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Designing Jigs with Enhanced Durability to Streamline the Map Lamp Assembly Process

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ABSTRACT – *This paper discusses designing and implementing a jig for the assembly workstation on the Polybond line. Child parts like map lamp brackets, external microphones, foam, and wire hardness are installed at the assembly workstation. This project focuses on enhancing job handling to complete the map light bracket installation on the header. Currently, the map lamp bracket installation proceeds without any supervision. This results in inconsistent cycle times and procedural neatness, as it relies on the operator's proficiency, varying from 17 to 19 seconds for skilled operators to 34 to 37 seconds for unskilled operators. This article aims to create a jig that will serve as a guide for the hot glue gun nozzle, thereby improving the work outcome. CATIA V5 was used to complete the design process before the jig prototype was manufactured for testing. When the prototype worked as expected, the actual jig was created using appropriate material to ensure its long-term functionality on the manufacturing line.*

KEYWORDS: Jig, CATIA V5, car interior part, headlining, map lamp bracket

1. INTRODUCTION

The global economy depends on industrial production, yet there are several obstacles that limit its sustainability and effectiveness. The fiercer competition in emerging areas is one of the biggest obstacles. In order to stay competitive, businesses need to streamline their production processes, invest in new ideas and technology, and prioritize customer happiness (Hansen et al., 2018). Equipment used in production is essential for maximizing output since it can lower production costs while guaranteeing effective production at the appropriate level of quality. Production equipment can support effective production processes in a number of ways: (1) Automation: many processes that ordinarily require manual work can be automated using production technology, lowering the risk of human mistakes while increasing productivity. Automation also frees up human resources, allowing them to focus on more specialized jobs. (2) Speed: modern manufacturing equipment can manufacture things at a much faster rate than older technology, cutting production times and hence improving output. (3) Precision: advanced production equipment can complete jobs with great accuracy, lowering waste and boosting product quality. (4) Flexibility: by lowering the requirement for several pieces of equipment, production tools capable of managing a variety of jobs or products can boost efficiency. Investing in the correct production equipment is vital for maximizing efficiency and profitability. This section emphasizes the fundamentals of jigs and fixtures because of their significance in the manufacturing industry.

A manufacturing system's jigs, fixtures, machines, and other devices are examples of production equipment. They aim to guarantee uniform and reproducible working conditions. Fiedler et al. (2024) state that jigs and fixtures are technical auxiliary devices utilized in manufacturing to guarantee the correct positioning and alignment of machines, workpieces, and tools. This gadget enhances the precision of operations on the workpiece. It is a significant component of production and is utilized in sectors such as automated manufacturing, inspection, and assembly. In machining, "jig" denotes a device that secures and positions the workpiece while concurrently directing the tool (Kb & Babu., 2013). The optimal jig can operate with accuracy and interchangeability, enabling the production of diverse objects that adhere to identical specifications. Jigs and fixtures are essential tools in the manufacturing industry since they facilitate the operator’s production process (Radhwan et al., 2019). The manufacturing sector often employs jigs and fixtures, contending that the design of this device should emphasize simplicity, user-friendliness, and cost-effectiveness to guarantee its economic feasibility. A distinct association exists between the level of flexibility in the jig and the outcomes of the design process. Line translation, line rotation, and plane translation are the three forms of constraint degrees of freedom applicable to the datum on the product (Wang et al., 2017). This pin or datum is generally situated in a fixed position, hence influencing the loading and unloading procedure of the workpiece on the jig (Bahadure & Waghmare, 2020). Proper positioning is essential to optimize the loading and unloading operation.

The XYZ Company uses eleven primary workstations for its headlining production. These workstations include incoming inspection, material cutting, MDI coating, catalyst spray, material layering, forming, cooling, waterjet cutting, assembly, final inspection, and packing and racking. The issue arises during the installation of the map light bracket at the assembly workstation, particularly for models P213A, P230D, and P231C. This component must be affixed to the headliner surface using a hot melt adhesive applied with a hot glue gun. The hot melt filling operation on the map lamp bracket surface is performed manually, lacking any direction on the hot glue gun nozzle. Consequently, the outcome of the work on the bracket surface is inconsistent and contingent upon the operator's proficiency.

