science, engineering and health studies

Research Article

Science, Engineering and Health Studies
https://li01.tci-thaijo.org/index.php/sehs
ISSN (Online): 2630-0087

Simulation of a welding station with RobotStudio

Predee Pasang, Peerawut Kerdsomya, Jarut Kunanoppadol, Vichuda Mettanant, and Thosapon Katejanekarn*

Faculty of Engineering and Industrial Technology, Silpakorn University, Nakhon Pathom 73000, Thailand

***Corresponding author**:*
Jarut Kunanoppadol
kunanoppadol_j@su.ac.th

***Received**: 21 March 2024*
***Revised**: 29 May 2024*
***Accepted**: 18 June 2024*
***Published**: 29 December 2024*

***Citation**:*
Pasang, P., Kerdsomya, P., Kunanoppadol, J., Mettanant, V., and Katejanekarn, T. (2024). Simulation of a welding station with RobotStudio. Science, Engineering and Health Studies, 18, 24040010.

ABSTRACT

Industrial robotic arms are key factors for smart manufacturing in the Industry 4.0 era. Technical and financial information are essential to robotic welding investment decisions, but the literature on analytical processes is lacking. This research proposes the use of the ECRS framework in enhancing welding processes, simulating workstations with RobotStudio, comparing productivity, and evaluating financial feasibility. The framework was applied to the manufacturing of off-road front bumpers. Results show that robotic welding reduces working time by 82.3%, increases productivity 5.64-fold, and reduces operational costs by 94.67%. The simple payback period is 4.65 years, and the discounted payback period is 5.73–5.84 years, depending on investing capital. Change in welder wage has the largest effect on the net present value and internal rate of return of the project, whereas change in electricity cost has the least effect.

Keywords: ABB RobotStudio; ECRS; industrial robotic arm; welding station

1. INTRODUCTION

The fourth industrial revolution (Industry 4.0 or I4.0) originated in 2011, and the Internet age is its major milestone (Leng et al., 2022; Maddikunta et al., 2022; Xu, et al., 2021). The I4.0 is a technology-driven revolution featured with a high level of automation and information communication technologies that enhance efficiency, flexibility, and productivity (Huang et al., 2022). Leyh et al. (2017) defined the I4.0 as “the intelligent flow of the workpieces machine-by-machine in a factory on a real-time communication between machines” (Alcácer and Cruz-Machado, 2019).

An industrial robotic arm (robot) is the main element of an autonomous cyber–physical system, which is one of the key factors under the umbrella of the I4.0 (Alcácer and Cruz-Machado, 2019; Flores et al., 2020; Jena et al., 2019). Since the creation of the first robot in the 1960s, industrial robotic technology has quickly advanced. In manufacturing processes, robots can reduce costs, increase productivity, enhance product quality, and ensure the safety of workers performing hazardous tasks (Li and Liu, 2019). Owing to the decreasing prices of robots and their increasing benefits, they have been extensively used in a wide range of applications in the manufacturing industry (Patsavellas and Salonitis, 2019). In the early stage of industrial robot development, robots had been used only for simple tasks, such as picking and placing, performing monotonous, dangerous, heavy, and repetitive tasks previously undertaken by humans. Current robots have external sensing capabilities for complex motions. Thus, the tasks of robots for welding, grinding, deburring, and assembling have become increasingly complex, and current robots can respond to the complexity of users’ requirements (Stuja et al., 2021). The current applications of industrial robots are generally categorized into material handling, process activities, and assembly (Wallén, 2008).

Robot programming methods are typically categorized into two types: online and offline programming (Holubek et al., 2014). Online programming is used when a robot is required to generate a program. An operator uses a pendent or teach pendant, which is a hand-held unit linked to a control system, to move and program the robot (ISO, 2011). Offline programming is used when a robot is not needed in the development of a control program at least until the final test of the program. Offline programming minimizes production downtime, and programming processes can be conducted in parallel and in series with production processes (Holubek et al., 2014). A robot is programmed and simulated through computer software, for example, RobotStudio from ABB, RT Toolbox from Mitsubishi, Simpro from KUKA, and Roboguide from Fanuc (Maiolino et al., 2017; Mocan and Fulea, 2011).

