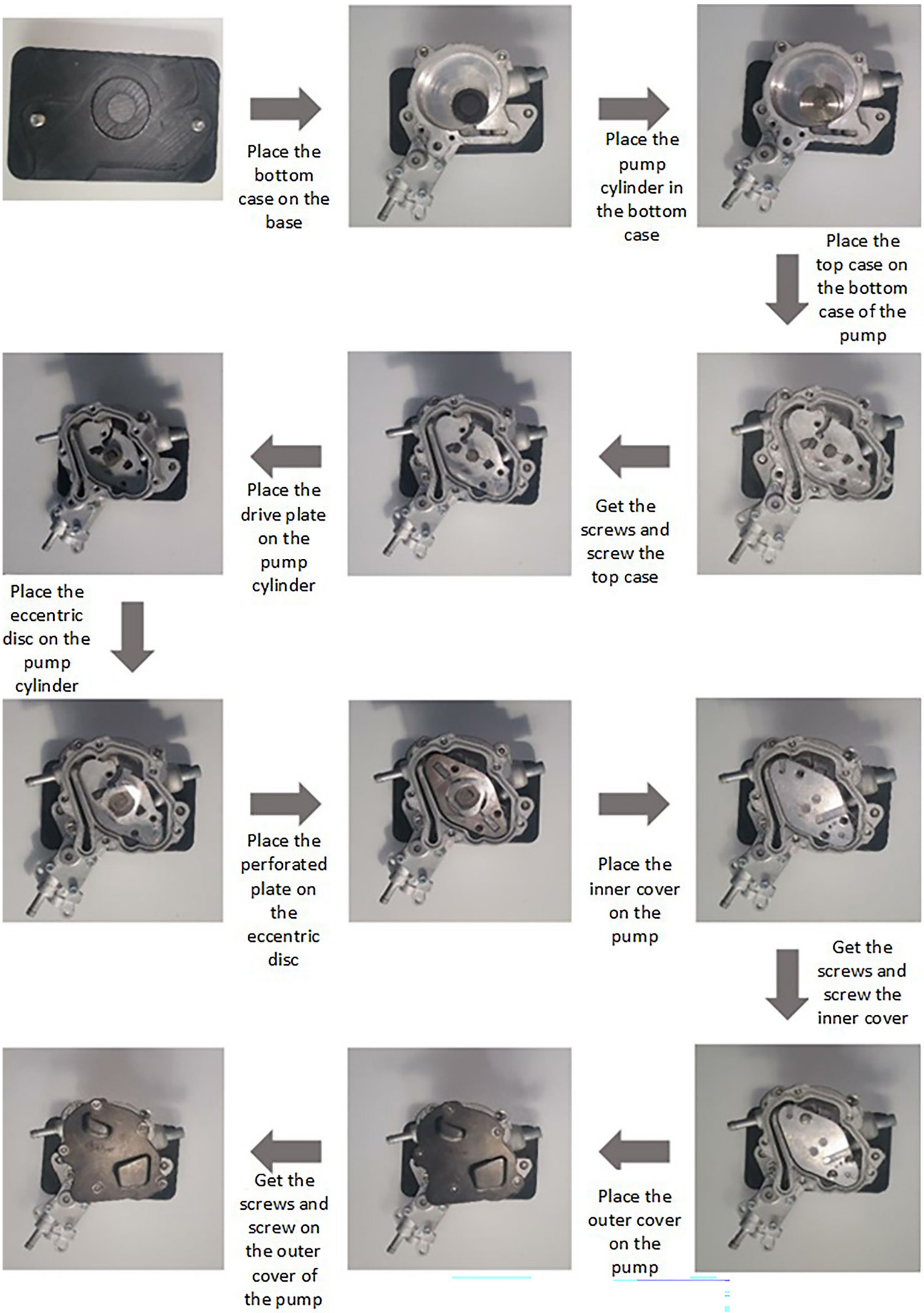

Figure 4. Pump assembly diagram

an important aspect when designing employee support systems is the correct preparation of instructions rich in information about the process, already at the early stage of their creation [12]

Another study looked at the potential of digital instructions over "paper" instructions. The experiment showed that digital instructions allow faster assembly of components with fewer defects, but paper instructions have better learning outcomes. The question that has been posed is under what conditions should digital instructions be introduced to make them profitable [24].