This article outlines the design of a highly durable jig specifically developed for the hot melt-filling process on the map lamp bracket surface. The design procedure of the jig was conducted to substitute for the manual approach employed at the assembly workstation. This jig will limit the movement of the map lamp bracket and feature a grooved design on its upper side to direct the hot glue gun nozzle during application. This jig design was created using CATIA V5, and ANSYS is employed for durability analysis. This jig is anticipated to serve as a guide for all operators, hence reducing reliance on merely two professional operators to manage the process across all models. Apart from that, the comparison between before and after using the jig on the assembly line was also analyzed.

2. METHODOLOGY

This comprehensive flow chart illustrates and elucidates the progress from the initial stages of project development to the manufacture and implementation of the project on the assembly line.

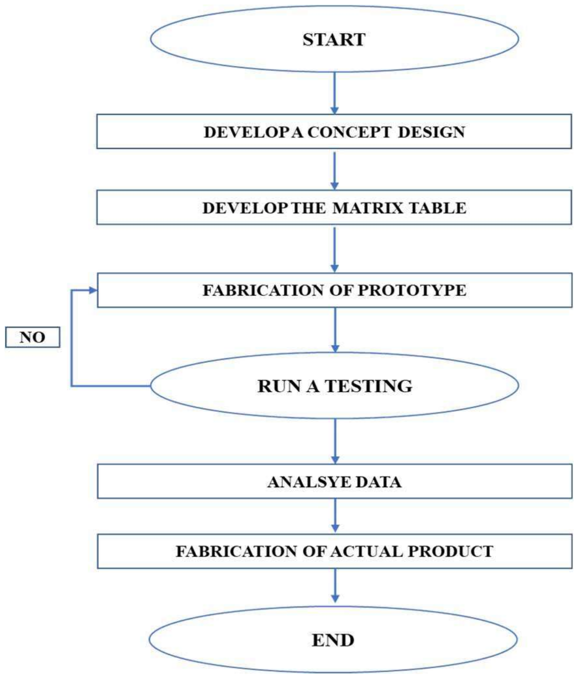


FIGURE 1: The comprehensive project flow diagram

2.1 Conceptual Design

CATIA V5 was utilized in the process of developing a concept design for the project. During the production process, the design of the project must ensure worker convenience, maintain acceptable costs, and exhibit durability. In addition, suggestions regarding the selection of materials can be made under this section. Jig body, Jig template, and Jig mold are the three central components that make up this jig (Figure 2). The jig body is the most fundamental component. The concept design was developed in three different varieties for this project.

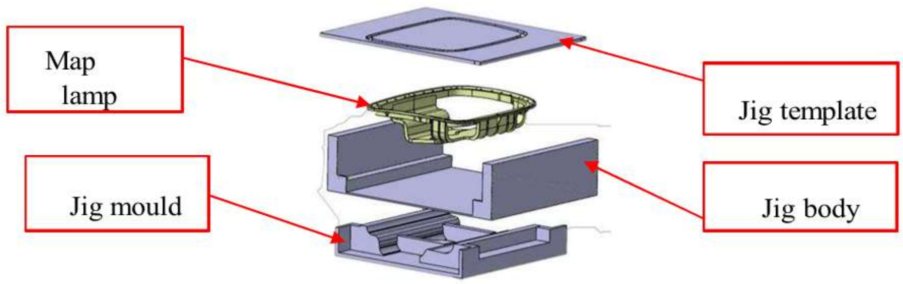
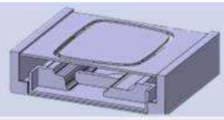
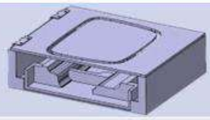
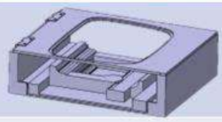


FIGURE 2: The basic part of the map lamp bracket jig

2.2 The Matrix Table

The creation of the matrix table for these three idea designs proceeded concurrently with the production of the designs themselves (see Table 1). The matrix table displays each concept design along with its unique characteristics. The assembly line operator assigns a score to each concept design based on how appealing the specs are.

