ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20240517165802

Preliminary communication
Received: 2024-05-17, Accepted: 2024-06-22

Integrating Robotic Systems into a Plasma Cutting Workstation - New Workstation Design Approach Using Techno-Economic Evaluation

Jakub Müller*, Tomáš Broum, Miroslav Malaga, Monika Milatová

Abstract: This paper proposes a procedure for implementing a robotic system in a plasma cutting workplace. The goal is to create an efficient and safe process for integrating a robot into the existing workspace, with an emphasis on increasing productivity and minimising the risk of human factors. The paper includes an analysis of the requirements for the robotic system, including compatibility with the plasma cutting equipment. The proposed procedure involves an analysis of the current state of the workplace, followed by recommended implementation steps. The procedure includes a comparison of the current state of the workplace with the proposed state and the establishment of criteria for evaluation, which are subsequently used in the techno-economic evaluation. The paper also presents an industrial case study to validate the proposed procedure.

Keywords: automation; industrial case study; plasma cutting; robotics; techno-economic evaluation

1 INTRODUCTION

The integration of robotic systems into industrial processes is a key step towards improving the competitiveness and efficiency of the production environment. When deciding on such an investment, a thorough economic and technical evaluation is essential. This paper focuses on just such an evaluation in the context of a robotic plasma cutting workstation. The research analyses not only the technical aspects, such as the reduction of the need for operators and quality control using laser technology, but also the economic implications, including savings and payback time of the investment, which according to the research conducted is often overlooked and not addressed in the available publications. Our findings suggest that automation through robotic systems is not only a suitable solution for existing manufacturing processes, but also a key to future innovative growth and competitiveness.

2 LITERATURE REVIEW

In today's industrial environment, there is a strong emphasis on innovative approaches and technologies to optimise production processes and increase their efficiency. Two of the key tools in this endeavour are robotic systems and simulations, which play an indispensable role in the design and improvement of production lines and processes [1].

Some analyses are devoted to the design of automated assembly stations to improve working conditions and efficiency, focusing on the integration of palletising stations with industrial robots and cobots to increase competitiveness [2], or they explore the use of multi-robot cells for production lines [2] e.g., with an extension to optimise reconfiguration capacities [3].

The studies also reflect the economic aspects of robotization of production processes [4] and at the same time deal with the practical problems associated with the implementation of Industry 4.0, especially in small and medium-sized enterprises [5]. In the context of the use of industrial robots, their impact on the qualitative development of the manufacturing industry [6] and their impact on employment and labour costs [7] are investigated. The contribution of industrial robots to labour productivity growth and economic convergence is also an important issue [8]. The issue of robot/cobot grippers is also very often discussed [9, 10].

Furthermore, specific aspects of the implementation of robotic systems and the optimisation of their number for the reconfiguration of modular manufacturing systems [11], or e.g. the modelling and evaluation of the use of workers in production [12] are investigated. Other authors focus on specific methods and tools for optimising manufacturing processes [13, 14].

The use of these innovative approaches can then be presented in scientific articles focusing on practical examples of the use of simulations for the optimisation of manufacturing processes often provided by robots [14, 15] [16, 17]. What is missing here is the economic aspect and directly targeting the area of plasma cutting.

In general, the authors do not deal with a more comprehensive techno-economic evaluation of the implementation/acquisition of industrial robots with a focus on plasma, with the exception of [18, 19], who touch lightly on these aspects.

3 METHOD

The proposed workflow describing the complete design and evaluation of an automated plasma workstation is shown in Fig. 1. A detailed description of the individual steps is given in the following subsections.

3.1 Analysis of the Current State

The first step of the workplace design is to analyse the current state of the workplace. In most cases, a comparison of the current state with the proposed state is made. But even in the case of a completely new workplace, it is advantageous to identify the criteria against which it will be evaluated. The criteria are then used for the later techno-economic evaluation. They are determined based on the findings and results of the analysis of the current state, as well as the identified deficiencies at the workplace. The established criteria are divided into measurable criteria, the expression of which is explicit, and the remaining criteria which are non-measurable and thus need a qualitative assessment. They are also divided according to their nature into maximising, where the aim is to achieve the highest possible value of the criterion to ensure a good result, and minimising, where the aim is to achieve the lowest possible value to obtain the best result. To accurately analyse the movement of operators over time, it is necessary to create a Spaghetti diagram, which is a tool used to reduce waste in the form of unnecessary transportation, movement and waiting or downtime. This tool is used to track the movement of materials and people, where a visual representation of the physical movement on paper occurs along with details of direction and distance over a predetermined period of time. It is a simple method of analysis used to capture the progress of the work. Everything is recorded in a pencil drawing of the workplace layout. Different colours are used to differentiate between persons or materials. [20]