In order to extend the research works available in the literature on the use of digital assembly instructions, the authors of the article decided to examine the impact of their use on the efficiency of the process, taking into account such parameters as: order execution time and possible production batch. The authors also decided to verify the impact of the use of programmable tools on the automatic generation of reports and the achievement of the "zero defects" effect.

The tests were divided into two stages: in the first stage, tests were carried out with the paper and digital instructions using power tools in the form of a traditional screwdriver, without the possibility of controlling the torque and flank angle. In the second stage, the manual screwdriver was replaced, programmable with torque and flank angle control, which allowed the generation of additional quality control reports.

The first test studies were conducted with the participation of two experienced workers who had previously manufactured this product many times. In order to minimise the learning effect, the experiment was conducted in an interleaved design. Each worker first assembled five pumps with paper instructions, then five with digital instructions, and then returned to the paper version. This enabled to better assess whether the reduction in assembly time was due to the type of instructions or to increased experience.

Additionally, in order to exclude the influence of experience on processing times, control studies were conducted on a group of 20 people. The first 10 people performed two assembly trials for the paper instructions, and the next 10 people performed two assembly trials for the digital instructions.

The obtained results were statistically analysed using the ANOVA test to compare the variance of the results for each method.

RESULTS AND DISCUSSION

The first stage of the research was carried out with the participation of two employees. Each of the employees had to complete an order covering 10 items of products. Three operations of screwing in the screws were also adopted for the analysis, because the times of these operations have the greatest impact on the total assembly time. Cycle times for individual products, together with the times of individual screwdriving operations, are listed in Tables 1–2.

Comparing the results in both tables, it can be seen that for both Worker 1 and Worker 2, the total time to assemble 10 pumps for the digital instruction is shorter than for the paper instruction. The average cycle time for both employees was also shortened - for Employee 1 by 6%, and for Employee 2 by 2%. During the observation of the assembly process, a number of remarks related to errors were noted, which were also reflected in the subsequent results. The following errors were

Table 1. Comparison of Employee 1 times for paper and digital instructions

No.	Employee 1							
	Paper instruction				Digital instruction			
	Total assembly time hh:mm:ss	Screwing time 1 hh:mm:ss	Screwing time 2 hh:mm:ss	Screwing time 3 hh:mm:ss	Total assembly time hh:mm:ss	Screwing time 1 hh:mm:ss	Screwing time 2 hh:mm:ss	Screwing time 3 hh:mm:ss
1	00:03:56	00:00:15	00:00:24	00:00:21	00:03:23	00:00:11	00:00:11	00:00:18
2	00:02:42	00:00:11	00:00:15	00:00:23	00:02:40	00:00:08	00:00:14	00:00:11
3	00:02:28	00:00:13	00:00:14	00:00:26	00:02:52	00:00:08	00:00:21	00:00:22
4	00:03:35	00:00:26	00:00:18	00:00:23	00:02:37	00:00:09	00:00:12	00:00:13
5	00:02:41	00:00:16	00:00:16	00:00:33	00:02:40	00:00:08	00:00:15	00:00:12
6	00:02:49	00:00:21	00:00:16	00:00:22	00:02:27	00:00:08	00:00:09	00:00:15
7	00:02:25	00:00:12	00:00:12	00:00:25	00:02:22	00:00:07	00:00:12	00:00:12
8	00:02:33	00:00:16	00:00:17	00:00:26	00:02:30	00:00:09	00:00:10	00:00:12
9	00:02:31	00:00:16	00:00:19	00:00:29	00:02:23	00:00:13	00:00:15	00:00:10
10	00:02:06	00:00:11	00:00:20	00:00:16	00:02:18	00:00:07	00:00:12	00:00:13
Sum	00:27:46	00:02:37	00:02:51	00:04:04	00:26:12	00:01:28	00:02:11	00:02:18
Average	00:02:47	00:00:16	00:00:17	00:00:24	00:02:37	00:00:09	00:00:13	00:00:14

