SIMULATION AND OPTIMISATION OF THE ASSEMBLY LINE PRODUCTION PROCESS

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Optimisations in production processes are routine in most engineering companies. The possibility of using simulation is crucial for the industry in the 21st century because it provides an opportunity to verify many variants in a very short time. The results obtained in this way can then contribute to faster decision-making in the field of manufacturing process optimisation. The paper includes a case study of the assembly line production process. The aim was to find bottlenecks in the product production process and capture and propose improvements not only in the technical but also in the production and ergonomic area. A "virtual twin" of the given process was also created in the Witness simulation program with the possibility to analyse and verify proposals for the work activities redistribution of assembly station operators.

KEYWORDS

Optimisation, Simulation, Manufacturing Process, Assembly Line, Operator

1 INTRODUCTION

The current turbulent environment has forced companies to optimise their processes as a routine. We encounter this not only in engineering and the automotive industry but also in transport, gastronomy and a whole range of other sectors. [Tureckova 2020].

The paper deals with the optimisation of an assembly line for automotive products. Companies use industrial engineering methods to have lean manufacturing processes and logistics [Gregor 2016, Sajdler 2020]. Each production process needs to be mapped in detail, time analyses must be performed, and bottlenecks affecting the whole production process need to be found. The goal is, therefore, to increase efficiency and reduce costs and thus always be one step ahead of the competition.

The use of dynamic simulation is a significant benefit that enables engineering companies to respond efficiently and quickly to customer requirements by validating a wide range of options in a very short time. [Cada 2021, Schindlerova 2021].

2 BASIC METHODOLOGY

In modern industrial practice, innovative solutions are often proposed to improve processes or entire production or logistics systems. Optimisation of the production process includes several areas that need to be addressed. This includes, for example, workplace ergonomics – arrangement and equipment, technical equipment – jigs, holders, production technology – welding, forming, surface treatments, etc.

Time studies

Time studies are an essential methodology used in determining the time consumption of work, work equipment and objects. Work measurement methods can be divided as follows:

- *Direct* – snapshots of the working day, snapshots of the operation (chronometry).
- *Indirect* – MTM (Methods Time Measurement), MOST (Maynard Operation Sequence Technique).

Motion studies play an important role in the design of an assembly line to improve working procedures. Individual movements are analysed, and the conditions under which the work is carried out at the workplace are examined. All of this is aimed at continuously improving and speeding up the production process. [Deighton 2016, Sproch 2019] World Class Manufacturing (WCM) is based on a theoretically perfect state. The goal is to design processes and motivate workers so that errors and losses do not occur. Production process planning is used to analyse alternatives in all planning stages. A simulation environment is applied to validate the process methods afterwards. These are effective methodologies and tools that pursue the realisation of three basic objectives: [Jurová 2016]

- high-quality products,
- delivery at the required time and quantity,
- products manufactured at the lowest possible cost. Methodologies include TQM, EFQM, JIT, Lean management, Kaizen, Six Sigma, PDCA a DMAIC. [Jurová 2016, Sajdlerova 2015, Sproch 2021, Cepova 2018]

Dynamic simulation

Simulation modelling involves the development of models that mimic actual operations, statistical analyses and their performance to improve efficiency and effectiveness. Thus, [Schindler 2020] knowledge of these mechanisms becomes an essential support tool for responsible decision-making by a company's top management. Simulation models form a standard part of decision support in production planning and management. [Gregor 2016].

As part of process optimisation, «digital twins» can be used very effectively. It is a digital model of a physical object or process that we use to understand relationships better and predict the impact of planned changes on individual components of the system and, thus, on its overall performance. Digital twins are used for simulation, prediction and optimisation before the actual investment and are an important tool for reducing the level of risk and costs from incorrect decisions. Thanks to simulation, it is possible to analyse the reasons for the system's behaviour and thus create effective procedures for its maximum efficiency. [Gregor 2016]

Dynamic simulation can be used in a number of areas (forming, welding, machining) [Cada 2003] and industry sectors (automotive, food, scaffolding), etc. [Vargova 2020]

The use of simulations in business practice has similar advantages:

- simulation is possible without interfering with the real operation;
- simulation offers a more comprehensive view of the problem to be solved and leads to a better understanding of the real system;
- simulation provides a better overview of business processes, and we can solve even very complex systems that cannot be used with analytical methods;
- several different solution options can be quickly checked;
- it is possible to find out or verify the real functioning of the system in contrast to assumptions and estimates.

The disadvantage is often the time or even financial demands, as well as the increased demands on the knowledge and experience of the staff in working with simulation software and creating models. [Sajdlerova 2015]

3 CASE STUDY – OPTIMISATION OF ASSEMBLY LINES

The case study focuses on optimising assembly lines in a selected company. The manufacturing company is mainly involved in the series production of products that are subsequently used for assembly in other companies operating worldwide. The production process is quite complex. Several types of products are produced on a given production line. The case study will only deal with part of it. Research and measurements have been carried out since 2020.

