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Design and Application for End of Arm Tooling in Plastic Injection Molding

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Abstract: This study discusses the implementation of End of Arm Tooling (EOAT) in the injection molding production process at Toyoda Kakou Co., Ltd. EOAT is a device installed at the end of a robotic arm that functions to automatically remove products from the mold. The research method used is a qualitative comparative before and after the use of EOAT. By recording data and then comparing the parameters of cycle time, defect rate, and work safety factors. The evaluation results show that the use of EOAT is able to reduce cycle time from approximately 26.0 seconds to 22.5 seconds, the product defect rate decreased from 4% to 1%, and reduce the number of employees from 1 to zero. The cost of the tool is calculated from the purchased components of Rp 6,350,000. The conclusion of this study is that EOAT has been proven to increase productivity. It is recommended that EOAT be implemented more widely in other production lines.

Keywords: end of arm tool, injection, molding, plastic

1. INTRODUCTION

Injection molding technology is one of the most common methods used in the plastics processing industry. It is a method that can be used for mass production of products with complex shapes (Czepiel & Ba, 2023). Plastic is used in products such as furniture, cosmetic packaging, electronics, transportation, and even children's toys. The injection molding process is used to mass-produce plastic products by melting the raw material and injecting it into a mold through a high-pressure nozzle. After solidification and cooling, the product is ejected from the mold (Basuki et al., 2022). This method offers advantages such as high shape precision and cost efficiency.

In conventional processes, product picking is done manually by hand. Some are done by dropping directly, but this has the potential to damage the product. Manufacturing companies are innovating using assistive devices in the form of product picking robots for maximize production capacity. Human physical limitations and endurance are the main reasons for designing and developing industrial robots (Dhanda et al., 2025). Robots here are more for general use, while each type of workpiece naturally has its own specific specifications. In large-scale production processes that require speed and precision, robots are considered very capable of overcoming these human resource limitations. Automation and robots enhance injection molding, improving efficiency (Fomekong et al., 2024), minimize the need for manual labor, and increase precision (Charan et al., 2024).

Cycle Time Injection Machine

The cycle time of an injection machine is calculated from one period of each product produced. For example, it is calculated each stages mold closed until the next one is mold closed again. Basically, cycle time is defined as a fully automatic operation, where the workpiece falls automatically during the ejection process. Meanwhile, a manual operation involves catching the workpiece by hand. This is to prevent it from colliding with the anvil when it falls and also to simplify setup in the packing area. A manual operation involves opening and closing the injection machine door. While the door is open, the mold closing movement is not possible. This ensures the operator's hands are not caught in the mold. The manual cycle time will be longer than a fully automatic operation. Efforts to reduce cycle time have been made by reducing cooling time (Wang & Lee, 2023). This article recognizes the importance of cycle time speed from an economic perspective. However, there are other influencing factors, including the far less consistent human work methods. The injection molding process consists of five stages. The stages area mold close, filling, packing cooling, mold open. For manual process the stage added machine door open and machine door close. For detail shown in Fig. 1.

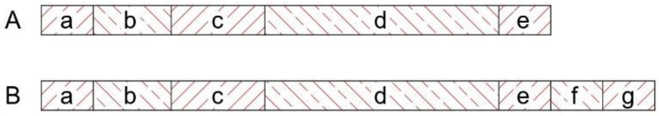

Fig. 1 Comparison of Manual Work A, B full auto, the description: a mold close, b filling, c packing d cooling, e mold open, f machine door open and g machine door close

Fully automated operations will be more efficient if product picking is performed using a robot. The robot is used to control the picking motion. The robot arm must have a specially designed tool tailored to each product type. The time difference between manual and fully automated operations is calculated using the equation 1. Where T man is manual time, T auto is full-auto time. The opportunity to reduce cycle time by eliminating the process of opening and closing the injection machine door.

$$Efisiensi\ = \left(\frac{T\ man - T\ auto}{T\ man}\right) \times 100\% \qquad (1)$$

End of Arm Tooling (EOAT)