Table 2. Comparison of Employee 2 times for paper and digital instructions

No.	Employee 2							
	Paper instruction				Digital instruction			
	Total assembly time hh:mm:ss	Screwing time 1 hh:mm:ss	Screwing time 2 hh:mm:ss	Screwing time 3 hh:mm:ss	Total assembly time hh:mm:ss	Screwing time 1 hh:mm:ss	Screwing time 2 hh:mm:ss	Screwing time 3 hh:mm:ss
1	00:02:41	00:00:14	00:00:16	00:00:21	00:03:35	00:00:21	00:00:16	00:00:17
2	00:07:38	00:00:14	00:00:17	00:00:33	00:03:06	00:00:10	00:00:09	00:00:13
3	00:02:18	00:00:11	00:00:15	00:00:18	00:02:58	00:00:10	00:00:22	00:00:16
4	00:02:10	00:00:15	00:00:14	00:00:20	00:02:38	00:00:10	00:00:15	00:00:18
5	00:02:13	00:00:11	00:00:14	00:00:18	00:02:49	00:00:10	00:00:13	00:00:17
6	00:02:20	00:00:15	00:00:18	00:00:22	00:02:34	00:00:09	00:00:11	00:00:22
7	00:02:42	00:00:13	00:00:14	00:00:36	00:02:45	00:00:15	00:00:14	00:00:20
8	00:02:13	00:00:11	00:00:14	00:00:24	00:02:49	00:00:09	00:00:22	00:00:19
9	00:02:05	00:00:15	00:00:18	00:00:17	00:02:21	00:00:09	00:00:10	00:00:14
10	00:02:19	00:00:10	00:00:17	00:00:18	00:02:29	00:00:10	00:00:13	00:00:13
Sum	00:28:39	00:02:09	00:02:37	00:03:47	00:28:04	00:01:53	00:02:25	00:02:49
Average	00:02:52	00:00:13	00:00:16	00:00:23	00:02:48	00:00:11	00:00:14	00:00:17

found: incorrect positioning of the cylinder and the need to correct its setting, a defective element in the form of an upper casing, which forced Employee 2 to correct it during the second product (correction time is 3 min 12 seconds), errors in the preparation of the assembly station – elements (screws) in the wrong container, bits falling out of the screwdriver. It should be noted that errors occurred with both instructions.

In order to better illustrate the changes in times, a comparison of individual times is shown in Figures 5–7. When analysing the average time of screwing in the screws in individual operations (Figure 7), one can also notice a significant decrease in the time needed to perform the operation. The obtained results indicate that for Employee 1 the time needed to perform screwdriving operations was shortened by 23–44%, and in the case of Employee 2 from 8–26% (Table 3).

The second stage of the research was carried out with the participation of Employee 1, due to his experience and results in the first stage of the research. The size of the order, as in the first stage of the research, was 10 items. Three operations of screwing in were also adopted for the analysis. Cycle times for individual products along with