The study aimed to demonstrate the advantages and possibility of using modern methods and tools of lean production, such as digital twins and dynamic simulation, in the production system.

Based on a series of analyses carried out on the assembly lines, the aim was to find bottlenecks in product B's production process and propose and find improvements in the technical, production and ergonomic areas. Subsequently, a "virtual twin" was created, the proposals for the redistribution of the work activities of the individual operators were verified, and the optimal solution was also evaluated from an economic point of view.

3.1 Phase 1 – Input analysis

As part of input analyses, it was necessary to specify the production process and the final product (FP) B, including assemblies B1 and B2. The assembly line SA (installation of assembly) is used to produce assembly B1 and a separate assembly station for assembly B2. For the time analysis of the production process, it was necessary to draw the layout of the current state of the assembly lines and the separate stations. The MOST methodology was used for the initial setup of operation times and CT. Subsequently, these layouts were used to optimise the workplace and improve the overall manufacturing process. Fig. 1 shows the FP assembly line for product B, which includes 17 stations (manual and machine) and a robotic workstation with three arms.

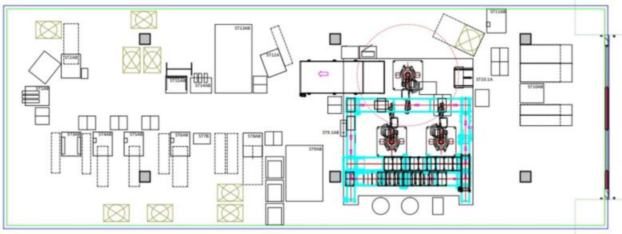

Figure 1. The layout of the FP assembly line for product B [Klepkova 2022]

Time analyses were carried out by the direct method of measuring labour consumption, i.e. by taking snapshots. An example of an operation snapshot is shown in Fig. 2.

Operation number		ST1AB								Date	29.06.2021	
Operation name and product		... B								Observer	Klepková	
										Shift	morning	
Measured action	Z	Measurement sequence numbers										average
		1	2	3	4	5	6	7	8	9	10	
component set-up	P	**12.00**	**12.00**	**10.80**	**9.60**	**10.80**	**11.40**	**11.40**	**8.40**			10.80
	N	0.20	0.80	1.39	0.43	1.30	1.92	2.57	3.12			
establishment of 1 part	P	**3.60**	**4.80**	**4.20**	**4.20**	**3.60**	**4.20**	**3.60**	**7.20**			4.43
	N	0.26	0.88	1.46	0.75	1.36	1.99	2.63	3.24			
machine	P	**7.80**	**6.60**	**6.00**	**6.60**	**6.60**	**6.00**	**6.00**	**7.20**			6.60
	N	0.39	0.99	1.56	0.86	1.47	2.09	2.73	3.36			
screw-in	P	**6.00**	**6.60**	**8.40**	**7.80**	**8.40**	**7.20**	**7.80**	**7.20**			7.43
	N	0.49	1.10	0.14	0.99	1.61	2.21	2.86	3.48			
component snap-in, label on and off	P	**6.60**	**6.60**	**7.80**	**7.80**	**7.20**	**10.20**	**7.20**	**7.80**			7.65
	N	0.60	1.21	0.27	1.12	1.73	2.38	2.98	3.61			
material change	P				**15.00**							0.36
42	N				0.68							
sum		36.00	36.60	37.20	51.00	36.60	39.00	36.00	37.80			**37.26**

Figure 2. Example of a snapshot of an operation for product B on the FP assembly line at station ST1AB [Klepkova 2022]

A capacity calculation was also carried out on individual lines, and the result was compared with the original cycle time (CT) MOST analyses performed when the new production project was assigned. The production of the given products has been ongoing since 2020. During this period, some adjustments to the CT and layouts of assembly and production lines based on the new time measurements have already been made. Time measurements were divided into categories according to activities:

- OP – assembly activity performed by the operator,
- Machine – machine time that is not influenced by the worker.

Fig. 3 shows a summary of time measurements for product B on the FP assembly line.