ABB RobotStudio is a text-based robot programming language for creating robot cells, programming robots, and simulating workstations (Holubek et al., 2014). It was developed using C#, which is a programming language customized by Microsoft for the Visual Studio.net framework (Wu et al., 2021). The first version of RobotStudio was published in 1998. It is a powerful offline robot programming and simulation tool and can be downloaded directly to a robot's controller without a translation step (Connolly, 2009). It can be used in designing basic and complicated robotic workstations (Ivan et al., 2010), for example, welding (Cohal, 2017; Shen, 2020), palletizing, packaging, and spraying. In addition, it can be utilized for in-depth analysis particularly of the location and speed of axes and tools, energy consumption, and kinetics (Fu et al., 2019; Kiwała et al., 2016; Qin, 2022).

Lean production is a multidimensional approach involving various management practices, such as just-in-time and quality systems, work teams, cellular manufacturing, and supplier management (Shah and Ward, 2003). This manufacturing approach has been integrated with industrial robotics to improve the use of industrial robots. Manufacturing time reduction and efficiency gains have been demonstrated in the literature (Hedelind and Jackson, 2011; Varodhomwathana and Subsomboon, 2014; Supsomboon and Varodhomwathana, 2017; Quenehen et al., 2021; Sordan et al., 2022).

The eliminate, combine, rearrange, and simplify (ECRS) concept is one of the lean manufacturing techniques for decreasing waste and improving production (Noamna et al., 2022). It can be used with other techniques, such as Six Sigma, to standardize work, ensure overall equipment effectiveness, reduce waste, and boost organizational productivity (Gamboa and Singgih, 2021; Junior et al., 2022). In addition, it can be applied to manufacturing and services, such as automotive component manufacturing (Rekha et al., 2016; Shan et al., 2018) and healthcare services (Phongthiya et al., 2021). However, the literature on the integration of the ECRS framework and RobotStudio tools is limited. Hence, the research question is how these tools can be complementarily used to enhance the manufacturing process.

This research aims to apply the ECRS framework to enhance the welding process, simulate a welding workstation with RobotStudio, compare productivity, and evaluate financial feasibility. Data on manual welding are used in the ECRS framework for the reorganization of the manufacturing process for off-road style front bumpers. The optimized process is created for the robotic welding workstation simulated using RobotStudio, and the outcomes of manual and robotic welding are compared.

2. MATERIALS AND METHODS

A welding station for front bumpers was used because it requires a considerable amount of welding work and Thai companies can produce and sell front bumpers to domestic and international markets. Figure 1 shows the off-road style front bumper for Toyota Hilux Vigo. Secondary data on welding procedures used by welders were used. Table 1 lists the average welding time per piece and productivity per day of manual welding in a factory in January 2022. The workflow requires one welder to install product parts on the welding jig fixture. Given that the jig cannot be rotated, a welder has to work in several positions, including flat (1F), horizontal (2F), and vertical (3F). Moreover, several cylinder parts of a bumper are welded by a worker in horizontally fixed pipe (5F) position. The welding time is 47 min, excluding the installation of the part into the welding jig fixture. In the station created in RobotStudio, the welding sequence and speed were the same as those used in manual welding.

The ECRS concept was implemented as follows. Eliminate (E): All manual welding procedures were eliminated and replaced with robot welding procedures. However, the station needed an operator to install components on a jig fixture and remove a product from the fixture upon the completion of the welding processes. Combine (C): The welding flow was continuous. A welder needs to stop welding when changing posture, whereas a robot could weld a workpiece continuously. Thus, robotic welding is continuous and more consistent and accurate than manual welding. Rearrange (R): The equipment in the welding cell of the station was rearranged, and the welding station used a fixed jig fixture. A welder had to work in difficult postures at several positions. A moveable positioner was added to the robotic welding station synchronization with the welding robot. The welding robot can work in its normal position, minimizing energy consumption. Simplify (S): Manual welding procedures are subject to uncertainty caused by human errors due to fatigue. Therefore, robotic welding simplified the welding path and speed into a routine. The robot was programmed to repeat the sequences of the defined tasks.