TABLE 1: The conceptual design matrix

DESIGN	CONCEPT DESIGN 1	CONCEPT DESIGN 2	CONCEPT DESIGN 3
			
LENGTH	265MM	265MM	265MM
WIDTH	210MM	210MM	210MM
TEMPLATE STYLE	SLOT ON EACH SIDE AND USED GROVE DESIGN	DOUBLE HINGE AND USED GROVE DESIGN	DOUBLE HINGE AND USED POCKET ON THE MIDDLE DESIGN
MATERIAL	TEMPLATE: STAINLESS STEEL BODY: PETG+ MOULD: PETG+	TEMPLATE: STAINLESS STEEL BODY: ALUMINIUM MOULD: PETG+	TEMPLATE: STAINLESS STEEL BODY: ALUMINIUM MOULD: PETG+
HOT GLUE GUN NOZZLE SUITABILITY	2.0MM DIAMETER OR 3.2MM DIAMETER, EITHER ONE	2.0MM DIAMETER OR 3.2MM DIAMETER, EITHER ONE	2.0MM DIAMETER AND 3.2MM DIAMETER, BOTH.
OPERATOR 1	3/5	4/5	5/5
OPERATOR 2	2/5	5/5	2/5
OPERATOR 3	1/5	4/5	3/5
OPERATOR 4	2/5	4/5	2/5
OPERATOR 5	4/5	5/5	4/5
TOTAL	12	22	16

2.3 Prototype Fabrication

The jig prototype (Figure 3) was constructed according to the chosen concept design from the matrix table. The jig prototype was utilized for the operational testing process. For this project, the prototype utilized the same design but employed less expensive materials than the actual jig, including a hardwood block, plywood, and polyurethane block. The EEC department conducted the initial testing of this prototype before the operator's evaluation. The primary aim of this prototype is to ascertain any vulnerabilities inherent in the design. This measure may also reduce the expenses associated with the project's development.

FIGURE 3: The prototype of the jig

2.4 Examining the Data

The last design was created following the decisions on all the little modifications. This model design was examined using the ANSYS program. Should the design shown on the ANSYS show a great performance, the present design would be applied to the actual jig. During this study procedure, real materials were used to design the model. Predicting the essential component of the model design was the aim of the analytical procedure. This part was quite crucial since it will show the outcome not evident from the process of prototype testing. Additionally, displaying the facts depending on the actual material was also the outcome of the analysis.

2.5 Fabrication of the Actual Product

Provided that the product prototype and the ANSYS analysis data yielded favorable results without any issues, the actual product was manufactured using the specified material. All vulnerabilities in the jig prototype required mitigation at this level. Figure 4 illustrates the final design before the fabrication process.

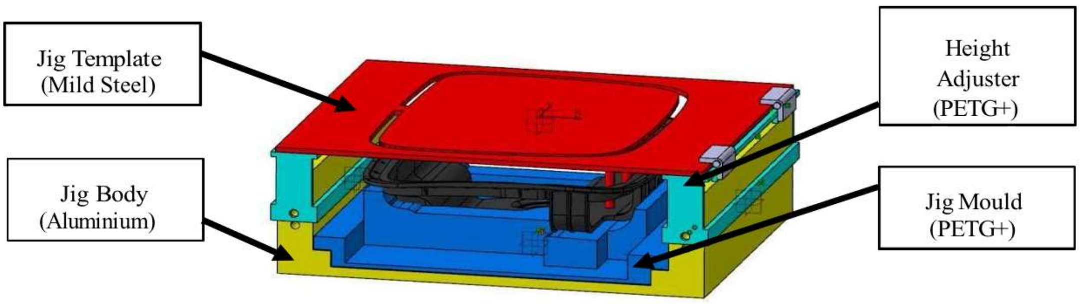


FIGURE 4: The final design of the map light bracket jig

3. RESULTS AND DISCUSSION

3.1 Design Analysis

A static structural analysis calculates and displays the impact that the design model experienced based on the force value. This type of analysis focuses on the overall deformation and stress effect on the jig. In this project, the force was added to the jig design model. The force value was calculated using the weight of the hot glue gun. The hot glue gun produced a total force of 4.032N, which was applied to the jig template surface (Figure 5).

