Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

The Effectiveness of Implementing a Milling Process in Reducing Production Process and Costs: A Case Study

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ABSTRACT

Every product's design has a different process flow. Sometimes, designed products consist of a repeated process flow. Repeated processes are a problem that can affect production management and production output. This study has potentially proposed a new process that can replace the existing process by adding a milling process. The result shows that introducing a milling process was added to item 2 to produce a step slot and reduced the number of items used (Item 3). The assembly of Item 2 and Item 3 was converted into Item 6, which showcases a more substantial time differential, with the existing process taking 12.25 minutes and the new process requiring 0 minutes. The additional process of the new alternative milling machine reveals lower Watt, less time duration for the welding machine, reduced energy consumption for a hand-grinding machine, and lower cost demand for the welding machine than the existing process. In addition, the total cost of the added milling process shows a slight reduction in overall cost and is associated with energy consumption.

Keywords:
Milling, MIG, Cost, Energy consumption

1. Introduction

Since machining is a prevalent process in product manufacturing, the accuracy of a specific energy characterisation model predicts the electrical energy consumed by a 3-axis milling machine tool during processing. The energy characterisation model had an accuracy of 97.4% for the part manufactured under varied material removal rate conditions and highlighted the potential for energy reduction using higher cutting speeds. Diaz [1] states interviews with cutting tool manufacturers and end users showed a genuine potential for energy reduction during milling operations due to the industry's extensive use of uncoated cutting tools. However, some assembly parts from the industry have problems with process flow which is a repeated process (duplicate work).

It is imperative to identify methods for estimating the energy consumption of manufacturing to propose efficient and realistic strategies for reducing the consumption of our natural resources. Gutowski *et al.* [2] mentioned that the electrical energy requirement of

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https://doi.org/10.37934/aram.60.1.265277

manufacturing processes was inversely proportional to the process rate. The specific energy consumed to provide electrical power to the production equipment decreased as the process rate increased. It is due to the dominance of the tare power demand in the electricity consumption of machine tools. Moreover, recent improvements in material, machine and cutting tool technologies are focused on reducing costs, improving productivity and enhancing product quality [3]. With an objective function to optimise costs through lowering operational expenses and increasing productivity, these two process parameters form a Pareto optimum. A solution space exists between the minimum cost and the maximum production rate for a particular machining process that will yield an optimum cost. Thus, a systematic approach must be applied as a part of planning procedures for the machining process [4,5]. Intending to attain manufacturing procedures that are more resource-efficient regarding costs, tool lifespan, and productivity, the correct set of parameter value sets, tools, and strategies need to be established. Still, the investigation regarding the combined effect on cost and production rate for a specific feature is not fully reported [6].

Welding joints are widely used in the fabrication sector, which includes shipbuilding, offshore projects, and steel bridges. High joint efficiency, watertightness, and reduced manufacturing costs are advantages of these joints [13]. The most popular welding techniques are submerged arc (SA), tungsten inert gas (TIG), manual metal arc (MMA), and metal inert gas (MIG) welding [14]. All specimen items will be permanently joined by following the drawing given. MIG welding is flexible, loses fewer alloying elements, and can be done manually or automatically [15, 25]. Many welding applications and procedures call for several types of joins and welds. The American Welding Society (AWS) lists five fundamental additions that are widely used and accepted. Each welding joint type represents the requirements and forces of various applications [16]. Nowadays, many industrial fabrications use five basic joint welding to apply structure which are butt joint welding, tee joint welding, corner joint welding, lap joint welding and edge joint welding. Because welding metal is an expensive purchase, joint design is crucial. Thus, putting the weld integrity element aside, the joint configuration is essential in deciding whether the welded joint can resist its weight. The butt joint is the sides of each base metal that will be joined by welding, and both metals in this joint are designed to align on the same plane [7]. Fabricators use several different forms of butt weld, and each has unique characteristics. The most popular ones are groove, square, bevel, and V-butt weld. The T-joint is a simple, easily designed weldment that requires little or no edge preparation except in the T-butt case. The precision with which the edge of the T upright is significantly prepared affects how accurately the fit-up is performed [8].