The front bumper model and jig fixture were generated in SolidWorks (Figure 2) and imported into RobotStudio. The workstation in RobotStudio consisted of an IRB 1660ID 6 kg welding robot and IRBP L2500 mm positioner (Figure 3). According to the data from the factory, the welding speed was set at 20 mm/s. The free-moving velocity was set at 80 mm/s, and the positioner velocity was set at 20 mm/s (Ivan et al., 2010). Data analysis included a comparison of welding time, calculation of productivity, estimation of running expenses, and evaluation of the investment's feasibility.

Figure 1. Off-road style front bumper

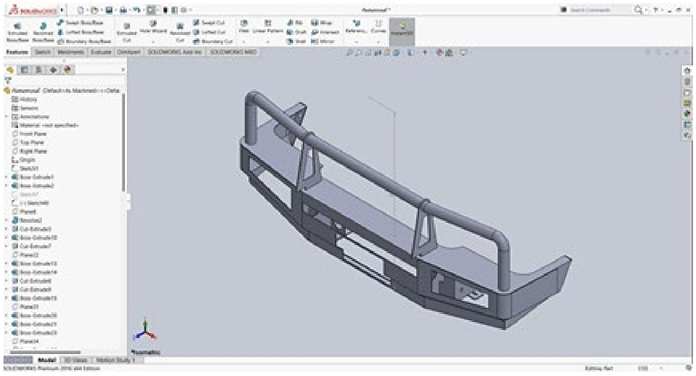


Figure 2. 3D model of the off-road style front bumper

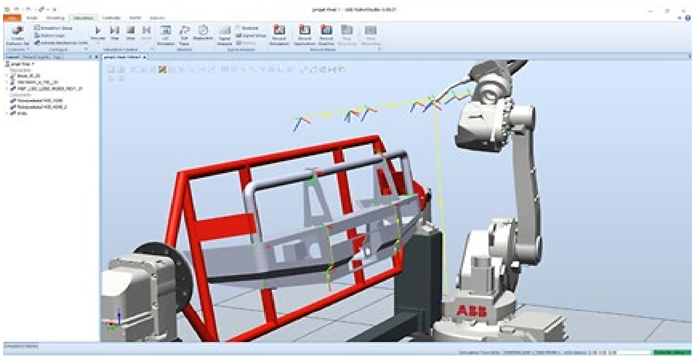


Figure 3. Welding Station in ABB RobotStudio

3. RESULTS AND DISCUSSION

Table 1 compares manual and robotic welding. Manual welding requires 2820 s (47 min) per piece, whereas robotic welding requires 500 s (8 min and 20 s), reducing welding time by 82.27%. In a daily work period of 8 h, human welding can produce 10.21 pieces, whereas robotic welding can produce 57.60 pieces, which is 5.64 times as high. At the same production volume, both welding techniques were investigated on the assumption that the product is in high demand on the market; that is, all manufactured products can be sold; therefore, a factory requires 5.64 welders to produce the same production rate as that of a single robot. According to the data provided by the factory, the welder's wage is 500 Thai Baht (THB) per day, and the number of working days is 240 days per year, resulting in an annual operating cost for human welding of 676,800.00 THB per year. The operational cost of robot welding consists of three parts: (1) electrical consumption of the robot, (2) welder who can work with the robot, and (3) depreciation. The power consumption of the equipment was calculated according to its technical specifications. The main equipment including an IRB 1660ID welding robot (0.62 kW), IRC5 controller (0.2 kW), and IRBP positioner (2.0 kW) consumes a total power of 2.82 kW. The price of electricity per kilowatt-hour is 4 THB. The operational cost of a robot welder per day is approximately 800 THB, and the depreciation expense is approximately 10% of the total investment of a robot station, that is, 180,686.57 THB per year. The operating cost of robotic welding is 394,344.17 THB per year, reducing annual operating expenses by 282,455.83 THB per year.

