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The Effect of Robotic Automation Systems on the Production Process Includes Cost Efficiency, Time, and Product Quality of Lid Assy Cargo, Board Seat Back, & Board Assy Deck at Pt Xyz, Using the Statistical Data Approach Method

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ABSTRACT: The object of this research is the glue application process on the production line of PT. XYZ, which initially used a manual spray glue method before transitioning to a robotic glue dispensing system. This study aims to comprehensively assess the impact of robotic automation on production cycle time efficiency, product defect rates, and operational costs. A comparative quantitative methodology was employed, utilizing descriptive and inferential statistical analyses, including paired t-tests, to determine the significance of performance differences between the manual and robotic processes. Data were collected through time studies on 20 sampled units and quality inspections of 5,000 monthly production units. The results demonstrate that the robotic system reduced the average production cycle time from 37.5 seconds to 23.1 seconds per unit, improving efficiency by 38.4%. The product defect rate significantly decreased from 5.0% to 1.2%, reflecting a 76% improvement in product quality. Annual operational savings amounted to Rp137,000,000 due to reduced labor requirements, decreased material waste, and lowered quality-related expenses. The Return on Investment (ROI) reached 68.5% annually, with a payback period of less than 1.5 years, indicating strong financial feasibility. Overall, the findings confirm that automating the glue application process using a robotic system at PT. XYZ significantly enhances process consistency, product quality, and operational cost sustainability. This automation initiative is recommended as a strategic approach for manufacturing companies aiming to improve productivity and maintain long-term competitiveness.

KEYWORDS: Automation, Robotic Glue, Production Efficiency, Product Quality, Statistical Analysis, ROI, PT. XYZ.

INTRODUCTION

The dynamics of the global market demand that the manufacturing industry continuously innovate to achieve lean manufacturing and meet international quality standards. One critical area that requires improvement is the assembly process, which still relies on manual labor. The Production Process of a Product at PT. XYZ, which initially still used the manual glue application method (manual spray glue), has several fundamental weaknesses, including: (1) Inconsistent Quality, caused by operator fatigue, variations in spray pressure, and application angle; (2) Long Cycle Time, because the application speed depends on the individual work rhythm; and (3) High Operational Costs, related to overtime wages, rework of defective products, and material wastage.

Based on that, PT. XYZ decided to invest in transitioning to automation technology, specifically using robots for glue application, offering a potential solution. The robots are designed to work with high precision, consistency, and repeatability. By switching to a robotic automation system, PT. XYZ can achieve significant efficiency improvements in terms of work cycle time, reduction in defect rates due to MP inconsistency, as well as operational cost savings. This study aims to provide empirical and quantitative evidence regarding the effectiveness of implementing robotic glue as a strategic solution to address issues of cost efficiency, time, and production quality. The results of this study are expected to serve as a credible investment guide for manufacturing management in making automation decisions..

Mapping Flow Process Manual (Flow Process Manual Assy Cargo, Flow Process Manual Assy B.Seat, and Flow Process Manual Assy B.Deck) before automation.