End of Arm Tooling (EOAT) is a special mechanical device installed specifically at the end of an industrial robot arm. This sophisticated device is designed as a link between the robot and the workpiece, functioning to pick up, clamp, hold, or move printed products in a programmed manner (Jing et al., 2018). Generally assembled from aluminum profiles (Fig. 2) equipped with pneumatic clamps, vacuum suction, actuator cylinders, and detection sensors (Tracht, 2014). Based on considerations of the strength and weight of aluminum material, EOAT is made using aluminum too. In line with the development of automation, PT Toyoda Kakou Co., Ltd., a modern manufacturing company in the automotive and electronic components sector has adopted the use of EOAT in its injection molding production line.

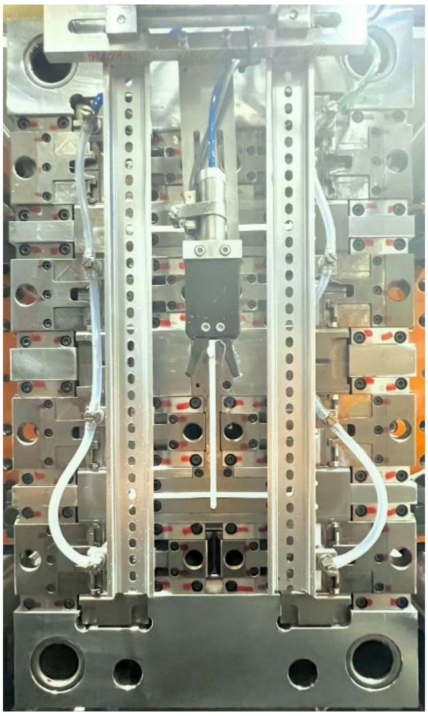

Fig. 2 EOAT made from Aluminum profile

2. METHOD

This research uses a descriptive comparative case study to evaluate the implementation of EOAT in an injection molding production line. It begins with measuring cycle time before EOAT implementation, analyzing product shape from the cavity layout to determine the grip shape, and analyzing space to adjust the robot arm stroke for each vertical and horizontal movement step, as well as the product release stroke from the robot arm. The data will be compared with the data after EOAT implementation. The research data collection and evaluation were carried out from April to June 2025. The observation location is in the production area of the molding division of PT Toyoda Kakou Co., Ltd., a modern company that produces automotive and electronic components in mold ID number 21TJ-0. The technical aspects evaluated include the components of the EOAT system, such as the main frame structure of aluminum profiles, pneumatic gripper or clamping mechanisms, vacuum suction cups, air tubing hose distribution systems, pneumatic position sensors, and fastening bracket systems. To support comprehensive data acquisition, this methodology utilizes a series of mechanical and analytical tools, including cameras for visual technical documentation, stopwatches for measuring the precision of work cycle durations, technical equipment such as screwdrivers and wrenches for the assembly process, and air compressors for testing the response level of the clamping actuator.

The process begins with the design and manufacturing stage of the EOAT following the needs of the mold and machine size, product, mold material, and movement steps. In this design phase, a precision clamping mechanism is created that connects the end of the robot arm with the actuator cylinder, solenoid valve, and position detection sensor control system. Before entering the testing stage, the EOAT instrument calibration process is carried out, to set the center point on the robot arm, measure the grip force, and verify the tolerance limits of the vacuum level and the function of the limit switch to meet the tool safety standards. The final phase is testing and analyzing production performance evaluation. This research evaluation uses comparative analysis by comparing performance before and after using EOAT. Measurements specifically focus on recording the cycle time, product defects percentage, the reliability of the clamping movement failure rate, reducing the potential risk of structural damage, and improving the work safety standardization system for operators.