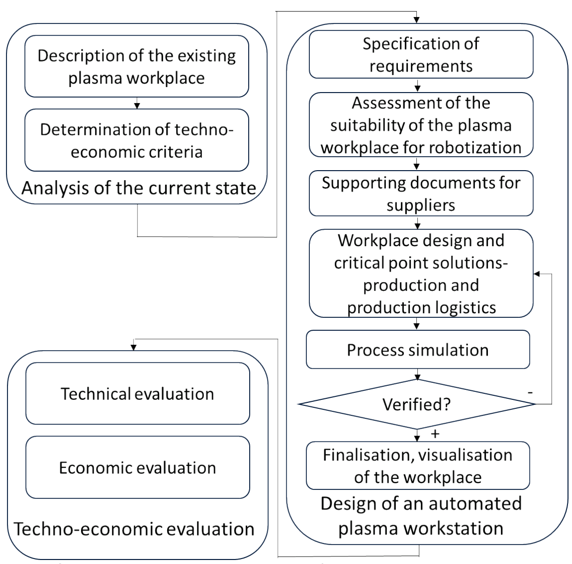

Figure 1 Complete design and evaluation of an automated plasma workstation

3.2 Design of an Automated Plasma Workstation

In this chapter, we outline the steps involved in the design of a new automated workplace for plasma cutting using robotic equipment. The design should be based on the requirements outlined by the company management and takes into account the analysis of the current state and the identified shortcomings of the existing workplace.

3.2.1 Specification of Requirements

An important part of the design process is the specification of the requirements. The basis of the entire design is the creation of a 2D spatial arrangement of the workstation, commonly known as a layout, detailing the placement of various components and elements. These elements include handling robots, plasma console, input and output material containers, scrap tray and other essential items that are key to ensuring the functionality of the workstation. This design should then be complemented by a 3D visualisation of the workplace and robots. It is important to have the information supported by data so that the economic evaluation and payback period calculation can be checked at the end of the design.

3.2.2 Assessment of the Suitability of the Plasma Workplace for Robotization

When deciding whether a plasma workplace is suitable for the introduction of robotics, consideration should be given to an analysis of the current situation and the individual activities performed by the operators at the workplace. In the current situation, it is assumed that all these activities are performed by humans, but the aim is to replace most of them with robots. It is assumed that some of the activities that are performed by humans will be performed in a different way in the new workplace, even though their purpose and output will be the same. The aim is that these activities should take no more than the same amount of time as it takes a human to do them, so that the introduction of robotics is beneficial. If there is complex handling of parts and complicated insertion of small parts into jigs, it would be worth considering whether such activities are strictly necessary to replace by robots. Sometimes it is possible that the complexity of the part insertion makes human work faster than robot work.

This decision is usually determined by consulting with experts from the companies supplying the robots and also from information and knowledge gained in the field of automation and robotics of production and manufacturing processes.

3.2.3 Supporting Documents for Suppliers

An important step is to have the right documentation for the supplier. The first very important parameter to determine is the average volume. The average volume is the ratio of the total volume per year to the number of working days per year (Eq. (1)).

$$AV = \frac{Total\ volume\ per\ year}{Number\ of\ working\ days\ per\ year}. \tag{1}$$

Another important calculation is the available time, where the length of one shift is determined (all calculations should be divided into hours and seconds). Next, the number of shifts per day is determined and lastly the number of hours and seconds per year is determined. The cycle time (Eq. (2)) required to produce one piece is obtained as the ratio of the available seconds per day and the average number of pieces per day shown in Eq. (1).

$$Cycle\,Time\ (CT) = \frac{Seconds\ per\ day\ (T_{\mathrm{D}})}{AV}. \tag{2}$$

This time must not be exceeded, so there is no room for any downtime or errors, but this is unrealistic in practice as the required number of units would not be produced in a given period. Hence, this cycle time is considered as the time at *OEE* - Overall Equipment Efficiency, Eq. (3). Therefore, the time needs to be recalculated to find the length of time at *OEE* = 100%. For this, it is sufficient to multiply the calculated CT by the *OEE* value shown in Eq. (4).

$$OEE = Availability * Performance * Quality, \tag{3}$$

$$CT_{100\%} = CT * OEE. \tag{4}$$

3.2.4 Workplace Design and Critical Point Solutions

When designing a new plasma workstation, there are almost always important points to consider and the best possible option to choose from.