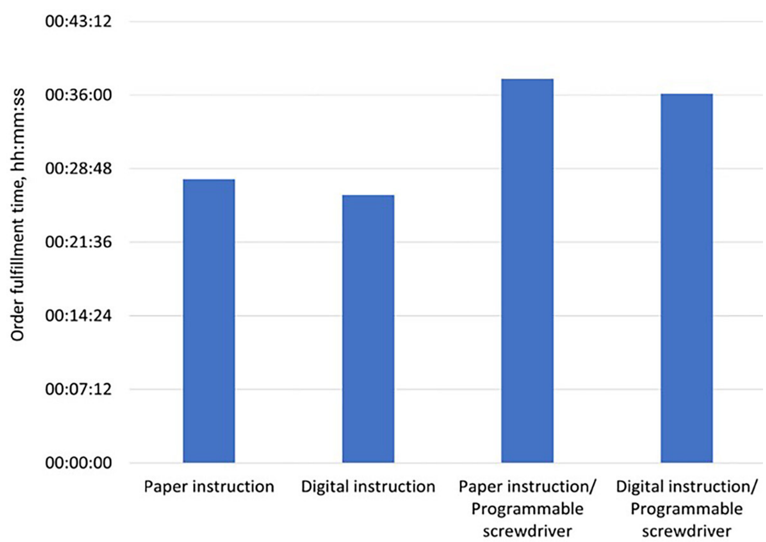

Figure 5. Comparison of order execution time (10 pieces) for both instructions

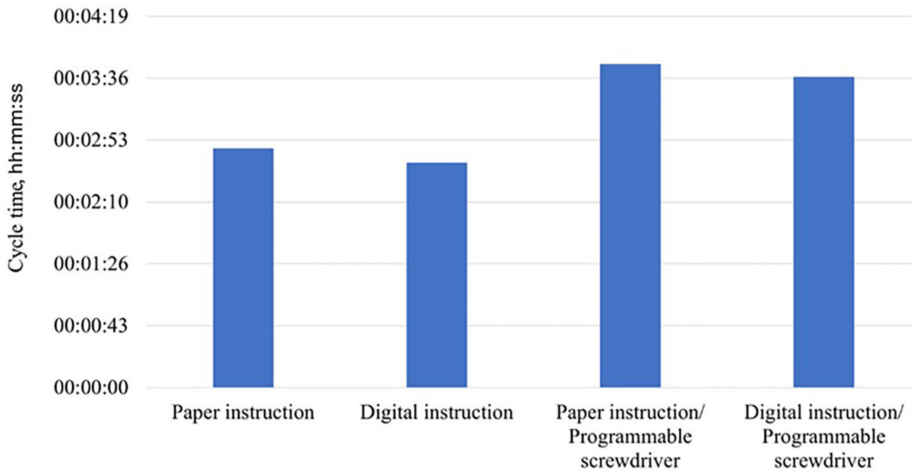

Figure 6. Comparison of the average cycle time for both instructions

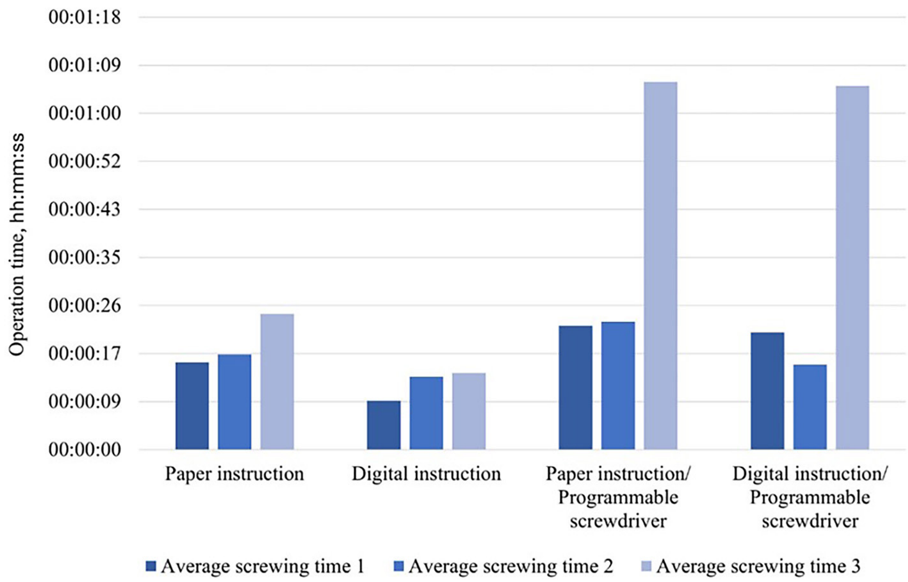

Figure 7. Comparison of screwing times 1, 2, 3 for both instructions

the time of individual screwdriving operations are listed in Table 5.

Comparing the results, it can be seen that the total assembly time of 10 pumps for the digital manual is 1 minute and 27 seconds shorter than for the paper manual. The average cycle time has also been shortened by 4%. When analysing individual screwing times, a significantly longer time can be noticed for 3 screwdriving operations for 7 products in the case of a digital instruction. Such a long screwing time (132% longer than the average) resulted from a defect in the thread on the screw, which resulted in several attempts to screw the screw in and, as a result, the replacement of the defective element. Unfortunately, the lack of functional control at the entrance to the warehouse caused a shortage, but the use of a programmable tool had a positive impact on the ongoing quality control as well as allowed the detection and removal of a defective item at the station.