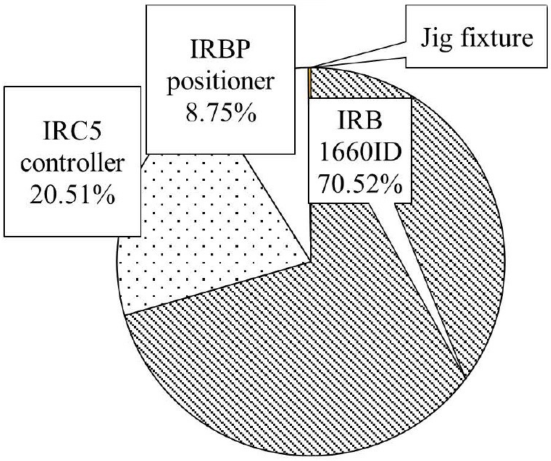
Table 1. Comparison between human and robot welding

Description	Unit	Human welding (Based case)	Robot welding	Remark
Productivity comparison				
Cycle time	s/piece	2,820	500	↓ 82.27%
Working time	h/day	8.00	8.00	
Productivity	piece/day	10.21	57.60	↑ 5.64 Time
Operational details				
Worker	person	5.64[a]	1[b]	
Wage	THB/day	500	800	
Power consumption	kW		2.82	
Electricity price	THB/kWh		4.00	
Working time	h/ day		8.00	
Working day	day/year	240	240	
Depericiations[c]	THB/ year		180,686.57	
Operational cost	THB/ year	676,800.00	394,344.17	↓ 282,455.83 THB
Cost of the robot welding system				
IRB 1660ID robot	THB		1,274,254.30	
IRC5 controller	THB		370,596.36	
IRBP positioner	THB		158,175.00	
Jig fixture	THB		3,840.00	
Total cost of investment	THB		1,806,865.66	
Feasibility analysis				
Simple payback period (SPB)	year		6.40	
Discount rate				
1) Inflation rate			6.20%	
2) MRR			6.73%	
Discounted payback period (DPB)				
1) Inflation rate	year		8.41	
2) MRR	year		8.65	
Net present value (NPV)				
1) Inflation rate	THB		237,736.69	
2) MRR	THB		189,248.03	
Internal rate of return (IRR)			9.07%	

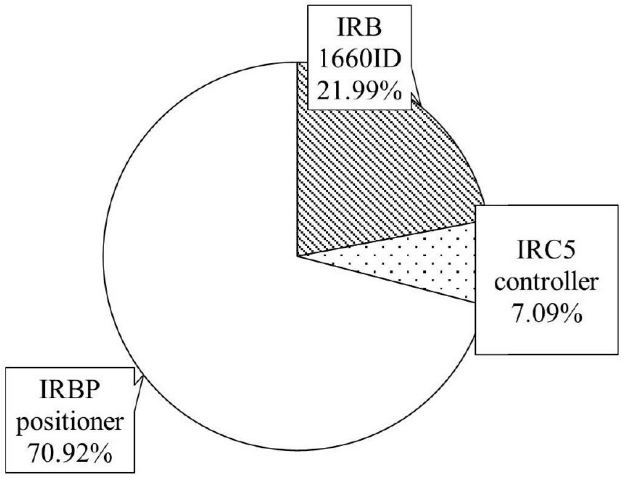
Remark: [a] General welder, [b] Robot welder, [c] Depreciation 10% of total investment

The main equipment cost based on the prices published in portal websites is divided as follows: IRB 1660ID welding robot (1,274,254.30 THB), IRC5 controller (370,596.36 THB), and IRBP positioner (158,175.00 THB). The jig fixture cost is estimated according to its drawing and local steel prices (3,840.00 THB). The entire cost of the investment is 1,806,865.66 THB. Figure 4 illustrates the percentage distribution of the main equipment cost of the robotic welding station and the percentage distribution of the power consumption of the main equipment. Initial investment of 1,806,865.66 THB and saved operating cost of 282,455.83 THB per year produce a simple payback period of 6.40 years. In addition, the discounted payback period is assessed in two different scenarios. The first scenario is the investment with factory capital using an inflation rate of 6.20% in 2022 as the discount rate, resulting in a discounted payback period (DPB_{FC}) of 8.41 years. The second scenario is the investment with a bank loan using the minimum retail rate (MRR) of 6.73% as the discount rate, resulting in a discounted payback period (DPB_{BL}) of 8.65 years. These payback periods are longer than the I4.0 investment (2–3 years) in the literature (Connolly, 2009; Jena et al., 2019).