Area	product	station	aktivity	04.09.2020	09.09.2020	15.10.2020	09.02.2021	16.02.2021	09.04.2021	14.04.2021	29.06.2021	12.07.2021
FP	B	ST1AB	OP	33.36				50.32	39.00		30.66	35.82
			machine	5.06				7.00	6.00		6.60	6.18
		ST2AB	OP	28.20				26.66	29.00		24.20	21.06
			machine									
		ST3AB	OP	30.20				23.83	27.00		27.75	23.10
			machine	15.00				18.60	14.00		14.25	
		ST4AB	OP	76.41				52.61	59.00		68.61	50.64
			machine									
		ST5AB	OP	47.87				41.64	35.00	34.18		40.56
			machine									
		ST6AB	OP	44.00				41.96	52.00			39.15
			machine									
		ST7B	OP				37.50	47.33	61.00			49.26
			machine									
		ST8AB	OP		62.78	56.24	51.01			58.53		
			machine									
		ST9AB	OP									
			machine		49.90	48.80	48.55	49.40		49.53		
		ST9.1AB	OP				10.32					
			machine			50.91	53.28	54.00		55.38		
		ST10AB	OP					42.00		51.44	49.78	
			machine									
		ST10.1A	OP					15.00			13.62	
			machine									
		ST11AB	OP		64.92			50.00		59.24	48.76	
			machine									
		ST12AB	OP									
			machine									
		ST13AB	OP								6.77	
			machine				37.90	39.00			41.40	
		ST14AB	OP	30.84				34.00			36.35	45.35
			machine									
		ST15AB	OP	38.80				42.00				47.02
			stroj									
		MAX OP		76.41	64.92	56.24	51.01	52.61	61.00	59.24	68.61	50.64
		MAX machine		15.00	49.90	48.80	48.55	49.40	14.00	49.53	41.40	6.18
		MAX		**76.41**	**64.92**	**56.24**	**51.01**	**52.61**	**61.00**	**59.24**	**68.61**	**50.64**
		station		**ST4AB**	**ST11AB**	**ST8AB**	**ST8AB**	**ST4AB**	**ST7B**	**ST11AB**	**ST4AB**	**ST4AB**

Figure 3. Summary of time measurements for product B on the FP assembly line [Klepkova 2022]

It can be seen that at several stations, the norm (actual CT) of 50 s was exceeded. Fig. 4 shows these stations in the production process on the FP line for product B.

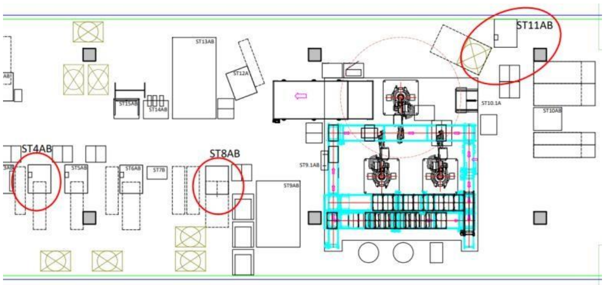

Figure 4. Problem stations in the FP production process [Klepkova 2022]

The assembly line SA is used for the continuous process of the assembly line FP for the production of assembly B1. During the measurement, this line did not significantly exceed the standard (actual CT) 50 s. The summary of time measurements for product B1 on the SA line is shown in Fig 5.

Area	product	station	aktivity	09.07.2020	12.08.2020	16.10.2020	21.01.2021	09.02.2021	12.04.2021	05.05.2021	15.09.2021	16.09.2021
SA	B1	ST1B1	OP	30.14	34.54		32.78	21.07	25.00	21.79	16.16	16.80
			machine									
		ST2B1	OP	33.59			33.84	26.18	39.00	27.46	24.62	21.33
			machine									
		ST3B1	OP	33.56			25.71	17.45	30.00	22.11	25.11	29.41
			machine									
		ST4-5B1	OP	29.70			18.84	13.80	21.00	28.50	19.18	19.20
			machine									
		ST6B1	OP	35.80	51.57		23.22	17.45	33.00	24.65	22.01	19.50
			machine									
		ST7B1x	OP									
			machine									
		ST7B1	OP		14.46	5.04	7.38		39.00	33.28	15.69	16.00
			machine		39.23	42.00	36.42		31.00	12.05	19.11	19.07
		ST8B1	OP		26.15		47.49					26.08
			machine									
		MAX OP		35.80	51.57	5.04	47.49	26.18	39.00	33.28	25.11	29.41
		MAX machine		0.00	39.23	42.00	36.42	0.00	31.00	12.05	19.11	19.07
		MAX		**35.80**	**51.57**	**42.00**	**47.49**	**26.18**	**39.00**	**33.28**	**25.11**	**29.41**
		station		**ST6B1**	**ST6B1**	**ST7B1**	**ST8B1**	**ST2B1**	**ST2B1**	**ST7B1**	**ST3B1**	**ST3B1**

Figure 5. Summary of time measurements for product B1 on the SA assembly line [Klepkova 2022]

The next station to be analysed was STB1.1, which is used for subgroup assembly that enters the SA assembly line for product B1. A summary of time measurements can be seen in Fig. 6. It is clear that the standard (actual CT) of 40 s was not exceeded here.