Simple strategies can be implemented for many machining parts, including machining simple surfaces parallel or perpendicular to a plane. The advantage of simple strategies is fundamental parameter setting, such as cutting parameters, stepover, depth of cut, or options for defining the tool movement. Input data settings such as cutting parameters, tools used, milling strategy, cooling, and tool holder can affect the surface quality of the machined surface and operational cost [9, 10]. In addition, end mills are made out of either cobalt steel alloys (known as high-speed steel, or HSS) or from tungsten carbide in a cobalt lattice (shortened to "carbide"). This end mill material has its own characteristics. The choice of tool material depends on the material to be cut as well as on the maximum spindle speed of the machine. Smaller milling machines may not be capable of reaching the spindle speeds recommended for carbide end mills [11].

Therefore, this research aims to evaluate the effect of milling strategies on the minimising production process and cost. The data collection of existing and alternative processes with milling strategies will also be investigated and compared. This is due to removing duplicate work from an existing process, proposing an alternative methodology, and applying it through a practical user interface.

2. Methodology

2.1 Sample preparation

In this study, five items need to be assembled to become one final sub-part as shown in Figure 1. All items are made from mild steel through the hot rolled steel process (HRS). According to Mandal [12], the hot strip mill route of slab rolling is preferred for economic and productivity reasons. There have been many developments in this area, whereby a wide range of strip thicknesses with high-quality surfaces can be rolled at very high speed in these mills, with coil weights varying between 5 tons and 50 tons. Due to high beam quality, all items have been cut using a fibre laser machine. Fibre lasers are an excellent first choice for precision applications requiring narrow kerf and high-quality cuts. Currently, another department has covered the bending process. Thus, time spent on laser cutting and bending processes will not be calculated. The calculation of the laser cutting process for the item 3 sample will only considered when implementing an alternative new process.

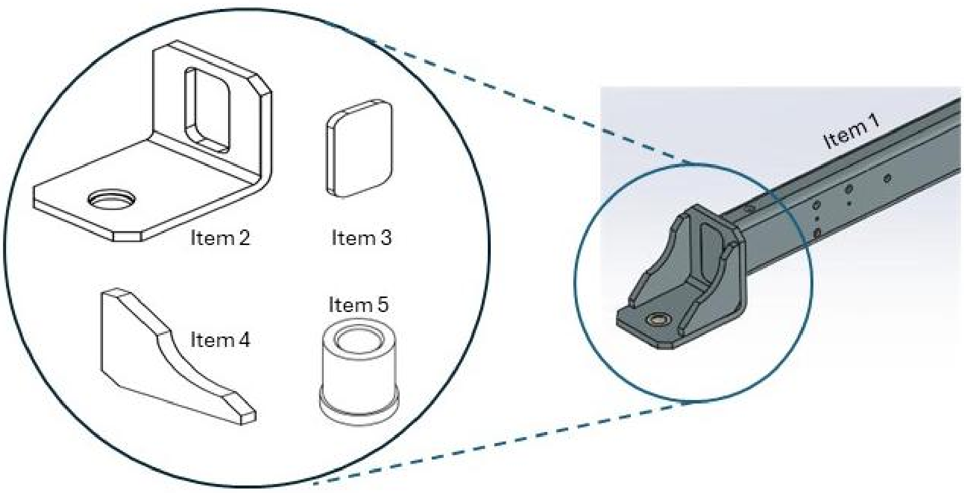

Fig. 1. The assembly of all items

2.2 Implementing Existing and New Process

Both samples of existing and new alternative processes were prepared for comparison. The flow chart of both processes is illustrated in Figure 2. The diagram is bifurcated, showcasing an existing process on the left and a proposed alternative process on the right. The existing process comprises five steps, beginning with the bevelling of Item 3, followed by the bevelling of Item 4. The third step involves a pre-welding phase where Item 3 is inserted into Item 2, collectively forming Item 6. The bottom surface of item 2 needs to be made to the same level as the surface of item 3. Thus, the top surface of item 2 automatically becomes a desired slot. Subsequently, a grinding process is implemented to ensure a flush welding area on Item 6. It provides no defect welding, such as spatter, undercut, or underfill defect welding. The final step entails a welding process integrating Items 1, 4, 5, and 6.