Number of robots. In terms of full automation and robotization of the workplace, it is necessary to consider the number of robots.

Types of robots. In most cases, the supplier proposes the use of robots based on experience and expertise.

Workplace safety. This depends on the types of robots. In the case of collaborative robots (cobots), no fencing is necessary as they are equipped with a sensor for human contact. In the case of industrial robots, security of the workplace is required in the form of fencing.

Robot tool for gripping parts. Choosing the right gripping tool is a very important part and there are many factors that go into choosing the best tool.

Checking for the presence of holes. Once the hole cutting process is complete, it is important to verify that the holes are indeed there. It is possible that the cycle has been performed but incompletely, or that the cut holes have a different shape than desired. Another factor is whether or not the workplace is close to other workplaces, since because of the heat generated by the plasma torch and the cutting of the holes, it is necessary to secure the workplace with a welding transparent red fence to protect other workers. It works on the same principle as the glass that welders have in their welding helmets to protect their eyesight.

3.3 Techno-Economic Evaluation

In this chapter, the focus will be on the techno-economic evaluation of the design of the workplace from several perspectives. First, the technical aspects of the workplace will be evaluated based on technical criteria. For this purpose, a multi-criteria evaluation method will be used with the determination of weights for each criterion. This will be followed by an economic evaluation, where the payback period (also called return on investment) will be determined.

3.3.1 Technical Evaluation

For the comparison of the new workplace with the current one, the technical criteria for the evaluation are established in the next chapter of the paper as part of the analysis of the current state. These criteria are listed in descending order of importance, with the most important criterion at the top. The ranking of the criteria is part of the pairwise comparison method used to determine the weights of each criterion. This method works on the principle of listing the criteria in the order in the table in both column and row so that each can be compared with the other. If a criterion is more important in the row than in the column, a number one is written in the corresponding cell, otherwise zero. The number of u_{er} is then calculated by simply summing the values in each row. This number tells how many times the criterion is more important than the others. [21] The resulting weight of each criterion p_r is determined according to the Eq. (5).

$$p_r = \frac{\sum_{e=1}^{q} u_{er}}{\sum_{r=1}^{s} \sum_{e=1}^{q} u_{er}}, \tag{5}$$

where: p_r – weight of importance of the criterion, u_{er} – number of criteria preferences, q – number of experts, s – number of criterion.

This is followed by a comparison of the variants according to the individual technical criteria, where the calculation and evaluation of the variants according to the technical criteria is then shown (Tab. 5). In the rank function method, the highest value, in this case 3, was assigned to the best variant, the remaining variants were then ranked 2 and 1. The final rating is calculated according to the Eq. (6).

$$w_t = \sum_{K=1}^{n} p_r * g_r, \tag{6}$$

where: w_t – ordinal function value, g_r – value of the assigned ordinal function.

3.3.2 Economic Evaluation

When deciding on a manufacturing investment, it is important to make investment calculations. These calculations use objective criteria that are determined on the basis of the company's objectives. Various methods are used for the calculations, which include the calculation of the payback period. A static method is used to determine this, which works with average annual values, and therefore average annual savings. It uses static values that the company itself uses. The criterion itself is a minimisation criterion and the aim is to achieve the shortest payback period. A general formula is used for this purpose (7).

$$Payback\ period\ (PP) = \frac{Investment}{Cost\ saving}. \tag{7}$$

4 INDUSTRIAL CASE STUDY

In the introduction of the Industrial Case chapter, following on from the previous Method chapter, we explore the practical application of the methodology in an industrial setting and analyse a specific case study that illustrates the effective implementation of the proposed procedures.

4.1 Analysis of the Current State

As there will be a comparison between the current situation and the proposed situation, it is necessary to determine the criteria against which the assessment will be made. A total of 8 criteria have been selected:

- K_1 - Number of produced pieces
- K_2 - Number of operators
- K_3 - Length of material flow
- K_4 - Method of disposal of cuttings
- K_5 - Level of automation
- K_6 - Method of checking the presence of holes
- K_7 - Method of supply
- K_8 - Workplace area.