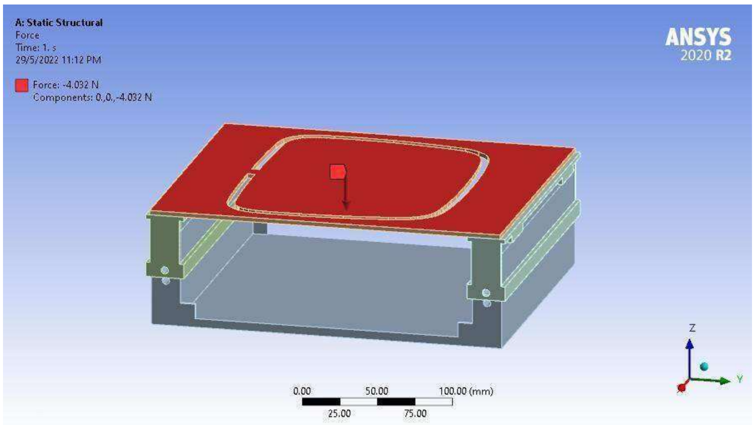
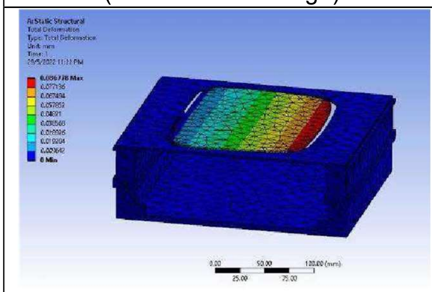
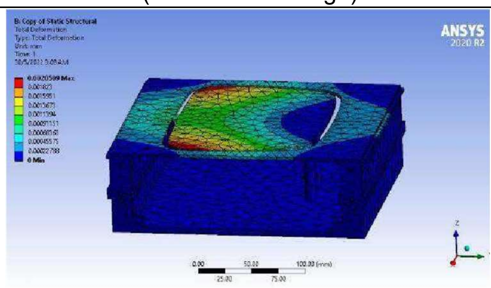


FIGURE 5: The force applied area

In this section, the analysis was carried out in two different designs. The first design was chosen from the matrix table, whereas the second design was the same but with a little alteration. The minor modification design idea that emerged after the design from the matrix table produced an unsatisfactory result during the prototype portion. The first design had only one supporter to support the middle of the template jig, whereas the second design had two pillars under the jig template to support the jig template given in Table 2. Table 2 displays the total deformation outcome for each design. The red hue represents the part that experienced the most deformation effect, while the blue color represents the part with the least deformation effect. The maximum value of deformation for design 1 was 8.6778e002 mm, while design 2 was 2.0509e-003 mm. This indicates that design 1 had the largest chance of bending the jig template, particularly the middle template. This risk can be mitigated by adding two pillars under the jig template (Design 2). The midsection of the jig template was also stronger to withstand the force of the hot glue gun.

TABLE 2: The total deformation results between before and after a minor change

	Design 1 (before minor change)	**Design 2** (after minor change)
Figure		
Minimum	0 mm	0 mm
Maximum	8.6778e-002 mm	2.0509e-003 mm
Average	6.4935e-003 mm	2.0002e-004 mm

To conclude the results for this solution, the average tensile stress value needs to be compared with the material's tensile strength. If the average tensile stress exceeds the material's tensile strength, the material is at risk of yielding or fracturing. Stainless steel material was used for each template jig, yielding a tensile stress value of 621 MPa. For the average equivalent stress result in Table 3, Design 1 resulted in 7.4977e-002 MPa while Design 2 resulted in 1.9771e-002 MPa. Therefore, Design 2 had better result in handling the force received during the production activity.

3.2 Cycle Time

In this study, cycle time was measured to determine differences in operating time. The Assembly Workstation recorded manual and jig cycle times on three separate occasions. This procedure compares the cycle times of these two approaches. A corrugated board supported the map lamp bracket during hotmelt filling in the instructions. No guidance was provided for the hot glue gun nozzle direction during hotmelt filling on the map light bracket. A jig mould was used to restrict the map lamp bracket movement, and a template to guide the hot glue gun nozzle, but expertise and focus are required from the operator. Five P213A, P231C, and P230D Assembly Workstation operators were responsible for hotmelt filling of the map light bracket. Each manual and jig operator repeated the process six times. Operators were categorized into expert and non-expert groups. According to the problem definition, only two expert operators were available to perform this procedure. Expert operators were stationed at P213A, P231C, and P230D Assembly Workstations. Non-expert operators, while working at these workstations, focused on assembling headlining child parts. The comparison involved analyzing results from expert and non-expert operators. Both the current and jig procedures were repeated three times by each operator, and cycle times were recorded for each process. The cycle time measurement required assembling 30 map lamp brackets.