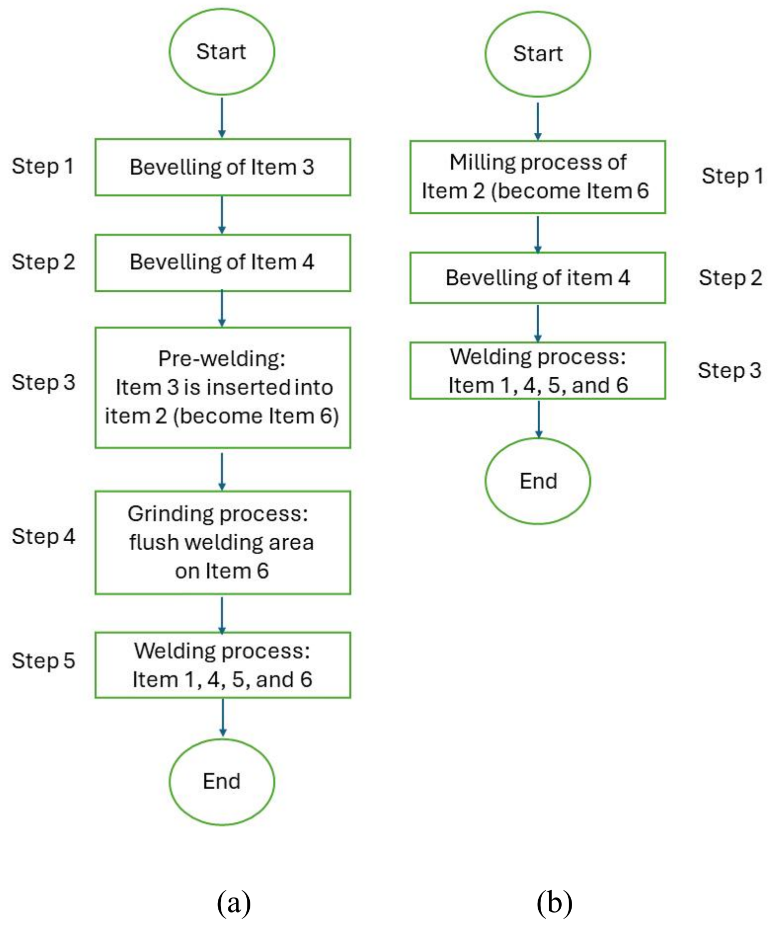

Fig. 2. The flow chart (a) existing process (b) new alternative process

In contrast, the alternative process is streamlined into three steps. It commences with a milling process applied to Item 2, which is then designated as Item 6. The milling process already reduces the number of sub-parts where item 2 was milled to become a slot, and item 3 is no longer applicable because the milling process (facing process) operates item 2 to create a step-down slot, as represented in Figure 3. The milling process was conducted for item 2 using a CKS MF-450VS vertical milling machine. A milling machine is a manual operation fully controlled by one staffing. Conventional machine tools require specific skills and expertise to operate, which can either overlap in certain areas or be exclusive to the particular type of machine tool or the production process. As the workforce is shrinking while the industry is experiencing substantial growth, a dire need for efficient, robust methods of quantifying, preserving and transferring machining knowledge becomes evident to ensure uninterrupted training of new professionals and applications in expert systems for process design [18, 19]. However, this conventional machine is suitable due to the project demand not being very high. According to Mariyeh Moradnazhad and Hakki Ozgur Unver [20], rising energy costs affect the manufacturing industry economically. Reducing the amount of consumed energy and implementing more energy-efficient manufacturing processes can significantly enhance the performance of processes and reduce their undesirable impacts. In addition, vertical milling machines are more commonly used and efficient for small jobs. The second step involves the bevelling of Item 4, mirroring the existing process. The final step consolidates the welding process, combining Items 1, 4, 5, and 6 in a single operation. Thus, it is a clear comparison between the two methodologies, highlighting the potential for process optimisation and efficiency improvements in the alternative approach. The reduction in steps and the integration of operations in the new process suggest a more streamlined manufacturing sequence. For time study purposes, the time of each operation was collected in 5 sets (10 pieces) for samples as tabulated in Table 1.