In order to verify the influence of experience on processing times, control tests were conducted on a group of 20 people. The first 10 people performed two folding attempts for the paper manual, and the next 10 people performed two folding attempts for the digital manual (Table 4).

In addition, the obtained results were subjected to statistical analysis using the ANOVA test to compare the variance of the results for each method (Tables 5–6).

The ANOVA results indicate that the mean assembly times in both cases are shorter for digital

Table 3. Comparison of Employee 1 times for paper and digital instructions - assembly using a programmable tool

No.	Paper instruction				Digital instruction			
	Total assembly time hh:mm:ss	Screwing time 1 hh:mm:ss	Screwing time 2 hh:mm:ss	Screwing time 3 hh:mm:ss	Total assembly time hh:mm:ss	Screwing time 1 hh:mm:ss	Screwing time 2 hh:mm:ss	Screwing time 3 hh:mm:ss
1	00:03:55	00:00:36	00:00:22	00:01:38	00:03:50	00:00:15	00:00:15	00:01:01
2	00:03:04	00:00:24	00:00:22	00:00:40	00:03:48	00:00:10	00:00:18	00:01:33
3	00:03:24	00:00:14	00:00:25	00:01:09	00:03:20	00:00:15	00:00:13	00:00:53
4	00:03:21	00:00:18	00:00:21	00:00:56	00:03:04	00:00:13	00:00:16	00:00:42
5	00:04:35	00:00:23	00:00:22	00:01:11	00:03:03	00:00:11	00:00:16	00:00:59
6	00:03:58	00:00:24	00:00:20	00:01:03	00:03:41	00:00:17	00:00:14	00:00:46
7	00:04:04	00:00:26	00:00:22	00:00:59	00:04:49	00:00:16	00:00:15	00:02:31
8	00:03:46	00:00:18	00:00:25	00:01:10	00:03:11	00:00:14	00:00:17	00:00:59
9	00:04:05	00:00:20	00:00:26	00:01:20	00:04:19	00:01:22	00:00:16	00:00:49
10	00:03:23	00:00:20	00:00:25	00:00:55	00:03:03	00:00:18	00:00:13	00:00:41
Sum	00:37:35	00:03:43	00:03:50	00:11:01	00:36:08	00:03:31	00:02:33	00:10:54
Average	00:03:46	00:00:22	00:00:23	00:01:06	00:03:37	00:00:21	00:00:15	00:01:05

Table 4. Comparison of two group of 10 people assembling using paper instructions and digital instructions

No. of employee	Programmable screwdriver			
	Paper instruction		Digital instruction	
	Total assembly time		Total assembly time	
	Attempt 1	Attempt 2	Attempt 1	Attempt 2
1	00:04:44	00:03:56	00:06:19	00:03:52
2	00:06:31	00:03:35	00:03:47	00:03:21
3	00:05:09	00:03:36	00:03:54	00:02:50
4	00:07:36	00:04:13	00:04:13	00:03:04
5	00:04:26	00:02:57	00:03:34	00:02:58
6	00:05:14	00:03:42	00:05:56	00:03:49
7	00:04:38	00:03:06	00:03:22	00:02:55
8	00:06:19	00:03:50	00:03:49	00:02:57
9	00:05:44	00:03:42	00:04:05	00:03:41
10	00:04:17	00:02:38	00:03:32	00:02:54
Average	00:05:28	00:03:32	00:04:15	00:03:14

instructions. Furthermore, the learning effect had a limited effect on the differences in assembly times (p-value > 0.05), suggesting that the reduction in time was mainly related to the type of instruction. Only in the case of the first trial on the group of 10 subjects, it can be seen that the P-value < 0.05, suggesting that there is no statistical relationship.

To better illustrate the changes in times for both types of instructions, as well as for both types of screwdrivers, a comparison was made presented in Figures 8–9. When analysing the average time of screwing in the screws in individual operations (Figure 8), it can also be seen that in both cases, shorter order completion times were obtained for digital instructions. Attention is drawn to the longer execution time when using a programmable tool, however, this is due to the on-going control of screwing parameters and the need to repeat the operation in case of making a mistake. The obtained results indicate that for the programmable tool, execution times were 31% longer for paper instructions and 28% longer for digital instructions.