Area	product	station	aktivity	12.08.2020	15.01.2021	09.02.2021	24.02.2021	05.05.2021	05.01.2022	01.02.2022
SA1	B1.1	STB1.1	OP	38.10	34.68	37.00	35.89	36.66	30.90	15.85
		STB1.1	machine	38.10	34.68	37.00	35.89	36.66	30.90	29.96
		MAX OP		38.10	34.68	37.00	35.89	36.66	30.90	59.24
		MAX machine		38.10	34.68	37.00	35.89	36.66	30.90	29.96
		MAX		**38.10**	**34.68**	**37.00**	**35.89**	**36.66**	**30.90**	**59.24**

Figure 6. Summary of time measurements for product B1.1 at the associated station [Klepkova 2022]

Fig. 7 shows a view of the layout of the SA assembly line for product B1 and the STB1.1 station. The stations that we focused on in the optimisation are highlighted here.

Figure 7. Selected stations in the production process SA_B1 [Klepkova 2022]

The last station, STB2, is used to complete the assembly that enters the FP assembly line for product B. A summary of time measurements is shown in Fig. 8. The specified standard (actual CT) of 30 s was not exceeded for most of the measurements.

Area	product	station	aktivity	02.07.2020	12.08.2020	14.01.2021	04.02.2021	10.02.2021	04.05.2021
SA	B2	STAB2	OP	30.16	18.70	28.18	26.42	25.69	24.98
			machine	30.16	18.70	28.18	26.42	25.69	24.98
		MAX OP		30.16	18.70	28.18	26.42	25.69	24.98
		MAX machine		30.16	18.70	28.18	26.42	25.69	24.98
		MAX		**30.16**	**18.70**	**28.18**	**26.42**	**25.69**	**24.98**

Figure 8. Summary of time measurements for product B1.1 at the associated station [Klepkova 2022]

The layout of the STB2 station is shown in Fig. 9.

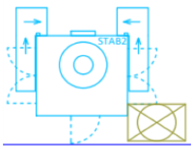

Figure 9. STB2 station in the production process FB_B [Klepkova 2022]

3.2 Phase 2 – Preparation of the simulation model

Based on the input analysis and the original layouts of the FP and SA assembly lines and associated stations, models of all lines were created using Witness 13 simulation program. The goal was to verify the correctness of the production settings in Excel program and also the optimal distribution of operator activities at the individual stations of the FP and SA assembly lines Fig. 10.

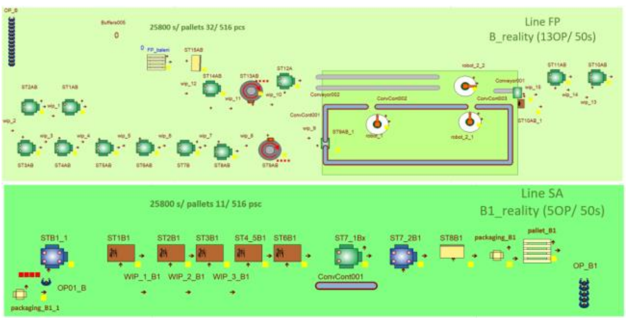

Figure 10. Creating a model of FP and SA assembly line, separate stations for B1 product in Witness 13 software [Klepkova 2022]

To create the assembly line model, it was necessary to input the individual elements (incoming parts, machines, packaging, conveyors, robotic workstations and workers) into the simulation program and set up the interrelationships and steps between the stations using an Excel file containing the input information. Next, the times and activities of the individual workers at the assigned stations were set. Subsequently, a verification of the current workload of workers was carried out based on the input analyses.

For **the FP assembly line for product B**, a workload chart was created for the current 13 operators. A comparison was made between the results calculated in Microsoft Excel and the simulation programme Witness 13 Fig. 11. The graph shows the busyness (Busy) and idleness (Idle) of individual workers operating the assembly stations.

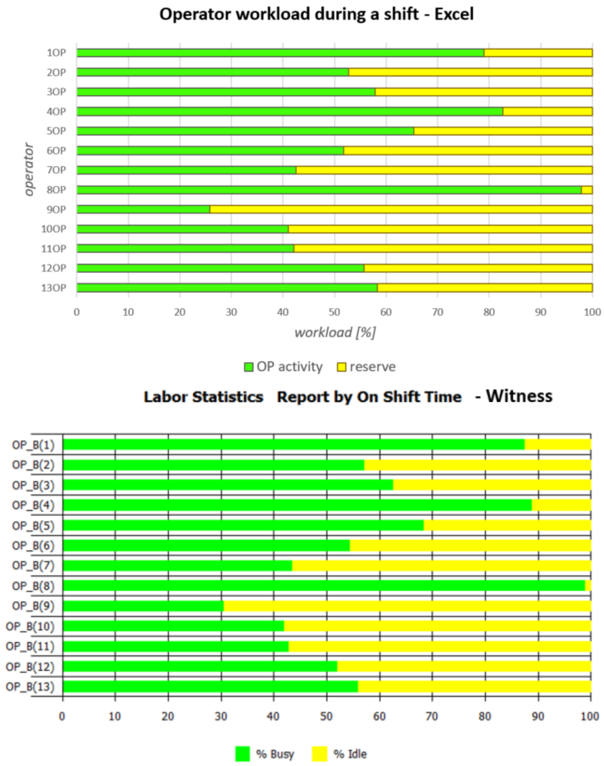

Figure 11. The busyness of 13 OPs on the FP_B assembly line in Excel and Witness program [Klepkova 2022]