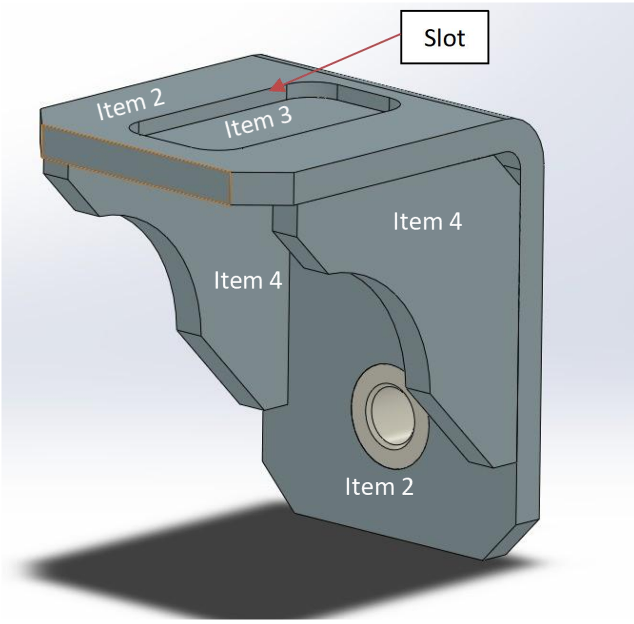

Fig. 3. Schematic diagram of step-down slot on item 2.

Table 1
Time is taken during the milling process for item 2.

Item 2 sample (10 pieces)	Time taken for the milling process on item 2 (m:s:ms)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
Average	

2.3 Pre-welding and Grinding Process

The pre-welding process combines several items to prepare for complete assembly. Two processes need to be operated under the pre-welding process: the sub-welding and grinding processes. The sub-welding process is to make a permanent joint between item 2 and item 3 using Miller XMt 350VS, a Metal Inert Gas (MIG) Welding machine. After welding (sub-welding process), all items 3 and 2 become new parts known as Item 6.

Next, item 6 was ground using Bosch GWS 060 hand grinding machine to scrape around the edge of item 3 to make a bevel as preparation for item 3 during the sub-welding process. Thus, the time taken for bevel process on item 3, the sub-welding process on items 3 and 2, and the sub-grinding process will be collected, and the bevel process on item 4, which has in both new and existing flowcharts will also be collecting data on time taken. All data for bevel will be collected for five sets (20 pieces) samples following Table 2.

Table 2
Sample time was taken for each process

5 sets recorded					
	Item 3 (1set=2unit)	**Item 4 (1set=4unit)**	**Assemble item 2,3 (Change to item 6) (1set=2unit)**	**Item 6 (1set=2unit)**	**Item 4 (1set=4unit)**
Unit	**Time taken for bevel (minutes)**	**Time taken for bevel (minutes)**	**Time taken for welding (minutes)**	**Time taken for grinding (minutes)**	**Time taken for bevel (minutes)**
1					
2					
3					

2.4 Welding Process

For welding process, a similar equipment of MIG welding machine was used in this process. This machine will use MIG wire ER70-6S with a diameter of wire 1.2 mm because this type of MIG wire is suitable for mild steel material. The data will be collected on the time taken of this welding process for five sets for the existence study and five sets for the new flowchart following Table 3.

Table 3
Sample time will be taken during the welding process.

No	**Time is taken welding for an existing process (m:s:ms)**	**Time is taken welding for a new process (m:s:ms)**
1		
2		
3		
4		
5		
Average		

3. Results and Discussion

All the average process times for both existing and new alternative processes were recorded as depicted in Figure 4. The graph compares the average time required to execute existing and new processes across various production or assembly line stages. The horizontal axis delineates the specific tasks or items, while the vertical axis represents the average time measured in minutes. In addition, the graph also elucidates the time disparities between the existing and new processes for each item. Item 3 and Item 4 exhibit relatively shorter average times; the existing process requires 1.57 and 3.75 minutes, respectively. Meanwhile, the new process demands Item 2 (23.85 minutes) and 4 (3.70 minutes). The existing process for Item 3 is faster than the new process for Item 2 because it only makes a bevel for welding preparations. In contrast to the new process, milling was added to item 2 to produce a step-down slot and reduce the number of items used (item 3). The "assemble Item 2,3 (change to Item 6)" task showcases a more substantial time differential, with the existing process taking 12.25 minutes and the new process requiring 0 minutes. This stark contrast implies a significant improvement or streamlining in the new process, potentially through implementing automation, process reengineering, or other optimisation techniques. Item 6, which could be a subsequent or related task, displays a similar trend, with the existing process averaging 20.13 minutes and the new process taking 0.00 minutes. This result implies that the new process has effectively eliminated the time required for this particular item or task, potentially through process consolidation or eliminating redundant steps.