The manual method first cycle time trial data is shown in Figure 6 below. For an expert operator, the hotmelt application took 17 to 19 seconds. Both had high neatness scores, which is commendable. For non-expert operators, the cycle times ranged from 34 to 37 seconds, approximately double those of expert operators. The non-experts also scored poorly on neatness, achieving only two middle and one low level. Currently, Worker 1 from the expert category recorded the lowest cycle time, while Worker 3 from the non-expert category recorded the highest. Figure 7 illustrates the results of Trial 2, which are consistent with those in Figure 6. Experts demonstrated the lowest cycle times, ranging from 18 to 19 seconds, and achieved the highest neatness scores. In contrast, non-experts recorded the highest cycle times, between 34 and 37 seconds, with poor neatness. Additionally, Figure 8 shows that the final cycle time for the manual method was slightly similar to the results of Cycles 1 and 2. Similarly, experts displayed better cycle time and showed greater neatness consistency compared to non-experts. Worker 3 scored high in the non-expert category, while the other two scored medium.

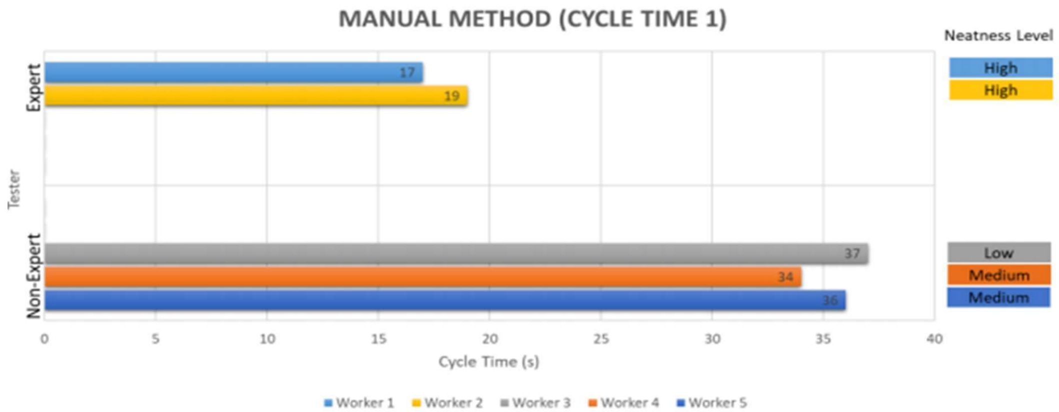


FIGURE 6: Cycle time Trial 1 (manual)

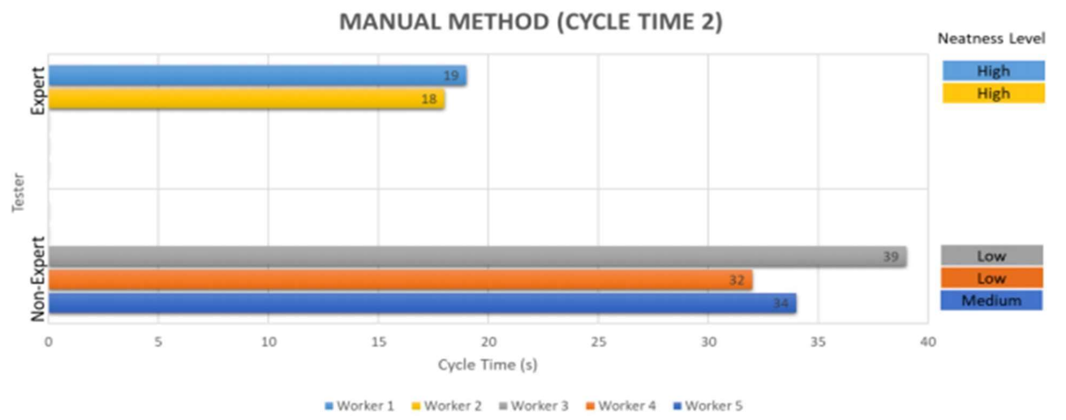


FIGURE 7: Cycle time Trial 2 (manual)