When comparing **the SA assembly line for assembly B1**, there were significant differences in the percentage of operator busyness when comparing Excel and Witness 13. This difference was caused by the operator's setting and the assembly time (CT) setting in the simulation program using a triangular and Poisson probability distribution, where the simulation program operates based on predefined algorithms. Excel draws the values on the graph according to chronometry cues, see Fig. 12.

From Figs. 11, 12, it can be seen that the busyness of most operators is insufficient. Therefore within the optimisation, it will be proposed to redistribute the activities to individual operators so that they are sufficiently busy and it is possible to produce more pieces per shift.

Figure 12. The busyness of 5 OPs on assembly line SA_B1 in Excel and Witness programmes [Klepkova 2022]

3.3 Phase 3 – Evaluation of acquired knowledge

For the FP assembly line for product B, problems were identified at some stations, especially in the measured times required to produce product B compared to the standard (actual CT) of 50 s. It can be seen from Figure 13 that the problem stations are ST4AB, ST8AB, and ST11AB for manual activities on the FP line.

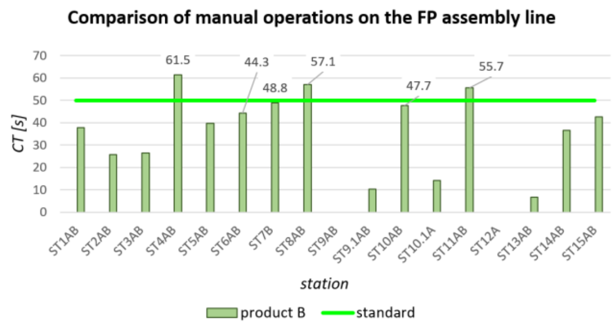

Figure 13. Comparison of manual activities on the FP line for product B [Klepkova 2022]

Workstations ST9AB and ST9.1AB Fig. 14, which include machine operations, were the bottleneck of the entire production process. For station ST9AB, it is the equipment that tests the product, and station ST9.1AB is the robotic workstation with three arms. The assembly line technologist was consulted about the need to improve the flow through the bottleneck, i.e. the ST9.1AB workstation, which was not technologically possible, so the whole production process had to be adapted to this flow.

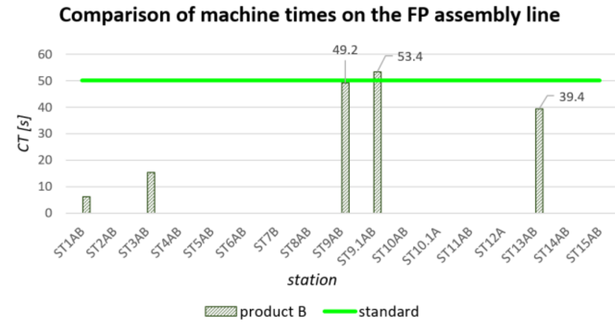

Figure 14. Comparison of machine times on the FP line for product B [Klepkova 2022]

Furthermore, the graphs Fig. 11 and Fig. 12 were evaluated for the busyness of 13 operators (OPs) on the FP_B assembly line and 5 OPs on the SA_B1 assembly line. It was found that the operators operating the stations on the FP assembly line are not sufficiently busy. These were OP_6, OP_7, OP_9, OP_10 and OP_11, and on the SA assembly station for product B1, the workers were mainly OP_1 and OP_2.

3.4 Phase 4 – Optimalisations

Input analyses and verification of the operator's busyness through simulation by creating a "virtual twin" led to assembly line optimisation. It was essential to ensure an even distribution of the activities of the individual operators on the assembly lines and to reduce the CT at the assembly stations. Based on the company's request, the lines were rebalanced on FP product B, and three variants of CT time distribution were created, including the allocation of the respective operator. These are:

- **Fast CT (R)** – the highest number of operators and full busyness (covering maximum customer requirements),
- **Medium CT (S)** – the lower number of operators (holidays, sick leave),
- **Slow CT (P)** - the lowest number of operators (preferably trained OPs).

The number of operators was consulted with the production planning and production department. A new standardised work procedure was created after the work activities of the workers were reallocated to the individual stations. An example of the standardised work procedure is shown in Fig. 15.