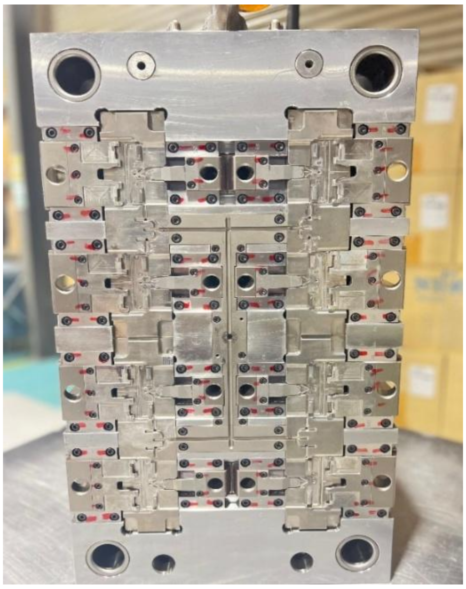

Fig.3 Mold 21TJ-0 Move/Core Plate Unit

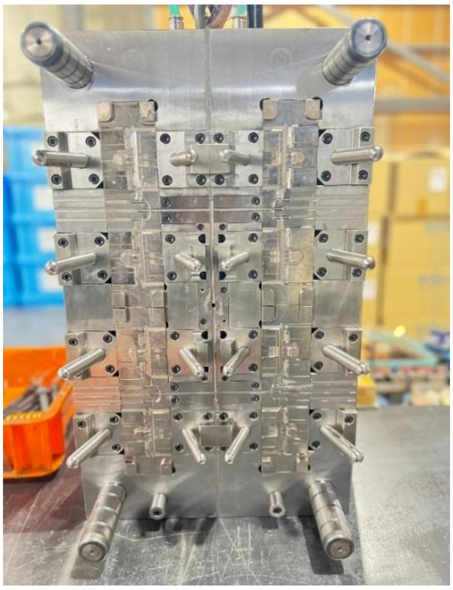

Fig.4 Mold 21TJ-0 Cavity

3. RESULT AND DISCUSSIONS

The EOAT implementation on the injection molding production line with mold identification number 21TJ-0 (Fig. 5) at PT Toyoda Kakou Co., Ltd. has been successfully assembled (Fig. 6) and put into operation (Fig. 7). This EOAT unit is designed using a strong yet lightweight modular aluminum profile frame as the main material, and is integrated with pneumatic gripper components, actuator cylinders, and vacuum suction cups. This assembly is also equipped with polyurethane air hoses PU tubing and a series of position sensors to ensure the status and accuracy of the product clamping run perfectly.