For an accurate analysis, Spaghetti diagrams must be created. In our case study there are diagrams for 1 operator (Fig. 2) and 2 operators.

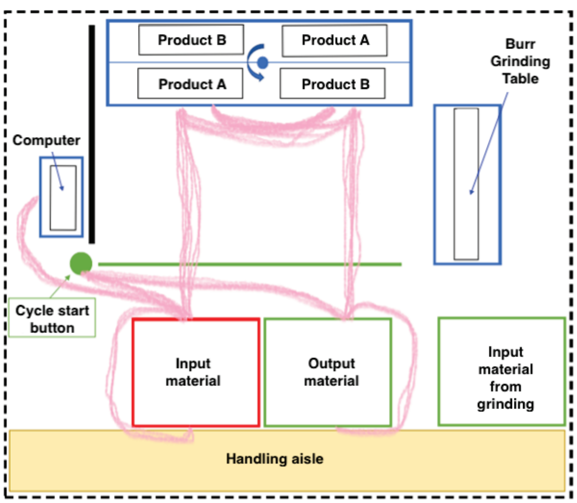

Figure 2 Spaghetti diagram – 1 operator

After their analysis, the routes and distances that operators have to travel during the part placement are visible. After measuring 15 cycles, the average times (cycle times) were calculated (Tab. 1).

Table 1 Operator times (Cycle times)

	One operator	Two operators
Average time (s)	41.99	24.45
Difference (s)	17.54	

The cycle time on a given project at *OEE*=100% should be 19.5 s. However, this value is difficult to achieve in practice. To achieve this value, there would have to be constant, and above all fast, loading of parts into the jigs, no downtime, no waiting and no machine failure. The average cycle time is 41.99 s for one operator and 24.45 s for two operators, a difference of 17.54 s. When the cycle times are converted to *OEE*, it is found that one operator achieves an *OEE* of only 46% and two operators 80%. The management of Shape Corp. decided to create a completely new design for a workplace using modern technologies - specifically robotics, which would eliminate the above-mentioned shortcomings.

4.2 Design of an Automated Plasma Workstation

The assessment of the suitability of the workplace for robotization includes the activities carried out at the plasma workstation and compares the current state with the proposed state. The activities to be assessed are as follows: 1. Opening the containers, 2. Removing the parts, 3. Transferring the part to the jig, 4. Loading the part into the jig, 5. Transferring the part from one jig to another, 6. Removing the finished part, 7. Placing the part in the final container, 8. Closing the containers, 9. Activities 2 to 7 are assumed to be performed by the new robot. The plan view of the new workplace shows the layout of all the items in Fig. 3. ("NOK" stands for "Not OK" = rejected parts.) It plays a key role in optimising the performance, efficiency and safety of the workplace. The right layout can greatly influence workflow, reduce production time and minimise the risk of operational errors.

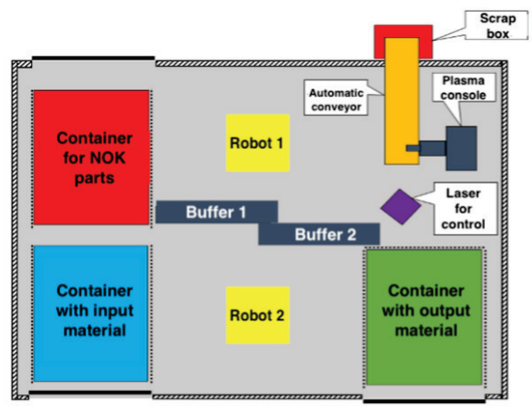

Figure 3 Location of workplaces

The objective was to cut holes at the workplace for two different projects, where each project contains one front and one rear bumper, for a total of four part types with different annual production volumes (Tab. 2).