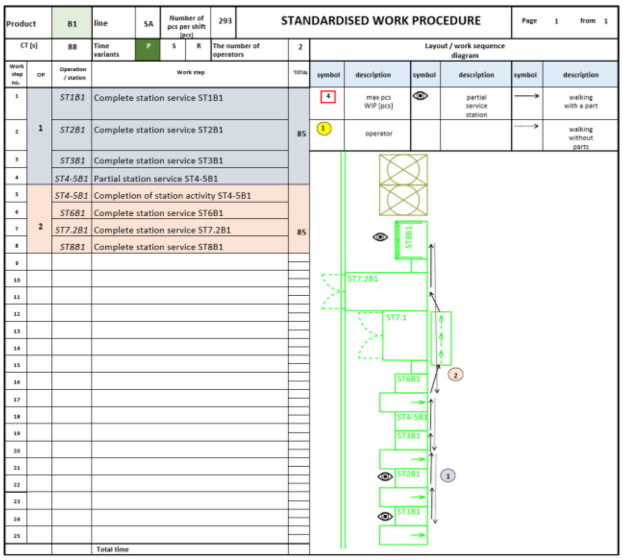

Figure 15. Standardised work procedure on the SA line for product [Klepkova 2022]

The work activities on the assembly lines FP for product B and SA for assembly B1 were set into time variants (R, S, P). The layouts of the lines are identical and are shown in Fig. 16. For the variants mentioned above, there have been changes in the number of OPs and the set CT for individual variants.

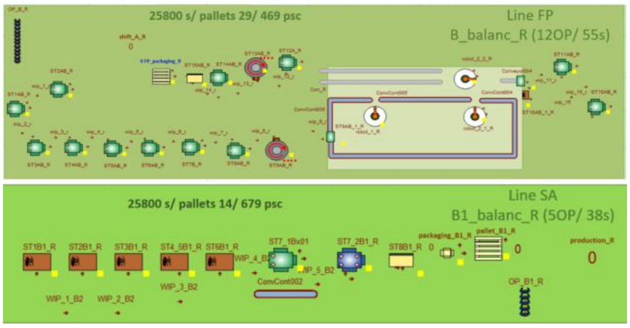

Figure 16. FP and SA assembly lines created in Witness 13 program for balance R [Klepkova 2022]

The table in Fig. 17 presents all variants, including settings.

line FP_B	MOST				reality				proposal			
	OP	CT	pcs/shift	Nh	OP	CT	pcs/shift	Nh	OP	CT	pcs/shift	Nh
B_R	12	56	461	0.19535	14	50	516	0.20349	12	55	469	0.19186
B_S	9	75	346	0.19535	9	78	332	0.20349	9	71.5	361	0.18706
B_P	7	96	269	0.19535	7	100	258	0.20349	7	94.3	274	0.19189

line SA_B1	MOST				reality				proposal			
	OP	CT	pcs/shift	Nh	OP	CT	pcs/shift	Nh	OP	CT	pcs/shift	Nh
B1_R	5	50	516	0.072674	5	50	516	0.072674	5	38	679	0.055233
B1_S	3	83	310	0.072674	3	83	309.6	0.072674	3	64	403	0.055814
B1_P	2	125	206.4	0.072674	2	125	206.4	0.072674	2	88	293	0.051163

station SA a SA1	MOST				reality				proposal			
	OP	CT	pcs/shift	Nh	OP	CT	pcs/shift	Nh	OP	CT	pcs/shift	Nh
STAB2	1	35	737	0.010174	1	30	860	0.008721	1	28	921	0.008140

Figure 17. FP and SA assembly line settings for variants (R, S, P)

All time busyness variations, including operator allocation (for products B and B1), are listed below.

FP assembly line for product B
Fast CT (R)

The analysis found that the bottleneck is station ST9.1AB (CT 54 s); see chapter 3.3. Based on this, the time for the processes on the FP assembly line for product B was adjusted to 55 s/ 12 OP, with a worker fund of working hours (shift - 25800 s). The balance of the FP line, including the allocation of individual operators to the lines, is shown in Fig. 18.

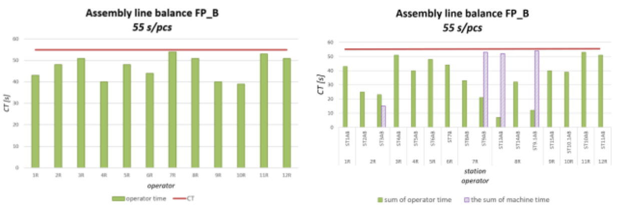

Figure 18. Balance of FP assembly line for product B (fast CT – 12 OP) [Klepkova 2022]

Fig. 19 shows the time busyness of individual operators (OPs). It can be seen that compared to the original utilisation distribution of 13 OPs, the proposal has reduced the number of operators to 12 and their better utilisation.