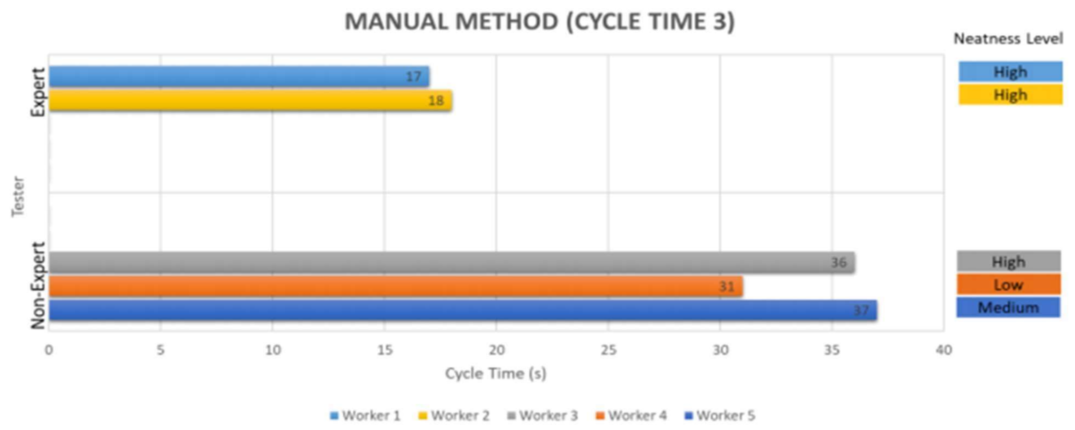


FIGURE 8: Cycle time Trial 3 (manual)

After manual techniques had been completed, the jig cycle time was measured. Figures below illustrates the first map lamp bracket jig testing. It indicates that the cycle time between expert and non-expert categories is minimal, unlike the manual technique. Cycle times of 19s for Worker 1 and 18s for Worker 2 were reached by experts, with excellent neatness. All three non-expert workers achieved estimated cycle times of 24–27s, lower than the manual approach, while achieving better appearance scores (two medium and one high). The expert category again produced 17s to 18s and exceptional neatness in the jig method trial. Fewer variable results were obtained from non-expert workers, with Worker 3 and Worker 5 both recording a time of around 23s and Worker 4 a time of around 24s. As far as neatness during the first try, those who were non-experts in that area received a high score, while one scored a middle level. Expert category maintained good performance with final cycle times below 20 seconds (19 seconds in the case of Worker 1; 18 seconds for Worker 2) and resulted in high neatness. The consistency of non-expert workers was comparable across all trials. The cycle time of Worker 5 was 25s, Worker 3 and 4, 24s. The neatness levels for non-experts were also satisfactory in this most recent experiment, with no low scores. Worker 5 was the neatest, followed by Workers 3 and 4 with medium levels of neatness.

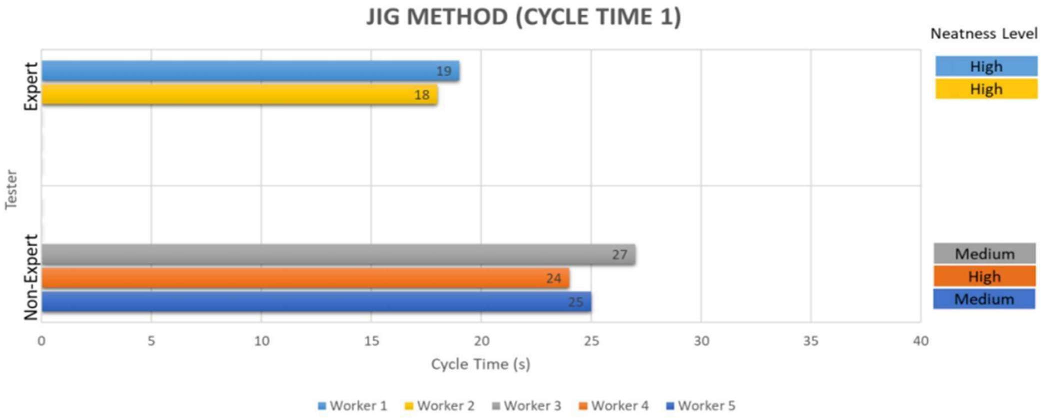


FIGURE 9: Cycle time Trial 1 (jig)