Table 2 Production volume

Project	Name	Annual production volume (pcs)
P33C	FRT BEAM	250 000
P33C	RR BEAM	250 000
HHM	FRT BEAM	128 000
HHM	RR HS	25 000
Total		653 000

It is therefore necessary to produce a total of 653,000 bumpers in one year, which has 240 working days, which is the standard value considered by Shape Corp., including downtime, which is twice a year. The simple quotient of these two values gives the number of pieces that need to be produced in one day (Eq. (8)).

$$AV = \frac{653\ 000}{240} = 2721\ \frac{\text{pcs}}{\text{day}}. \tag{8}$$

For further calculations, it was agreed with the labour consultant that 2.5 shifts per day would be calculated rather than three, as this deducted time for machine maintenance, tool changes, container changes, emptying the scrap box, etc. The Tab. 3 shows a summary of the available time in hours and seconds required to produce the required number of pieces per shift, per day with 2.5 shifts and per year.

Table 3 Disposable time

	Number of hours (h)	Number of seconds (s)
Shift	7.5	27 000
Day	18.8	67 500
Year	4500	16 200 000

Cycle time for production of 1 piece is calculated afterwards (9). The company considers standard value of OEE 85%, it is considered in Eq. (10).

$$CT = \frac{67\ 500}{2721} = 24.81\ \text{s}, \tag{9}$$

$$CT_{100\%} = 24.8 * 0.85 = 21.09\ \text{s}. \tag{10}$$

In terms of the workplace design and solution, the following points had to be solved in terms of full automation and robotization of the workplace: number of robots, types of robots, types of effectors, removal of the part from the container, positioning of the part in the jig, cutting of holes, placement of the part in the final container, selection of active and passive elements, removal of cuttings, checking the presence of holes and workplace safety. The key points are briefly described below. Based on experience and expertise, the supplier proposed the use of two identical FANUC type M-710iC/50 handling robots due to their specific characteristics and parameters.

Due to the different activities performed by the two robots, it was proposed that each would have a different effector (Tab. 4).

Table 4 Selection of gripper

Robot Tool Concept (Effector Type and Type)		
Robot 1	Magnetic	SCHUNK GSW-M
Robot 2	Pneumatic	SCHUNK PGN+P 200-2

The variant which grips the part from the side was chosen. In this variant, the bumper (Fig. 4) is pulled upwards out of the container. When the part is taken out of the container by the first robot, it has to be moved and positioned in the alignment jig in a precise position, from which the second robot takes it and transports it to the plasma torch. Clamping the part from the side has the following advantages: fast handling, the possibility to remove all parts and no need to open the container door.

For the alignment of the parts in the handover point, the option of data holes or also RPS (reference point system) holes was chosen, which are holes on the back of the part that ensure the precise alignment of parts in jigs for example for welding, riveting and cutting. The build through the data holes is very precise and the emphasis was placed on this.

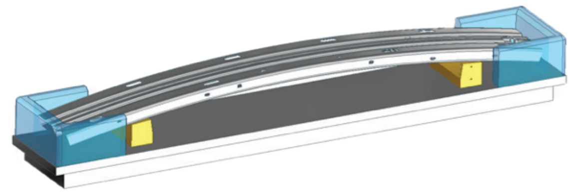

Figure 4 Bumper

To check for the presence of holes, the option of using a laser beam was chosen, which checks for the presence of holes by shining a beam on the spot and having it pass through. This is a fast and high-quality way of evaluating the presence of a hole although relatively more expensive than the other options. Another advantage is the large measurement distance and sufficient accuracy.

5 RESULTS

On the basis of specifications and consultations based on the defined items and processes in the previous chapter, a technical design of the new workplace was created by the supplier ARC-Robotics, s. r. o. Based on this information, the supplier also created a quotation for the delivery of the workstation. Several items were not included in the quotation, these are the robots that the company will use from the existing workplace, as well as the plasma source itself, the burner and the exhaust, which will also use the existing one. The quotation included additional information such as the delivery time of the workstation, which was approximately 18-22 weeks from ordering, defined payment terms, warranty, service coverage and a detailed description of the specification and design of the workstation.

Regarding the 3D design of the workplace, a simplified simulation of the workplace was received. This simulation was mainly used to test the speed of the robots, whether it is sufficient to ensure the process and the reach distances of the robots and thus determine the position of the different elements of the workplace.