In addition, the "fully assemble item 1,4,5,6" task, which could represent the final assembly or integration stage, exhibits a significant time difference, with the existing process averaging 49.75 minutes and the new process requiring 47.10 minutes. While the new process offers a modest improvement, the required time for this task suggests potential areas for further optimisation or process redesign. Cumulatively, the total average time for the existing process is 82.42 minutes, while the new process takes 74.88 minutes. This overall reduction in time highlights the potential benefits of the new processes, which could lead to increased efficiency, productivity, and cost savings in the manufacturing or assembly operations.

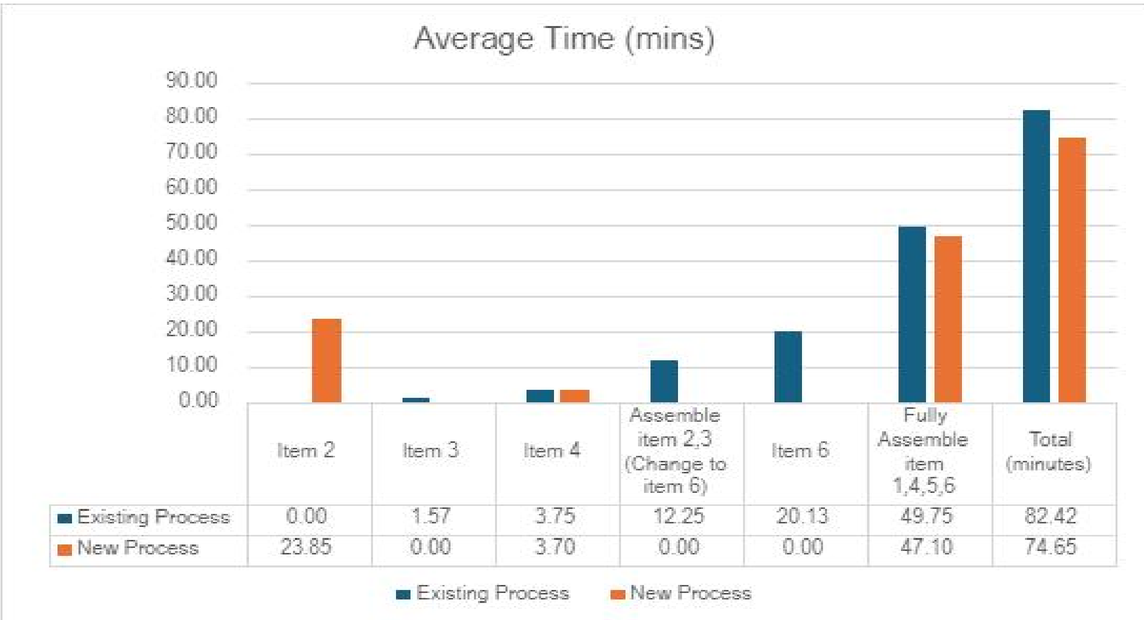

Fig. 4. Average process time taken for an existing and new process

Table 4 and Table 5 present information about the parameters and costs associated with the tools used in existing and new processes, respectively. The cost of each raw material involved in this analysis is based on existing local market range prices [21-23]. The differences and similarities between the two processes regarding the tools employed and their related expenses were analysed by comparing the tables. Starting with the tools used, Table 4 includes the MIG wire and flapping disc Grit P80, while Table 5 incorporates the endmill bit, MIG wire, and flapping disc grit P80. The inclusion of the endmill bit in the new process indicates a change or addition to the tooling requirements. The MIG wire shows that the brand and model remain the same (ER70S-6) in both processes. However, the average quantity or length differs, with 513 meters in the existing process and 424 meters in the new process. Additionally, the price per unit (RM) and the total price (RM) vary slightly, from RM151.00/1824 meter and RM42.50 in the existing process to RM151.00/1824 meter and RM35.10 in the new process.