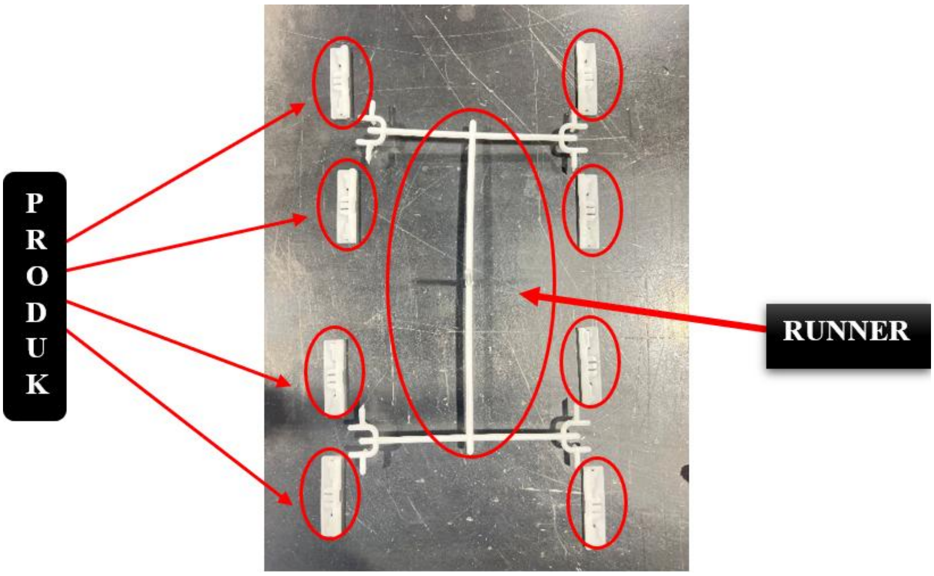

Fig. 5 Mold 21TJ-0

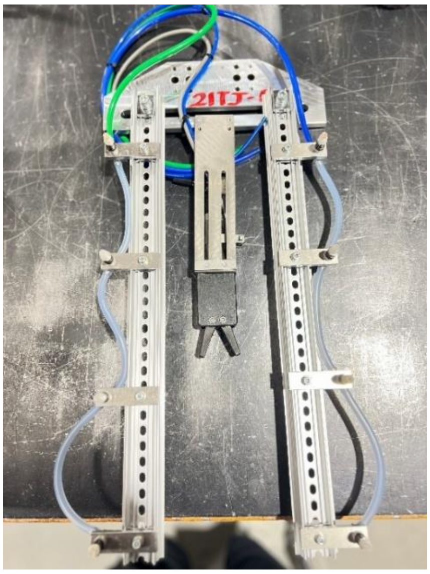

Fig. 6 EOAT for mold 21TJ-0

Fig. 7 EOAT insalled on robot injection machine

The operation of the robot arm is fully controlled by an integrated pneumatic system, where pressurized air is via a regulator to a solenoid valve whose activation with the opening and closing cycle of the molding machine. The robot's movement has been programmed. The mold is opened by 292 mm (Fig. 8), the EOAT will descend from the zero point as far as 637.5 mm to pick up the product, then precisely retreat to prevent collisions, and move back up. Next, the system automatically sorts by removing defective products as far as 979.3 mm, then places products that pass the quality standards on the machine's conveyor.

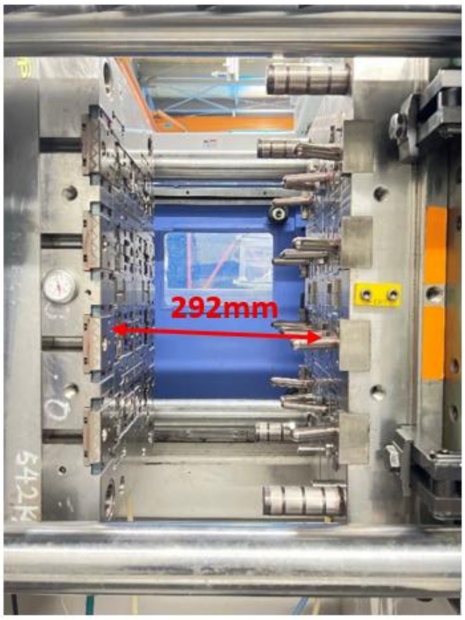

Fig. 8 Mold open mold size

Work Safety

Using robots equipped with EOAT eliminates the need for an injection machine operator. Mold and close movements are highly susceptible to hand trapping. The mold and barrel are hot areas. With no operator present in these areas, the potential for workplace accidents is significantly reduced.

Efficiency and productity

The manual change to full auto method successfully reduces the cycle time. While using manual average cycle time was 26.0 seconds and after EOAT was activated is 22.5 seconds. The calculation is based on formula 1 efficency is 15,56%.

$$
\begin{aligned}
Efisiensi &= \left(\frac{26-22{,}5}{22{,}5}\right)\times 100\% \\
&= \left(\frac{3{,}5}{22{,}5}\right)\times 100\% \\
&= \mathbf{15{,}56}\ \%
\end{aligned}
$$

Product Defect Rate

In addition to increasing productivity, the installation of EOAT also reduced the reject rate. The evaluation results showed a significant reduction in the defect rate from 4% to only 1% (Table 1). Before the use of EOAT, the operator's hand-picking of products led to inconsistent handling and picking directions, resulting in defects. After the use of EOAT, the picking direction was stable according to the program.

Table 1. Defect rate before vs after EOAT

Production Monitoring Duration	**Before**			**After EOAT Implementation**		
	Product quantity	Defect quantity	Defect Percentage	Product quantity	Defect quantity	Defect Percentage
0,5 hour	70	3	4,29%	80	1	1,25%
1 hour	138	6	4,35%	160	2	1,25%
12 hours	1662	66	3,97%	1920	19	0,99%
24 hours	3323	133	4,00%	3840	38	0,99%

Cost of tools

The components used to manufacture the EOAT an aluminum profile main frame assembled using nuts and bolts. The main frame serves as a mounting point for the grip, chuck, vacuum tube, and holding element. The estimated cost is Rp6,350,000 (Table 2).