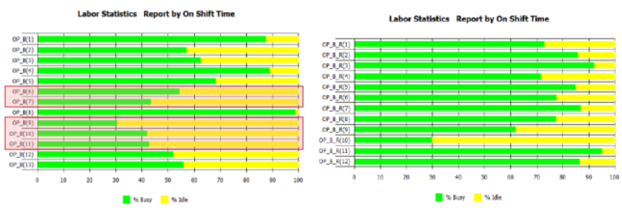

Figure 19. Distribution of work activities before and during proposal (fast CT_B) [Klepkova 2022]

Medium CT (S)

The balance of the FP line, including the allocation of individual operators to the lines, is shown in Fig. 20.

Figure 20. Balance of FP assembly line for product B (medium CT – 9 OP) [Klepkova 2022]

Fig. 21 shows the time busyness of each operator (OP), the values calculated in Excel and the results obtained by simulation in Witness 13 were compared. It can be seen that there was better utilisation of operators compared to the original state in Fig. 11, even with a lower number of operators.

Figure 21 Busyness comparison 9 OP Excel/Witness 12 (medium CT – 71,5 s) [Klepkova 2022]

Slow CT (P)

FP line balance, including the distribution of individual operators to the lines, is shown in Fig. 22.

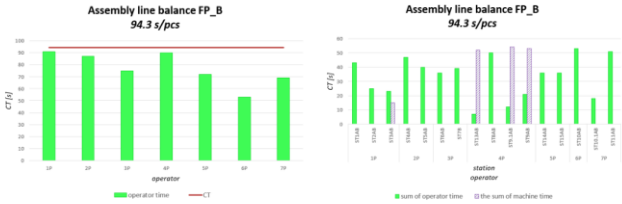

Figure 22. Balance of FP assembly line for product B (slow CT – 7 OP) [Klepkova 2022]

Fig. 23 shows the time busyness of each operator (OP), the values calculated in Excel and the results obtained by simulation in Witness 13 were compared. It can be seen that there was better utilisation of operators compared to the original state in Fig. 11, even with a lower number of operators.

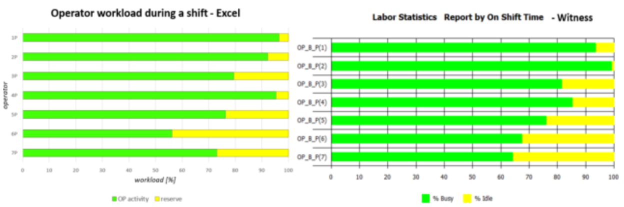

Figure 23. Busyness comparison 7 OP Excel/Witness 12 (slow CT – 94,3 s) [Klepkova 2022]

SA assembly line for product B1

Fast CT (R)

The SA link balance, including the distribution of individual operators to the links, is shown in Fig. 24.

Figure 24. Balance of SA assembly line for product B1 (CT – 5 OP) [Klepkova 2022]

Fig. 25 shows the time busyness of individual operators (OPs). It can be seen that compared to the original utilisation of 5 OPs, the design has reduced the CT (original 50 s, proposed 38 s) and thus their better utilisation.

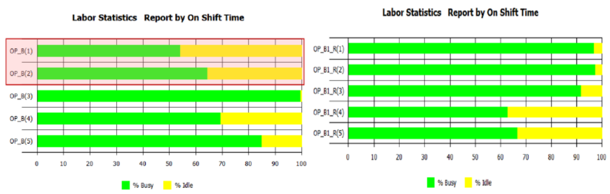

Figure 25. Distribution of work activities before and during proposal (fast CT_B1) [Klepkova 2022]

Medium CT (S)

The SA link balance, including the distribution of individual operators to the links, is shown in Fig. 26.

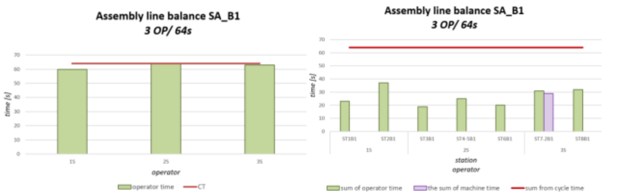

Figure 26. Balance of SA assembly line SA subassembly B1 (medium CT – 3 OP) [Klepkova 2022]

Fig. 27 shows the time busyness of each operator (OP), the values calculated in Excel and the results obtained by simulation in Witness 13 compared. It can be seen that there was better utilisation of operators compared to the original state in Fig. 12, even with a lower number of operators.

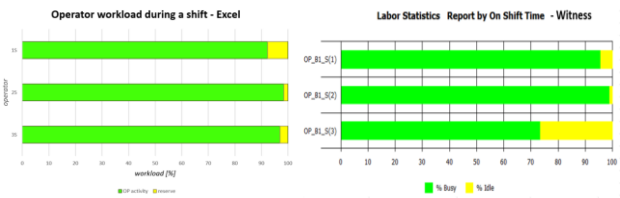

Figure 27 Busyness comparison 3 OP Excel/Witness 12 (medium CT 64 s) [Klepkova 2022]

Slow CT (P)

The FP link balance, including the distribution of individual operators to the links, is shown in Fig. 28.