When analysing the screwdriving operations (Figure 10), it can be seen that for the 1st and 3rd operations with the programmable tool, the average times are at a similar level for both types of instructions, the difference is only for the second

Table 5. ANOVA test for Employee 1 and Employee 2

Parameters						
Groups	Count	Sum	Average	Variance		
Employee 2, Paper instruction, Total assembly time, s	10	1719	171.9	10255.66		
Employee 2, Digital instruction, Total assembly time, s	10	1684	168.4	447.6		
ANOVA						
Source of variation	SS	df	MS	F	P-Value	F crit
Between groups	61.25	1	61.25	0.011445	0.915987	4.413873
Within groups	96329.3	18	5351.628			
Total	96390.55	19				
Summary						
Groups	Count	Sum	Average	Variance		
Employee 1, Paper instruction, Total assembly time, s	10	1666	166.6	1122.933		
Employee 1, Digital instruction, Total assembly time, s	10	1572	157.2	365.5111		
ANOVA						
Source of variation	SS	df	MS	F	P-Value	F crit
Between groups	441.8	1	441.8	0.59364	0.45101	4.413873
Within groups	13396	18	744.2222			
Total	13837.8	19				

Table 6. ANOVA test for two group of 10 people assembling using paper instructions and digital instructions

Parameters						
Groups	Count	Sum	Average	Variance		
Paper instruction, Attempt 1, s	10	3278	327.8	4120.844		
Digital instruction, Attempt 1, s	10	2551	255.1	3768.989		
ANOVA						
Source of variation	SS	df	MS	F	P-Value	F crit
Between groups	26426.45	1	26426.45	6.698861	0.018553	4.413873
Within groups	71008.5	18	3944.917			
Total	97434.95	19				
Summary						
Groups	Count	Sum	Average	Variance		
Paper instruction, Attempt 2, s	10	2115	211.5	846.7222		
Digital instruction, Attempt 2, s	10	1941	194.1	603.2111		
ANOVA						
Source of variation	SS	df	MS	F	P-Value	F crit
Between groups	1513.8	1	1513.8	2.088096	0.165636	4.413873
Within groups	13049.4	18	724.9667			
Total	14563.2	19				

operation, which required a manual change of the screwdriving program for the paper instruction. With the digital instruction, the tightening programs were called up automatically. However, in the case of a manual screwdriver, comparing the paper manual with the digital one, there is a significant difference in screwing times for all 3 operations. The greatest difference in screwing time between the use of a manual and programmable screwdriver can be seen for 3 screwdriving operations, where the screwing time for 5 screws is 170% longer than for a manual screwdriver in

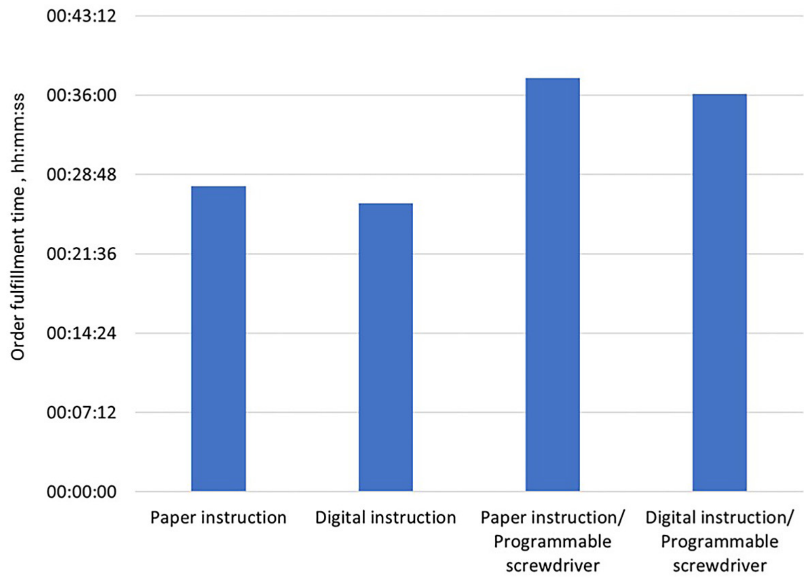

Figure 8. Comparison of order processing time (10 pieces) for manual and programmable screwdrivers