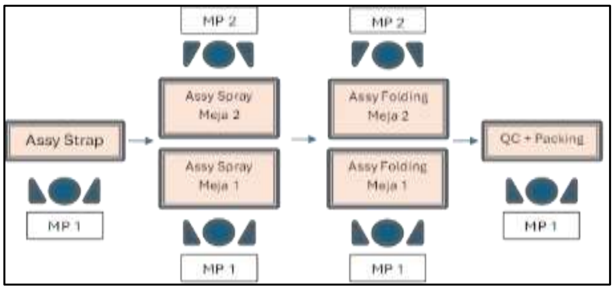


Figure 1 mapping Line Lid Assy Cargo before automation

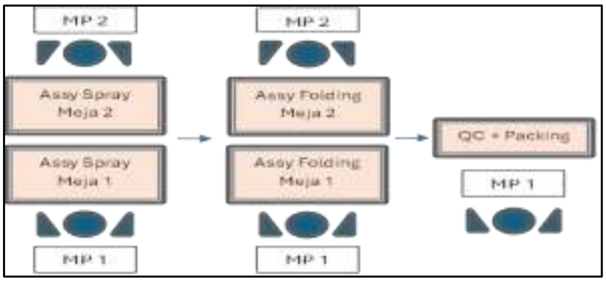


Figure 2 mapping Line Board Seat back before automation

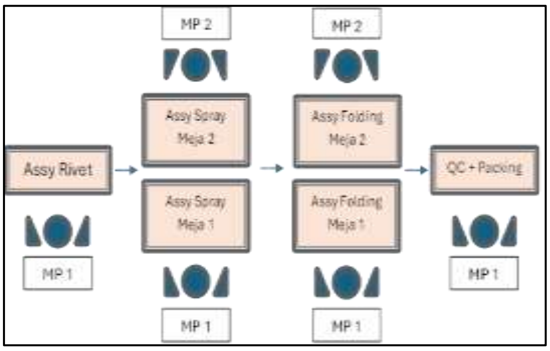


Figure 3 mapping Line Board Assy Deck before automation

In the mapping of the Lid Assy Cargo product Line (figure 1), the Board Seat Back Line (figure 2), and the Board Assy Deck Line (figure 3) before automation, the total manpower quantity for these three lines was 17 people, plotted from the beginning to the end of the process. This is one of the indicators that will later be used in setting efficiency targets. When automation using robotic gluing processes is implemented, it will improve efficiency by reducing the assembly spray manpower, where in these three lines, 6 people can be replaced by 1 gluing robot unit (spray robotic process). Besides manpower efficiency, this automation also aims to reduce the reject ratio, which is usually caused by variations in the spray glue process performed by manpower.

Robotic Flow Process Mapping (Combining 3 Manual Process Lines into one (Assy Cargo, Assy B.Saet, Assy B.Deck))

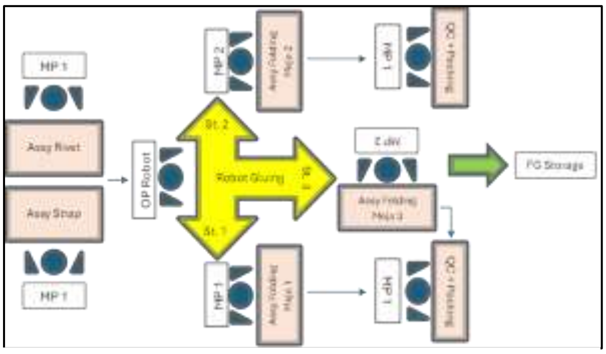


Figure 4 mapping Line Lid Assy Cargo, Line Board seat Back ,Line Board Assy Deck after automation (made in one line process)

By implementing automation through investment in robotics, the company can achieve savings, as reflected in the process flow mapping in (figure 4), which initially had three production lines with a total of 17 personnel, can be reduced to one production line with a total of 8 personnel, and the use of gluing robots reduces the defect ratio that is usually caused by process variations by manpower.

LITERATURE REVIEW

Industrial automation has become a key strategy in improving efficiency, process consistency, and the competitiveness of modern manufacturing. Groover (2019) emphasizes that the implementation of automation systems allows production processes to operate with high precision and lower variability compared to manual processes, particularly in repetitive operations such as adhesive applications. The impact of automation on improving assembly line performance is also demonstrated by Hernández and Gómez (2018), who show that automated systems can significantly reduce cycle time and increase throughput compared to conventional methods. These findings confirm that automation plays a crucial role in achieving lean manufacturing and production process stability.

From a product quality perspective, statistical approaches play a crucial role in evaluating the effectiveness of process improvements. Montgomery (2020) emphasizes the importance of statistics-based quality control to identify and reduce process variation. In line with this, Ahmed and Patel (2020) demonstrate that applying comparative statistical analysis before and after process improvements can reveal significant enhancements in adhesive product quality. This approach provides a strong methodological foundation for objectively and quantitatively assessing the impact of automation.

Research specifically discussing robotic glue dispensing shows substantial technical benefits. Kim and Lee (2018) reported that using a robotic system in the adhesive dispensing process in the electronics industry can significantly reduce scrap rates through more precise control of application volume and patterns. Zhao, Li, and Chen (2020) also found that the accuracy of robotic dispensing directly contributes to the consistency of adhesive volume, which positively impacts the quality of the final product. Furthermore, Fernandez, Garcia, and Diaz (2021) emphasized the importance of robotic nozzle calibration to maintain uniform spray patterns, while Oliveira and Santos (2020) demonstrated that robotic precision can significantly reduce adhesive consumption, thereby improving material efficiency.