This research estimates the 10-year project by setting the initial investment cost of 1,806,865.66 THB at year 0 and setting the benefit of operational expense saving of 282,455.83 THB per year. The feasibility analysis uses two discount rates: (1) the inflation rate for the factory capital scenario is 6.2% and (2) the MMR for the bank loan scenario is 6.73%. The analysis reveals the net present value of the factory capital scenario (NPV_{FC}) of 237,736.693 THB, net present value of the bank loan scenario (NPV_{BL}) of 189,248.03 THB, and internal rate of return (IRR) of 9.07%. The sensibility analysis investigates four factors: discount rate, welder wage, electricity, and equipment cost. Figure 5 shows trendlines from the sensibility analysis of these factors. From the sensitivity analysis, the welder wage and equipment cost show considerable effects on the NPVs and IRR of the project, whereas the electricity cost and discount rate show minor effects. Table 2 reports the percentage change in NPVs and IRR from the sensibility analysis. The wage presents the largest effect on the NPVs and IRR of the project. Increasing the welder wage by 1% results in a 14% and 17% increase in NPVs for the factory capital and bank loan scenario, respectively.

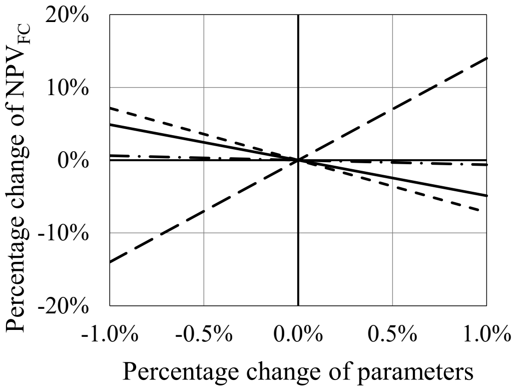


(a) Main equipment cost

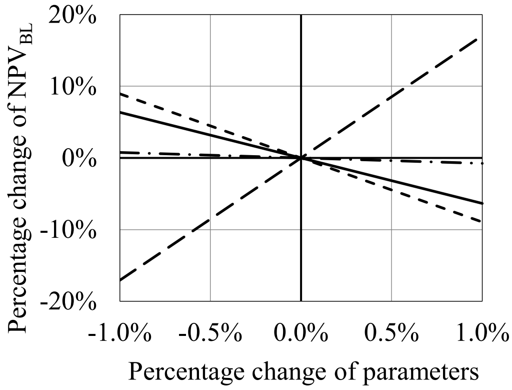


(b) Power consumption

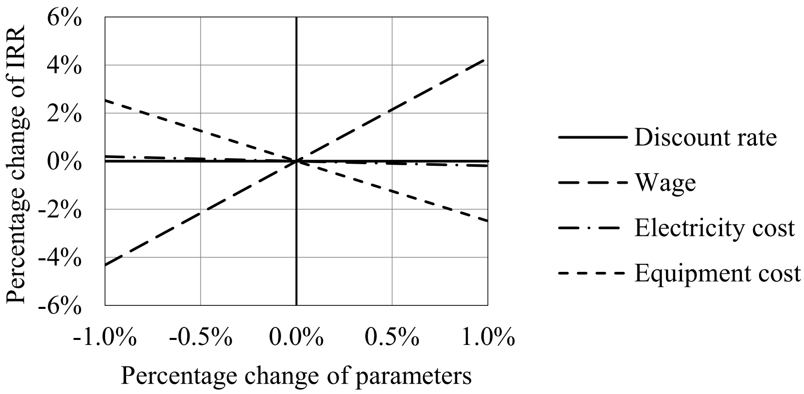
Figure 4. Main equipment cost and power consumption



(a) NPV$_{FC}$



(b) NPV$_{BL}$



(c) IRR

Figure 5. Sensibility analysis

Table 2. Changes in NPV and IRR due to the variation of the discount rate, welder wage, electricity cost, and equipment cost

Parameter		Parameter variation					
		Change of NPV_{FC}		Change of NPV_{BL}		Change of IRR	
		-1%	+1%	-1%	+1%	-1%	+1%
1	Discount rate	4.80%	-4.88%	6.36%	-6.35%	-	-
2	Wage	-14.00%	14.00%	-17.07%	17.07%	-4.32%	4.29%
3	Electricity cost	0.63%	-0.63%	0.76%	-0.76%	0.19%	-0.19%
4	Equipment cost	7.16%	-7.16%	8.95%	-8.95%	2.53%	-2.49%