Table 2. Cost of EOAT

Component	**Spesification**	**Quantity**	**Unit**	**Price/unit (IDR)**	**Total (IDR)**
Aluminium Profile	Modular 20x20 mm	2	rod	110.000	220.000
Chuck single action	Yushin mini hop	1	unit	2.800.000	2.800.000
Tubing PU	Ø6 mm	3	meter	50.000	150.000
Gripper atau Clamp Unit	PAD-2-L25	8	buah	200.000	1.600.000
Sensor Posisi	MR-S1	1	buah	500.000	500.000
Vacuum Suction Cup	Mini suction pad	8	unit	60.000	480.000
Bracket & Clamp	Modular Set	1	set	600.000	600.000
		Total Cost			**6.350.000**

The implementation of End of Arm Tooling (EOAT) in the injection molding production line demonstrated a clear improvement in production efficiency, product quality, and work safety. The cycle time decreased from 26.0 seconds in the manual process to 22.5 seconds after EOAT implementation. This means that the production cycle was shortened by 3.5 seconds, or approximately 13.46% compared with the previous manual cycle. If calculated based on the automated cycle time, the efficiency improvement reaches 15.56%. This result confirms that the elimination of manual door opening, manual product picking, and inconsistent operator movement has a direct impact on production time reduction. This finding is in line with the recent development of robotic end-effectors in manufacturing. Mohammad et al. (2026) emphasized that end-effectors are critical components in robotic automation because they directly determine how accurately, safely, and efficiently robots interact with workpieces. Similarly, Andronas et al. (2026) showed that advanced end-effectors combining vacuum and parallel grasping can improve cycle time, reduce unnecessary tool changes, and minimize human involvement in repetitive tasks. Therefore, the EOAT developed in this study can be positioned as a practical and low-cost automation solution for injection molding operations, especially for product removal activities that require consistent gripping direction and stable handling.

The reduction in defect rate from 4% to 1% also indicates that EOAT contributes to more stable product handling. In the manual process, product defects may occur because the operator's hand movement is inconsistent, the picking direction changes, or the product experiences impact after removal from the mold. After EOAT implementation, the robot movement becomes more repeatable because the product is picked using a programmed pneumatic and vacuum mechanism. This supports the findings of Pae et al. (2026), who stated that injection molding quality is strongly influenced by process parameters such as injection rate, melt temperature, mold temperature, packing pressure, and packing time. Although the present study focuses on the product removal stage rather than molding parameters, the result shows that post-molding handling is also an important factor affecting final product quality. The quality improvement obtained in this study can also be discussed from the perspective of defect control in injection molding. Kim et al. (2026) explained that surface defects in injection-molded products can increase setup time and reduce production competitiveness, especially in products requiring high appearance quality. Their study showed that process control strategies can reduce surface defects and support defect-free production. In this study, EOAT does not directly modify the injection speed or mold temperature, but it contributes to defect reduction by ensuring that product removal is performed consistently and safely. Thus, EOAT can be understood as a supporting technology for quality stabilization in the final stage of the injection molding cycle.

From a productivity perspective, EOAT implementation supports the current trend of intelligent and automated injection molding. Wang et al. (2026) highlighted that data-driven quality prediction in smart injection molding can improve production reliability by linking process signals with product quality indicators. Wang, Ye, and Chien (2026) also showed that real-time decision-support systems can reduce parameter adjustment time and improve responsiveness in injection molding production. Although the EOAT system in this study is still mechanical-pneumatic and has not yet been integrated with AI-based monitoring, its implementation provides an important foundation for future smart manufacturing development. In the next stage, EOAT can be combined with sensors, production data logging, and quality monitoring systems to support more advanced process control. The safety aspect is another important contribution of this study. Before EOAT implementation, the operator had to work near the moving mold area and hot machine components. This condition created potential risks such as hand trapping, burns, and fatigue-related accidents. After EOAT installation, the product removal process no longer required direct operator intervention near the mold area. This finding is consistent with Cai et al. (2026), who emphasized that human–robot collaborative manufacturing can improve efficiency, quality, and safety by combining human decision-making with robotic precision and continuous operation. Du et al. (2026) also highlighted that safe manufacturing automation requires robots to understand task relevance and reduce unsafe interaction between humans and machines. Therefore, EOAT implementation in this study supports the transition toward safer and more human-centered production systems.