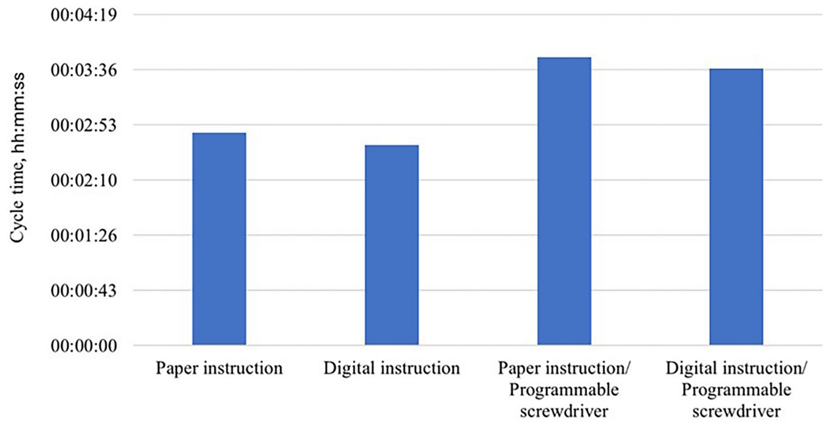

Figure 9. Comparison of the average order processing time (10 pieces) for manual and programmable screwdrivers

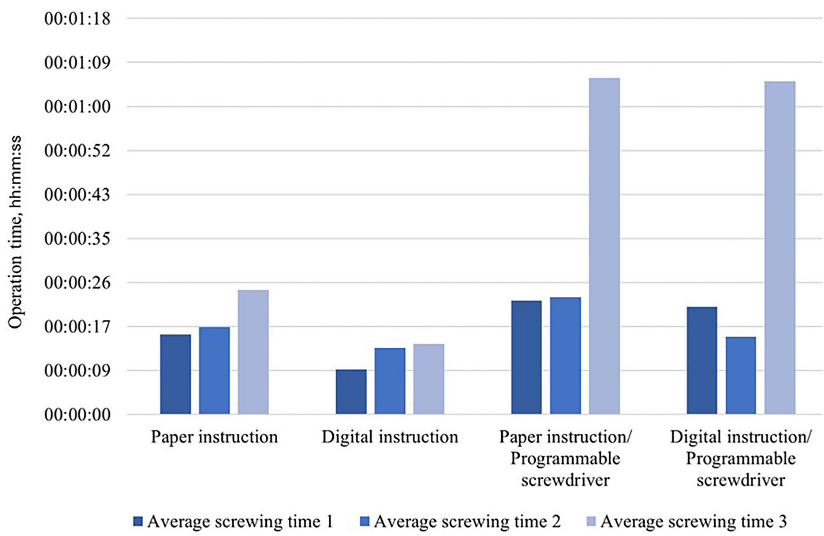

Figure 10. Comparison of average screwdriving times for three operations for manual and programmable screwdrivers

Table 7. Screwdriving parameter report

Operation	No.	Torque	Flank angle
		Nm	Grad
Screwing 1	1	1.81	29
	2	1.8	41
	3	1.84	20
Screwing 2	1	1.22	26
	2	1.23	22
	3	1.22	22
Screwing 3	1	1.82	14
	2	1.84	14
	3	1.81	46
	4	1.82	15
	5	1.85	20

Table 8. Supportive information

Shift [h]	8.0
Break [h]	0.5
Daily working time available [h]	7.5
Number of working days in a month	20
Unit selling price [PLN]	800
The hourly cost of a quality control worker [PLN/h]	33
Inspection time at random inspection [min/pcs]	7

the case of a paper manual and 360% longer in the case of a digital manual. Such large differences result from the fact that two out of 5 screws have to be screwed in twice. Correct positioning of the cover is very important to maintain the tightness of the pump. In the case of a manual tool, it was not controlled during the operation, while in the case of a programmable tool, controlling the torque parameter meant that with the wrong setting of the cover, it was not possible to screw and it forced the setting to be corrected.

The screwing parameters obtained for 10 pieces of the product are presented in Table 7. For operations 1 and 3, the correct torque was 1.8 Nm, while for operation 2 the set torque was 1.2 Nm. The report shows that the measured results are within the error margin of less than +3% (0.05 Nm).