The development of supporting technology also strengthens the effectiveness of robotic automation systems. Li and Wang (2022) revealed that the integration of machine vision in the glue dispensing process allows for real-time defect detection, thereby enhancing the reliability and quality of the process. In addition, Park, Kim, and Kang (2020) highlighted the role of the Internet of Things (IoT) in continuously monitoring robot performance to maintain manufacturing process stability. The integration of this technology expands the role of robotics not only as a tool automation, but also as part of an intelligent manufacturing system.

From an economic and managerial perspective, investment feasibility is a key factor in automation adoption. Rahman, Islam, and Hasan (2019) show that robotic investment in the medium-scale manufacturing industry provides attractive returns when analyzed using a cost-benefit analysis approach. These findings are reinforced by Sharma and Kulkarni (2021), who found that the implementation of robots on repetitive production lines consistently results in operational cost savings. Local studies by Suryanto, Wijaya, and Purnomo (2021) also confirm that the adoption of robotic technology in the Indonesian automotive industry contributes to improving the efficiency and competitiveness of national manufacturing.

In addition to technical and financial aspects, automation also has an impact on the workforce structure and work safety. Müller and Schmidt (2017) emphasize that automation is changing the competency needs of the workforce, requiring retraining programs and improving technical skills. In terms of ergonomics, Tanaka, Ito, and Sato (2019) show that the automation of repetitive tasks is able to reduce the risk of work injuries and improve operator safety. The study of robotic design by Alfred et al. (2025) and the research of Anggita et al. (2025) also strengthen the evidence that a well-designed robotic system is able to improve process efficiency while maintaining work quality and safety.

Based on the literature review, it can be concluded that the application of robotic glue dispensing is a strategic solution in improving cycle time efficiency, product quality, and operational cost efficiency. However, most previous research still focused on technical or financial aspects separately. Therefore, this study seeks to fill this gap by presenting a comprehensive evaluation that integrates statistical analysis of production performance, quality, labor reduction, and investment feasibility in one actual case study in the manufacturing industry.

RESEARCH METHODOLOGY

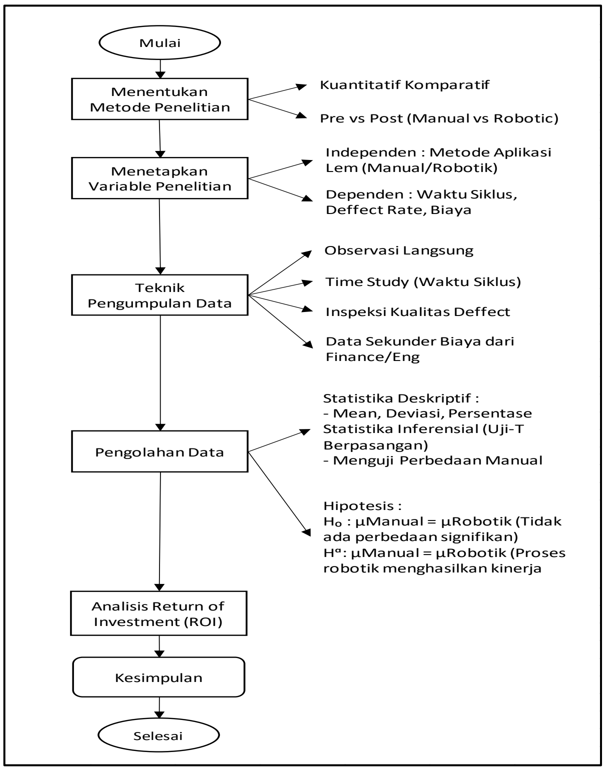


Figure 5. Research Flow Diagram

RESEARCH METHODS

This study uses a comparative quantitative approach with a before–after study design, which aims to compare the performance of the production process before and after the implementation of the robotic glue dispensing automation system. This approach was chosen because it is able to objectively measure changes in process performance based on measurable and economically relevant numerical indicators.

The object of the research is the glue application process on the Lid Assy Cargo, Board Seat Back, and Board Assy Deck production lines at PT. XYZ. The research is conducted on an actual production line with normal operational conditions to ensure the external validity of the research results.

Research Variables

• Independent Variable: Glue application method
• Manual Spray Glue
• Robotic Glue Dispensing
• Dependent variables:
1. Production cycle time (sec/unit)
2. Product defect rate (%)
3. Production operational costs (Rp/year)

Population and Sample and Data Collection Techniques

The research population includes all production output in the three related lines. The research sample is determined as follows:

• Production cycle time: 20 paired sample units for each condition (manual and robotic).

• Product quality: 5,000 units of monthly inspection results before and after automation.