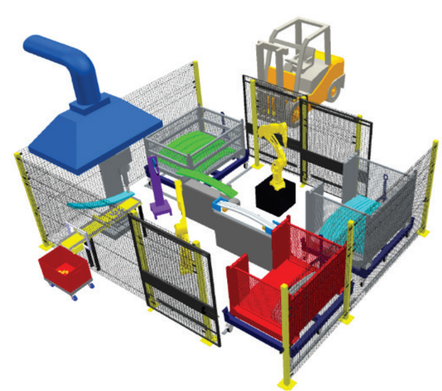

Figure 5 3D workplace design

The resulting detailed workstation design is shown in Fig. 5. The plasma process is carried out in several steps. The starting point is the supply and placement of one input material container, one empty output container and one red container (NOK parts). The actual process is as follows. The first robot drives its arm to the input material container and grabs a workpiece. It proceeds with it towards the first setting jig, into which it inserts the material. In this exact position, the second robot grabs it using a shape effector to ensure its exact position. It then proceeds to the plasma burner where the holes are cut. The part drops out of the cut-off, which is conveyed by a conveyor to the red box. The holes on the finished part are checked with a laser. The robot inserts the matching part into the second setting jig. Here, the first robot takes over again and places it in the output container.

5.1 Technical Evaluation

The technical criteria set out in the previous chapter were used to compare the new workplace with the current one. For the criteria, their importance was determined in consultation with the responsible experts from the company. Subsequently, the weights of each criterion were determined using the pairwise comparison method. Using the ordinal function method, the degree of fulfilment of the criteria for the three variants was determined by comparing the current WELD003 site with two operators (V1), with one operator (V2) and the new site (V3). A comparison of the variants against each criterion is presented below. A list of all criteria was provided in the analysis of the current situation, and the comparison is shown on one representative criteria.

Workplace area K_8. The current WELD003 occupies an area of 66.8 m^2 with a table for burr grinding included, which is the same for V1 and V2. At the same time, there is a large area where workers only walk when they go to set up a part, otherwise they must not stand there when turning the jig for safety reasons. This area is not needed in the new workplace, so V3 only occupies an area of 30 m^2. The comparison of the variants and the selection of the best one is shown in Tab. 5.

Table 5 Comparison of variants

		V1		V2		V3	
K	p_r	g_r	w_t	g_r	w_t	g_r	w_t
K_1	0.25	3	0.75	1	0.25	2	0.50
K_2	0.21	3	0.64	1	0.21	2	0.43
K_3	0.18	2	0.36	1	0.18	3	0.54
K_4	0.14	1.5	0.21	1.5	0.21	3	0.43
K_5	0.11	1	0.11	2	0.21	3	0.32
K_6	0.07	1.5	0.11	1.5	0.11	3	0.21
K_7	0.04	1	0.04	1	0.04	1	0.04
K_8	0.00	1.5	0.00	1.5	0.00	3	0.00
$\sum w_t$			**2.21**		**1.21**		**2.46**

The pairwise comparison method [21] was used to calculate p_r. It is clear from the results that the best variant according to the technical criteria is V3, which is a new workplace.

5.2 Economic Evaluation

When deciding on a manufacturing investment, it is important to make investment calculations. Various methods are used to make the calculations, including the payback period calculation required by Shape Corp. and it is therefore the focus of this evaluation.

The size of the investment is based on the quotation from the supplier, and this may be added together with other purchased items. The cost savings of the workplace is, according to the company's decision, in the form of salary cost savings as there will be no operators at the new workplace. This item is considered essential. Overheads and material costs are considered to remain the same. The annual saving is therefore calculated as the difference between the total cost of the workplace and the total cost of the workplace excluding wages.

This is followed by a calculation of the payback period of the investment in years (Eq. (11)). Monetary units in the fraction are EUR.

$$PP = \frac{115\ 709{,}64}{99\ 583{,}72} = 1.16 \text{ years.} \tag{11}$$

This is a very short payback period, which may be an important factor for the company in deciding to go ahead with it, as it has requested a payback period of up to two years.

6 DISCUSSION

Focusing on the results achieved, it is first necessary to stress the need to finalise the design of the new workplace. This requires a specific techno-economic evaluation and comparison with the existing situation. In the technical evaluation, it was found that the number of units produced for the new workplace is almost comparable to the better original version. The reduction in the number of operators is the key factor, which in turn has a key impact on cost savings. Another key aspect is the minimisation of claims by means of laser inspection for the presence of cut-out holes, which is also fast. It is also worth mentioning the reduction of the workplace area, which can be used in other ways. The economic evaluation comes out well below two years. In summary, automation can be clearly recommended.