This research demonstrates the advantages of employing ECRS concepts in enhancing welding processes, simulating the operation via RobotStudio and analyzing the data derived through the experimental method. To the best of our knowledge, no study has extensively explored the integration of the ECRS framework and RobotStudio tools for welding applications. The findings show that robot welding reduces manufacturing time by 82.27% and reduces annual operating expenses by 282,455.83 THB per year. Financial feasibility analysis demonstrates that the payback periods of the investments are between 6.40 and 8.65 years, which are significantly longer than the periods recommended by Connolly (2009) (2 years) and Adegbola et al. (2019) (4.8 years). The welding process with an industrial robotic arm synchronized with a moveable positioner performs is considerably better than current manual welding in terms of productivity and operational cost. Managers can use the investment feasibility analysis results for decision-making or comprehensive engineering economic analysis of industrial robotic arms.

This research contributes to the automation field from three aspects. First, this research combines the ECRS framework and RobotStudio as tools for designing a robotic station. The research utilizes the framework to improve the welding station and simulate the designed station with RobotStudio. The simulated results can facilitate the evaluation of productivity, energy consumption, and financial feasibility. Further study could focus on optimizing robotic programming according to dynamic parameters and energy consumption or even using multiple robots for welding stations (Gadaleta et al., 2019; Wang and Liu, 2019). Second, it demonstrates a system integrator's task and considers customers' requirements in designing a robot station to provide comprehensive information for managerial decision-making (KUKA, 2015; Stuja et al., 2021). Further study could include virtual and augmented reality technologies in design, communication, and demonstration processes to improve users' or customers' experience (Holubek et al., 2018; Vigier, 2022). Third, the offline programming of a robot station belongs to the simulation element, which is only one of the elements under the large umbrella of the I4.0. This current industrial revolution requires the complementarity between a robotic piece and other pieces, for instance, the Industrial Internet of Things, cloud computing, big data, cognitive computing, and cyber security; this complementarity has emerged as large puzzle in the development of sustainable manufacturing model (Alcácer and Cruz-Machado, 2019; Jena et al., 2019).

This research has three limitations that could be addressed in a future study. The first is that only one product sample from a single factory was utilized for the research because of the COVID-19 pandemic. Factory visit was limited to a short period, and the welding area was observed remotely; hence, some processes were not recorded. A future study should examine additional sample items or use a robot to manufacture several products to obtain more accurate data. Moreover, the whole process should be recorded and reported using a flow chart (e.g., value stream mapping) to show a bottleneck or non-value-added time, which could be improved with the ECRS framework. The second limitation is the cost of the primary equipment excluding the cost of accessories. The estimated cost was based on the prices listed on websites, and the installation and maintenance costs were not included. Therefore, the exact prices should be obtained from actual vendors, and additional costs should be considered in determining feasibility. Finally, the economic study in this research considered initial investing and operational expenses but did not cover the total cost of ownership throughout a system's entire life cycle, which can be 20–200 times the initial investment (Landscheidt and Kans, 2016; Seif and Rabbani, 2014). Further study, could cover the total cost of ownership; moreover, business requirements or strategic direction should be evaluated in terms of their alignment to investments for autonomous manufacturing.

4. CONCLUSION

Automation, productivity, and employment are complicated issues, and the introduction of robots into a factory could not resolve all these issues (Wallén, 2008). In a cyber–physical system, the relationships between robots and labor should be comprehensively explored. To achieve high productivity from automated production lines, technical equipment and operating personnel are both important (Vidal and Ogorodnikova, 2021). In the I4.0 era, operators should work collaboratively and enhance their skill in operating technological equipment; otherwise, they can be replaced by new technologies in the wave of rapid disruption. Operator 4.0 is regarded as skillful and clever for integrating with technology (Flores et al., 2020). Education 4.0 is necessary for training personnel to improve their competencies and soft skills (Maisiri et al., 2019).

ACKNOWLEDGMENTS

The authors would like to thank the Department of Mechanical Engineering, Faculty of Engineering and Industrial Technology, Silpakorn University, Thailand, for supporting this research.

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