The number of cycle time samples is established in reference to the general practice of manufacturing industry studies and is considered adequate for parametric statistical tests with a significance level of 5%.

Data Collection Techniques :

• Direct observation and time study to measure the production cycle time.

• Quality inspection data from the Quality Control department.

• Cost data obtained from the Engineering and Finance departments, including the cost of labor, materials, quality, and robotics investment.

Statistical Data Analysis Methods

Descriptive Statistical Analysis & Production Cycle Time

Descriptive analysis was used to calculate the mean value, standard deviation, and percentage change in each study variable.

Table 1. Descriptive Statistics

Metode	Mean (detik)	Std. Deviasi	n
Manual	37,5	3,2	20
Robotik	23,1	1,4	20

Table 2. Production Cycle Time Data (20 Units Sample)

Unit Ke -	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Rata-rata	STD Dev
Waktu Siklus Manual (detik)	35	38	36	40	34	37	39	35	41	38	36	39	42	37	35	38	40	36	39	37	37,6	2,19
Waktu Siklus Robotic (detik)	22	25	23	24	21	25	23	22	24	23	21	25	23	22	24	21	25	22	24	23	23,1	1,37

Statistical Assumption Test

Before the hypothesis test was carried out, the cycle time data was tested for normality using the Shapiro–Wilk Test. The data is declared to be normally distributed if the p value > 0.05.

Paired Sample T-Test

The paired t-test is used to test the significant differences between manual and robotic processes with the following hypothesis:

• H_0: μManual = μRobotics (no significant difference)

• H_1: μManual $\neq$ μRobotics (there are significant differences)

The significance level used was $\alpha = 0.05$.

In addition to the p-value, the power of influence was analyzed using Cohen's d to assess the practical significance of automation.

Table 3. Paired Sample t-Test Test Results

Parameter	Nilai
t-hitung	12,84
df	19
p-value	< 0,001
Cohen's d	2,87 (large effect)

Return on Investment (ROI) Calculation Method

Return on Investment is calculated using the equation:

ROI = (Total Annual Net Benefit / Total Initial Investment) × 100%

The total annual net benefit consists of:

• Labor cost savings

• Saving adhesive materials

• Reduced quality costs (scrap and rework)

Payback Period is calculated to determine the payback time of the investment:

Payback Period = Total Initial Investment / Total Annual Net Benefit

Table 4. ROI & Payback Paid Calculation Formula

Parameter	*Rumus*	*Keterangan*
ROI	$ROI = \dfrac{\text{Total Penghematan Tahunan}}{\text{Biaya Investasi Robotic}} \times 100\%$	-
Payback Period	$Payback = \dfrac{\text{Biaya Investasi}}{\text{Penghematan Tahunan}}$	*Tahun*

Table 5. Financial Analysis of Robotic Automation

Komponen	*Nilai (Rp)*
Investasi Awal	*200.000.000*
Penghematan Tahunan	*137.000.000*
ROI	*68,50%*
Payback Period	*1,46 tahun*

Total Annual Net Benefit is calculated from:

Labor Cost Saving + Material Saving + Quality Cost Savings.

Results and Discussion

1. Analysis of Production Cycle Time Differences (Dependent Variables)

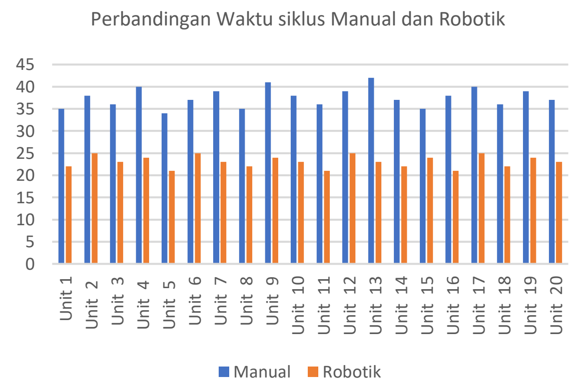
Table 6. Production Cycle Time Data (Variable

Parameter	Manual Spray Glue (Before)	Robotic Gloe (After)	Perubahan
Rata -rata Waktu Siklus	37,5 detik/unit	23,1 detik/unit	↓38,4% lebih cepat
Standar Deviasi	2,19	1,37	Variasi proses turun

Based on the raw data, there was a significant decrease in average cycle time.

Paired T-Test (Assumption of Results)

The results of the paired t-test showed a p value of < 0.05. Thus, H_0 is rejected, which means that there is a significant difference between the manual and robotic process cycle times. The robotic process is statistically much faster and more consistent (lower Standard Deviation), in line with the principle of automation.