Figure 28. Balance of assembly line SA subassembly B (slow CT – 2 OP) [Klepkova 2022]

Fig. 29 shows the time busyness of each operator (OP), the values calculated in Excel and the results obtained by simulation in Witness 13 compared. It can be seen that there was better utilisation of operators compared to the original state in Fig. 12, even with a lower number of operators.

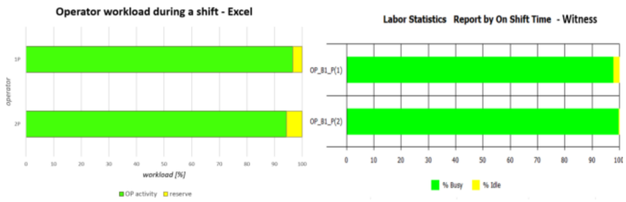

Figure 29. Busyness comparison 7 OP Excel/Witness 12 (slow CT - 88 s) [Klepkova 2022]

CT change at STAB2 associated station

The associated station is used for assembling B2 products (Fig. 9). The original CT of the assembly was set at 30 pcs, and the number of pieces per shift was 860 pcs. After technological adjustments and long-term training of the operators, it was found during repeated scanning that the assembly time was reduced. A CT of 28 pcs was proposed, increasing productivity to 921 pcs per shift.

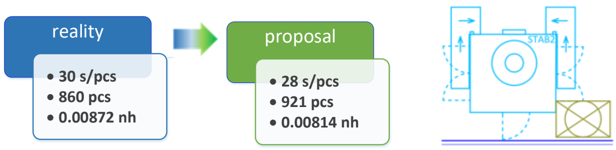

Figure 30. STAB2 associated station for product B2 [Klepkova 2022]

4 EVALUATION OF THE RESULTS

Based on the above results, it is possible to state that savings can be obtained in several areas. Savings related to:

- number of workers on the assembly line FP for product B and SA for assemblies B1,
- CT changes at associated stations.

For the FP assembly line for the production of product B, it was found that in comparison with the standard hours of the initial analysis (MOST), i.e. the priced standard hours, the financial savings were insignificant. The main benefit is that work activities can be better redistributed among operators and thus more flexible in responding to customer requirements. Furthermore, the findings obtained during the design and calculation of CT on the FP assembly line were verified by dynamic simulation.

The optimisation has proved to be more significant for the SA assembly line for the B1 assembly and the separate associated station STAB2. The financial savings related to the individual time variations in the number of workers on the SA assembly line for subassembly B1 and station STAB2 are shown in Fig 31.

line SA_B1	reality				proposal				reality/ proposal difference [%]	production plan [ks]	saving in nh	saving	
	OP	CT	pcs/ shift	Nh	OP	CT	pcs/ shift	Nh				Kč	EU
B1_R	5	50	516	0.072674	5	38	679	0.055233	24%	138000	2406.977	585362	23419
B1_S	3	83	309.6	0.072674	3	64	403	0.055814	23%	138000	2326.744	565850	22639
B1_P	2	125	206.4	0.072674	2	88	293	0.051163	30%	138000	2968.605	721946	28884
station													
STAB2	1	30	860	0.008721	1	28	921	0.008140	23%	276000	561.628	136584	5464

Figure 31. Summary table of financial savings for CT proposals [Klepkova 2022]

5 CONCLUSIONS

The case study focused on optimising the assembly line FP and SA for products B and B1. The theoretical research provided a summary of knowledge in the field of optimisation of production processes and also "Digital twins", i.e. the use of dynamic simulation for verification of the analysed line and the possibility of variant adjustment of the line according to the needs of the company in response to customer requirements.

As part of the optimisation, layouts of the assembly line were created, and the times of assembly activities were measured. Subsequently, the line was modelled in Witness 13 software, and the proposals for redistributing operators' work activities and their allocation to assembly stations were verified. Based on the input analyses, bottlenecks were identified, and workstation optimisation proposals were made, including ergonomic workstation modifications. All data were processed in Microsoft Excel and subsequently verified by dynamic simulation. The results were slightly different in some cases, mainly because the simulations work with triangular and Poisson probability distributions, which makes it much closer to the real environment. Proposals for the number of employees in time variants (R, S, P) can help the company management respond more quickly to the market demands and the company environment.

It is evident that the current competitive environment cannot do without advanced technologies. The ability to use simulation is crucial for the industry in the 21st century and has a significant impact on reducing costs, eliminating losses and maintaining or increasing profits. The case study results confirmed the importance of optimising production processes by using "digital twins" as a dynamic simulation tool to facilitate and speed up management decisions.

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