To determine the profitability of using digital instructions as the working time of employees, work in one shift with a 30-minute break was taken into account. It was assumed that the company works 5 days a week, which gives an average of 20 days a month. On the basis of the market review, the selling price of the vacuum pump produced was set at PLN 500. The listed supporting information is presented in Table 8, while the results of the comparison are presented in Tables 9–10.

Table 9. Sales volume comparison for both manuals

Employee	Type of instruction	The number of products that can be produced during a working day	The number of products that can be produced in a month	The value of manufactured products in a month [PLN]	The difference between paper and digital instructions [PLN]
Employee 1	Paper instruction	161	3220	2 576 000,00	100 000,00
	Digital instruction	171	3420	2 736 000,00	
Employee 2	Paper instruction	157	3140	2 512 000,00	30 000,00
	Digital instruction	160	3200	2 560 000,00	

Table 10. Sales volume comparison for both instructions using manual and programmable tool

Screwdriver	Type of instruction	The number of products that can be produced during a working day	The number of products that can be produced in a month	Method of quality control of threaded connections	Monthly cost of quality control	The value of manufactured products in a month	The difference between paper and digital instructions
		piece	piece		PLN	PLN	PLN
Manual	Paper instruction	161	3220	random every 10 pcs.	1239.48	1,610,000.00	100,000.00
	Digital instruction	171	3420	random every 10 pcs.	1316.70	1,710,000.00	
Programmable	Paper instruction	119	2380	automatic 100%	–	1,190,000.00	50,000.00
	Digital instruction	124	2480	automatic 100%	–	1,240,000.00	

The presented data clearly show that within a month, using digital instructions, it is possible to obtain from PLN 30,000.00 to PLN 100,000.00 more revenue from sales than in the case of paper instructions. This is related to the possibility of producing an additional 60–200 pieces of the product per month, depending on the employee's experience and the tool used. In addition, the comparison presented in Table 10 shows that the use of a programmable tool allows for the reduction of quality control costs while obtaining 100% control by PLN 1,239.48 for a paper instruction and PLN 1,316.70 for a digital instruction.

CONCLUSIONS

The research presented in the paper shows that the digitisation of instructions can increase control over processes on production lines, such as the assembly process. The easy-to-use program can facilitate quick modification of process step data if necessary and detailed analysis of performed operations, owing to which the station can be constantly improved. Several conclusions emerge from the study. When using the digital manual, it was common to forget to press the button confirming the download of the item (pick-to-light system), which resulted in the extension of the operation time. The location of the assembly instructions also had an impact. For the paper manual, this was the place directly on the table, while the digital manual was displayed on the screen at eye level at the right edge of the station. After the study, it can be concluded that moving the screen with the displayed instructions to the table can lead to even better results, because an employee will not have to move their head so extremely to read the instructions.

One of the potential limitations of digital instructions is their dependence on IT infrastructure. In the event of an ELAM system failure, it is necessary to switch to a paper version, which can temporarily reduce work efficiency. To minimise the risk, it is recommended to use redundant systems and local storage of instructions at assembly stations.

It was possible to demonstrate the positive impact of digital instructions. Both the turnaround time for an order of 10 pumps and the average cycle time have been shortened and profitability has increased. The use of programmable tools has a positive effect on the quality control process, enabling 100% control and automatic generation of reports without additional time expenditure on the part of the quality control department. The techniques used should be constantly improved and in the future more simulations should be carried out with more participants, also using programmable power tools and quality control elements of manufactured products, paying attention to the number of rejects.

The limited number of participants in the conducted research may affect the representativeness of the results. In the future, the authors are planning to conduct research on a larger sample, which will allow obtaining more generalised conclusions.

Moreover, the experiment was conducted in the context of pump assembly used in the automotive industry, and the efficiency of digital instructions may differ in other industries. In the next stages of research, it is worth extending the analysis to the electronics or aviation industry. In future studies, the authors also consider extending the cost analysis, taking into account: costs of implementing a digital instruction system, including hardware, software and training, potential savings resulting from reducing errors, reducing assembly time and reducing quality control costs and return on investment projections based on available market data.

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