Graph Interpretation: The bar graph shows a clear difference in the average cycle time. Shorter error bars on robotic processes indicate much lower process consistency and variation, confirming improved process capabilities.

Production Quality Analysis (Defect Level)

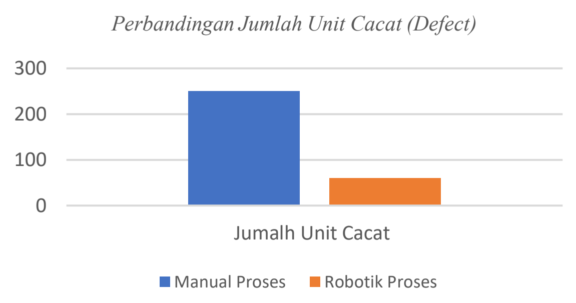
Data from quality inspection results from 5,000 production units per month:

Table 7. Quality Comparison (Deffect Rate)

Parameter	*Manual*	*Robotic*	*Perubahan*
Total Produksi	*5000 unit*	*5000 unit*	*-*
Unit Cacat	*250*	*60*	*↓190 unit*
Deffect Rate	*5.0%*	*1,20%*	*↓76% meningkatkan kualitas*

Quality Improvement: The defect rate drops from 5.0% to 1.2%, or a 76% reduction in defects.

This drastic reduction in defect rate confirms the findings regarding a significant reduction in scrap after robotic adoption.



Analysis of Operational Costs and ROI

Table 8. Operational cost analysis

Komponen Biaya	*Proses Manual (Tahunan)*	*Proses Robotic (Tahunan)*	*Rumus Perhitungan*	*Penghematan*
Biaya Tenaga Kerja	*Rp 150.000.000*	*Rp 40.000.000*	*BTK = (Gaji MP)*	*Rp 110.000.000*
Biaya Material (Wastage)	*Rp 80.000.000*	*Rp 68.000.000*	*BM = Konsumsi Adhesive x Harga*	*Rp 12.000.000*
Biaya Kualitas (Scrap/Rework)	*Rp 45.000.000*	*Rp 15.000.000*	*BK = Jumlah Scrap x Biaya per u*	*Rp 30.000.000*
Biaya Utility & Mainenance Robot	*Rp -*	*Rp 15.000.000*	*BU = Biaya Maintenance Robot*	*-Rp 15.000.000*
Total Biaya Operasional	***Rp 275.000.000***	***Rp 138.000.000***	***BU = BTK + BM + Bk + BU***	***Rp 137.000.000***

ROI calculation

Table 10. ROI calculation

Parameter	*Rumus*	*Perhitungan (angka)*	*Hasil*
Total Penghematan Bersih Tahunan (saving)	-	-	*Rp 137.000.000*
Biaya Investasi Robotic (Inv)	-	-	*Rp 200.000.000*
ROI (%)	$\frac{Saving}{Inv} \times 100\%$	$\frac{137.000.000}{200.000.000} \times 100\%$	*68,5%/tahun*
Pay Back Period (tahun)	$\frac{Inv}{Saving}$	$\frac{200.000.000}{137.000.000}$	*1,46 tahun*

With an ROI of 68.5% per year, the payback period is around 1.46 years. These results show that the investment in robotic glue systems is very financially feasible.

CONCLUSION

The transition from manual spray glue to robotic glue processes has proven to significantly improve cost, time, and production quality efficiency. Statistically, the automation process works:

Improved Time Efficiency by 38.4%, supported by significant paired t-test results.Reduced the need for Man power from 17 Man Power to 8 Man Power (↓ 9 Man Power).Improve Product Quality by reducing defect rate by 76%.

Improve Operational Cost Efficiency and generate a Return on Investment (ROI) of 68.5%, with a return on capital period of less than 1.5 years.

This automation is a comprehensive solution that addresses inconsistencies caused by human factors, while ensuring long-term cost savings and alignment with industrial technology adoption.

Suggestions

1. **For Enterprises:** It is recommended to continue the automation program to other production lines. Companies should also allocate budgets for *upskilling* manual operators to robot maintenance operators and technicians, given the changing workforce structure.

2. For Further Research: It is recommended to conduct a comparative analysis of the *adhesion performance of* the final product (e.g., through tensile or shear tests) between the two methods, to complement the visual quality and cost data.

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