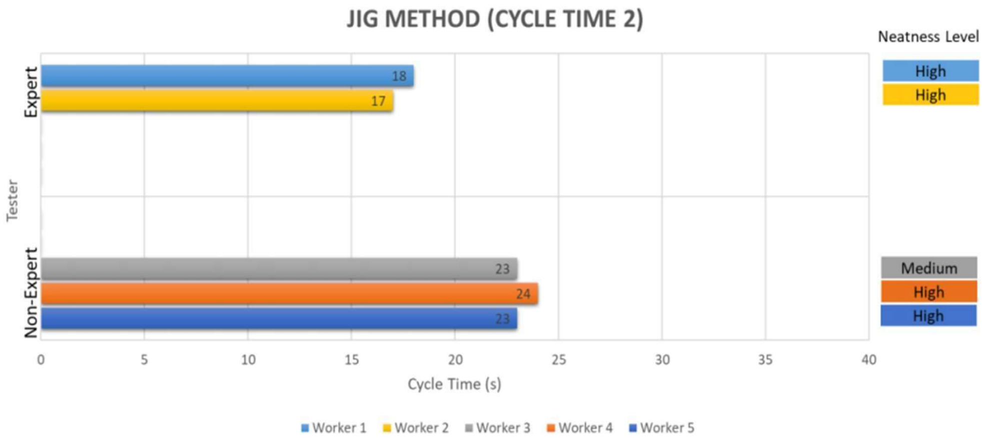


FIGURE 10: Cycle time Trial 2 (jig)

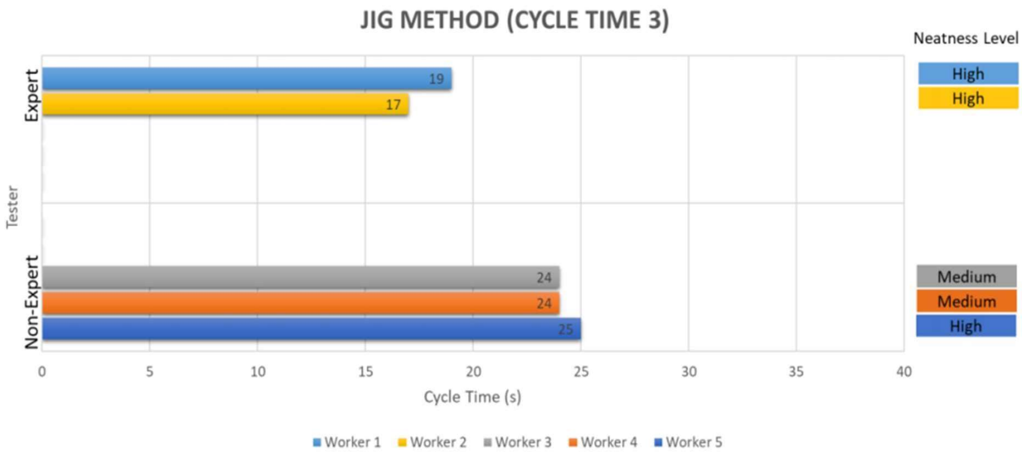


FIGURE 11: Cycle time Trial 3 (jig)

4. CONCLUSION

This project aims to reduce the reliance on specific operators for the job. Both expert and non-expert operators can handle the hotmelt filling process of the map lamp bracket with the same level of skill, if they use the map lamp bracket jig. Based on the cycle time data, the jig proves to be a valuable tool for users who are less skilled or experienced. Before the implementation of this jig, the cycle time difference between skilled and non-skilled operators was approximately 20 seconds. After implementing this jig, both expert and non-expert workers can reduce the cycle time up to 10 seconds. It also adds to the fact that a new worker can even work efficiently with hotmelt filling. Nevertheless, for reproducible results, the new user needs to be trained beforehand. The tool increases the quality level of work across both skilled and less-skilled operators, lowering performance variability and facilitating overall efficiency.

Subsequently, this jig will be implemented during the production process, with particular emphasis on the P230D and P231C production. The headlining issue can be mitigated by reducing the hotmelt excess. The jig utilization was previously estimated to be between 22% to 30%. Following the utilization of the jig, the percentage of hotmelt excess decreased to 18% to 25%. This implies that the jig template has the capacity to enhance the accuracy of the task. However, this jig template is exclusively appropriate for use with the 3M Polygun LT Glue Gun nozzle that is currently in use on the Assembly Workstation. Using different hot glue guns, particularly with varied nozzle designs, can reduce the accuracy of hotmelt application on the map lamp bracket surface.

Finally, this project can assist operators during the hotmelt filling process; however, it requires a minor modification to enhance its efficacy. Initially, the jig template requires enhancements in terms of design. This enhancement should enable the hot glue gun nozzle to be held more securely at a variety of angles. The current map lamp bracket jig is effective in delivering precise hotmelt application on the bracket surface, consistently producing excellent results. However, a minor issue has been observed with achieving accuracy in the left corner of the bracket.

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