Based on previous research and analysis in robotic systems and their integration into industrial processes, our paper has moved towards greater specificity and innovation by focusing on the integration of robotic systems into a steel cutting workstation. Our innovative integration of robots into steel cutting workstations is shown in [1] in the design of robotic assembly stations and [22, 3] in the application of industrial and collaborative robots. The study also emphasises the selection of grippers, a topic that is often discussed in robot selection [10, 11]. With this approach, we extend the theoretical and practical knowledge in robotics and present new opportunities for improving competitiveness and innovation in manufacturing processes.

In terms of the economic impact of robotization, [3, 5, 6] provide examples of the economic aspects of robotizing manufacturing processes, while [18] and [20] focus on the factors affecting the cost side of implementing industrial robots in the context of Industry 4.0. These data can support our claims about the possibilities of reducing costs and increasing efficiency in specific manufacturing sectors through the integration of robotic systems.

7 CONCLUSION

This paper presents a comprehensive approach to the design and evaluation of an automated plasma workstation. The steps to follow are detailed, including verification with a case study. The case study concludes that the integration of robotic systems into a plasma cutting workstation provides significant technical and economic benefits. The technical evaluation showed comparable production to existing methods, with the key benefits being a reduction in the need for operators and minimisation of errors due to laser control. The economic evaluation confirmed significant savings, making automation highly recommended for improving competitiveness and efficiency. To achieve these benefits, it is important to follow a systematic approach and evaluate the results afterwards, which this paper attempts to present.

Acknowledgments

This paper was created with the subsidy of the project SGS-2023-025 'Environmentally sustainable production' carried out with the support of the Internal Grant Agency of the University of West Bohemia.