The EOAT cost of Rp6,350,000 indicates that automation does not always require expensive and complex equipment. The tool was assembled using modular aluminum profiles, pneumatic grippers, vacuum suction cups, sensors, tubing, and brackets. This makes the system relatively affordable and adaptable for similar production lines. In relation to sustainable manufacturing, Van Emburg et al. (2026) emphasized that injection molding has significant implications for energy performance because it dominates thermoplastic production. Wu and Yao (2026) further showed that adaptive control in injection molding can reduce energy consumption per cycle. Although this study did not directly measure energy consumption, the reduction in cycle time implies better machine utilization and potentially lower energy use per product. The results also show that EOAT can support process standardization. Manual product removal is influenced by operator skill, fatigue, and working rhythm, whereas EOAT produces repeated movements based on programmed robot motion. This is relevant to recent studies on process optimization and parameter recommendation in injection molding. Hedayati-Dezfooli and Moayyedian (2026) proposed an integrated optimization framework to reduce injection molding defects, while Roy et al. (2026) emphasized real-time optimal parameter recommendation to improve productivity. These studies indicate that modern injection molding improvement should not rely only on manual judgment, but should move toward structured, repeatable, and data-supported decision-making. The EOAT developed in this research contributes to this direction by reducing variability in product handling.

Furthermore, the implementation of EOAT can be connected to the broader development of digital twin and training systems in plastic injection molding. Peris et al. (2026) showed that digital twins can be used to virtually replicate injection molding processes, helping users understand the effects of temperature, pressure, injection speed, and cooling time without using physical machines. In the context of this study, future EOAT development could be supported by digital simulation to optimize robot stroke, gripping position, collision avoidance, and cycle sequence before implementation on the production floor. This would reduce trial-and-error during installation and improve the reliability of EOAT design. Recent advances in injection molding also show that product and mold design are increasingly integrated with optimization and predictive modeling. Rosli and Khor (2026) demonstrated that Moldflow simulation and response surface methodology can help minimize shrinkage and filling defects. Wang et al. (2026) introduced 4D injection molding as an advanced approach that integrates predictive modeling and multi-objective optimization for mass customization. These studies indicate that injection molding improvement is no longer limited to machine parameters, but also includes tooling design, process modeling, and automation devices. Therefore, the EOAT in this study should be viewed as part of a broader production improvement strategy that combines mechanical design, automation, and process efficiency. Overall, this study proves that EOAT implementation can improve injection molding productivity by reducing cycle time, lowering product defects, and increasing work safety. The novelty of this study lies in the practical design and application of a low-cost EOAT system that can be directly implemented in a real production line. Although the system has shown positive results, further research is needed to evaluate EOAT durability, gripping force stability, sensor reliability, robot motion optimization, energy consumption, and return on investment. Future studies may also integrate EOAT with digital twin simulation, real-time monitoring, and AI-based quality prediction to support smart and sustainable injection molding production.

4. CONCLUSION

After implementing EOAT, a before-and-after comparison was performed, resulting in a 3.5-second increase in cycle time. This occurred because there was no opening or closing of the injection machine door. The defect rate decreased from 4% to 1% due to the robot's more consistent movements compared to human hands, which can change direction or be affected by fatigue. Holding the workpiece with a vacuum gripper clearly demonstrated greater consistency compared to human fingers. Because there was no operator near the moving and hot machine, workplace safety increased. This research focused on the workpiece, not the robot's movement program, so it can serve as a reference for those implementing production process automation. Future research is still needed on how to program robot movements to the needs of each shape and location of the object being held.

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