8 REFERENCES

[1] Daneshjo, N., Sabadka, D., Malega, P., Dzuro, M. & Jankovič, M. (2022). Creation of More Efficient Work Environment through the New Design of the Automatic Robotic Assembly Station. *Adv. Sci. Technol. Res. J., 16*, 74-84. https://doi.org/10.12913/22998624/151547
[2] Baláž, V., Vagaš, M., Semjon, J. & Zubrzycki, J. (2014). Proposal of Multirobotic System with Two Robots. *AMM, 613*, 243-247. https://doi.org/10.4028/www.scientific.net/AMM.613.243
[3] Ulewicz, R. & Mazur, M. (2019). Economic Aspects of Robotization of Production Processes by Example of a Car Semi-trailers Manufacturer. *Manufacturing Technology, 19*, 1054-1059. https://doi.org/10.21062/ujep/417.2019/a/1213-2489/MT/19/6/1054
[4] Ingaldi, M. & Ulewicz, R. (2019). Problems with the Implementation of Industry 4.0 in Enterprises from the SME Sector. *Sustainability, 12*, 217. https://doi.org/10.3390/su12010217
[5] Guo, Q. & Su, Z. (2023). The Application of Industrial Robot and the High-Quality Development of Manufacturing Industry: From a Sustainability Perspective. *Sustainability, 15*(16), 12621. https://doi.org/10.3390/su151612621
[6] Jung, J. H. & Lim, D.-G. (2020). Industrial robots, employment growth, and labor cost: A simultaneous equation analysis. *Technological Forecasting and Social Change, 159*, 120202. https://doi.org/10.1016/j.techfore.2020.120202
[7] Eder, A., Koller, W. & Mahlberg, B. (2024). The contribution of industrial robots to labor productivity growth and economic convergence: a production frontier approach. *J Prod Anal., 61*, 157-181. https://doi.org/10.1007/s11123-023-00707-x
[8] Marschall, M., Gregor, M., Ďurica, L., Vavrík, V., Bielik, T., Grznár, P. & Mozol, Š. (2022). Defining the Number of Mobile Robotic Systems Needed for Reconfiguration of Modular Manufacturing Systems via Simulation. *Machines, 10*, 316. https://doi.org/10.3390/machines10050316
[9] Pollák, M. & Dobránsky, J. (2020). Structural Design and Material Cutting Using a Laser End Effector on a Robot Arm. TEM Journal, 9(4), 1455-1459. https://doi.org/10.18421/TEM94-17
[10] Xie, G., Holladay, R., Chin, L. & Rus, D. (2024). In-Hand Manipulation with a Simple Belted Parallel-Jaw Gripper. *IEEE Robot. Autom. Lett., 9*, 1334-1341. https://doi.org/10.1109/LRA.2023.3346750
[11] Krajčovič, M., Furmannová, B., Grznár, P., Furmann, R., Plinta, D., Svitek, R., Antoniuk, I. (2021). System of Parametric Modelling and Assessing the Production Staff Utilisation as a Basis for Aggregate Production Planning. *Applied Sciences, 11*, 9347. https://doi.org/10.3390/app11199347
[12] Vavrík, V., Gregor, M., Marschall, M., Grznár, P. & Mozol, Š. (2019). The design of manufacturing line configurations with multiagent logistics system. *Transportation Research Procedia, 40*, 1224-1230. https://doi.org/10.1016/j.trpro.2019.07.170
[13] Kováč, J., Malega, P., Rudy, V., Svetlík, J. (2023). Vumark's Method of Production Layout Designing. *Applied Sciences, 13*, 1496. https://doi.org/10.3390/app13031496
[14] Daneshjo, N., Mareš, A., Malega, P., Chlpek, S. & Baňas, T. (2023). Creating a Simulation of Assembly of a Selected Component in a Virtual Environment. *TEM Journal, 12*(1), 558-565. https://doi.org/10.18421/TEM121-66
[15] Daneshjo, N., Malega, P., Hlubeňová, J. & Štuller, P. (2022). Implementation of Simulation in the Design of Robotic Production Systems. TEM Journal, 11(1), 179-188. https://doi.org/10.18421/TEM111-22
[16] Daneshjo, N., Mareš, A., Malega, P. & Župčan, V. (2023). Proposal of Workplace Modification in the Assembly Line in Automotive Production. *Adv. Sci. Technol. Res. J., 17*, 88-100. https://doi.org/10.12913/22998624/163423
[17] Pollák, M. & Goryl, K. (2023). Simulation Design and Measurement of Welding Robot Repeatability Utilizing the Contact Measurement Method. *Machines, 11*, 734. https://doi.org/10.3390/machines11070734
[18] Zenisek, D. & Broum, T. (2020). Factors Affecting the Production Cost Function of Assembly Lines in Relation to the Level of Automation in Context of Industry 4.0. In: Soliman, K. (ed.) University of West Bohemia Pilsen, 18229-18239.
[19] Zenisek, D., Broum, T. & Simon, M. (2023). Payback Calculation Refinement of Industrial Robot Applications. *MM SJ*, 2023. https://doi.org/10.17973/MMSJ.2023_10_2023077
[20] LEAN SYSTEMS: applications and case studies in manufacturing, service. ROUTLEDGE, S.l. (2021)
[21] Kułakowski, K. (2020). *Understanding the analytic hierarchy process*. CRC Press, Boca Raton, FL https://doi.org/10.1201/9781315392226
[22] Kováč, J., Jenčík, R., Andrejko, P., Hajduk, M., Pilat, Z., Tomči, P., Varga, J. & Bezák, M. (2020). Integrated Palletizing Workstation with an Industrial Robot and a Cobot. In: Berns, K. & Görges, D. (eds.) *Advances in Service and Industrial Robotics*. Springer International Publishing, Cham, 202-209. https://doi.org/10.1007/978-3-030-19648-6_24

Authors' contacts:

Ing. **Jakub Müller**
(Corresponding author)
Department of Industrial Engineering and Management,
University of West Bohemia,
Univerzitní 22, 301 00 Pilsen, Czech Republic, Europe
+420 377 638 456, mullerja@fst.zcu.cz

Grupo Integrado de Ingeniería, Universidade da Coruña,
Campus de Esteiro, 15403, Ferrol, Spain, Europe
jakub.muller@udc.es

Ing. **Tomáš Broum**, PhD
Department of Industrial Engineering and Management,
University of West Bohemia,
Univerzitní 22, 301 00 Pilsen, Czech Republic, Europe
+420 377 638 431, broum@fst.zcu.cz

Ing. **Miroslav Malaga**, PhD
Department of Industrial Engineering and Management,
University of West Bohemia,
Univerzitní 22, 301 00 Pilsen, Czech Republic, Europe
+420 377 638 457, malaga@fst.zcu.cz

Ing. **Monika Milatová**
Shape Corp.,
Havířská 1388, 330 23, Nýřany, Czech Republic, Europe
+420 770 114 330, milatovam@shapecorp.com