Furthermore, regarding the Flapping Disc Grit P80, the average quantity or length has decreased from 11 pieces in the existing process to 4 pieces in the new process. The price per unit remains the same at RM2.00/unit, but the total cost has decreased from RM22.00 in the existing process to RM8.00 in the new process. The endmill bit tool, with a brand and model of S904-20mm is a new addition to the new process. It has an average quantity or length used of 1 piece with a price per unit of RM1160.00. In summary, while some tools are common to both processes, the new process introduces the endmill bit. It exhibits changes in the average quantities or lengths used and variations in the total costs associated with specific tools. This is because the price of an end mill tool is costly. However, cutting tools can be used for an extended period, depending on the feed and cut speed. Cut speed is the speed at the outside edge of the milling cutter as it is rotating, while feed rate is the velocity at which the cutter is advanced along the workpiece; its vector is perpendicular to the vector of cutting speed [24]. Therefore, it is of great significance to manage energy consumption and optimise the cutting parameters according to the machining requirements for the realisation of green and low-carbon manufacturing [17].

Table 4
Parameter and cost of tool used for existing process

Tools Used	Brand / Model	Average Quantity/Length Used	Price Per Unit (RM)	Price (RM)
MIG Wire [21]	ER70S-6 1.2mm	513 meter	RM151/1824 meter	42.50
Flapping Disc grit P80 [22]	N/A	11pcs	RM2/unit	22.00

Table 5
Parameter and cost of tool used for new process

Tools Used	Brand / Model	Average Quantity/Length Used	Price Per Unit (RM)	Price (RM)
Endmill Bit [23]	S904 20mm	1pc	RM1160.00	1160.00
MIG Wire [21]	ER70S-6 1.2mm	424 meter	RM151/1824 meter	35.10
Flapping Disc Grit P80 [22]	N/A	4pcs	RM2/unit	8.00

Each electronic equipment or machine used has its own electric consumption based on the duration of the machine's operation and type of machine. Thus, the formula calculation of energy consumption is:

$$E(kwh)= P(kw) \times t(h) \quad (3.1)$$

where E= Energy in, P= Power, and t= operation duration.

After energy consumption has been calculated for each machine used, the electric cost demand was calculated using the formula below.

$$Cost\ (RM)= E\ (kwh) \times unit\ cost\ (RM/kwh) \quad (3.2)$$

Unit cost depends on the tariff already stated by Tenaga Nasional Berhad (TNB) in Malaysia. A few industrial tariff rate categories are available as shown in Figure 5. However, Tariff D for low voltage industrial tariffs are considered in this analysis.

TARIFF CATEGORY	CURRENT RATE
TARIFF D - LOW VOLTAGE INDUSTRIAL TARIFF	
For the first 200 kWh (1 -200 kWh) per month	38.00 sen/kWh
For the next kWh (201 kWh onwards) per month	44.10 sen/kWh
The minimum monthly charge is RM7.20	
TARIFF E1 - MEDIUM VOLTAGE GENERAL INDUSTRIAL TARIFF	
For each kilowatt of maximum demand per month	29.60 RM/kW
For all kWh	33.70 sen/kWh
The minimum monthly charge is RM600.00	
TARIFF E2 - MEDIUM VOLTAGE PEAK/OFF-PEAK INDUSTRIAL TARIFF	
For each kilowatt of maximum demand per month during the peak period	37.00 RM/kW
For all kWh during the peak period	35.50 sen/kWh
For all kWh during the off-peak period	21.90 sen/kWh
The minimum monthly charge is RM600.00	
TARIFF E3 - HIGH VOLTAGE PEAK/OFF-PEAK INDUSTRIAL TARIFF	
For each kilowatt of maximum demand per month during the peak period	35.50 RM/kW
For all kWh during the peak period	33.70 sen/kWh
For all kWh during the off-peak period	20.20 sen/kWh
The minimum monthly charge is RM600.00	

Fig. 5. Tenaga Nasional Berhad (TNB) rate for low voltage industrial tariff

Table 6 and Table 7 illustrate the details of energy consumption for an existing and a new process, respectively. By comparing these two tables, it can be analysed that the differences and similarities in energy consumption between the two processes. Both tables include the welding machine and hand-grinding machine. Table 8 introduces an additional milling machine, indicating a new process step or requirement. The welding machine operates at 415 Volts and 30 Amps in both processes. Meanwhile, the hand-grinding machine operates at 240 Volts and 2.9 Amps, consistent across both processes. The new milling machine in Table 8 operates at 415 Volts and 20 Amps. In terms of Watt products, the additional process of the new milling machine has lower Watt than the existing process. Besides, the time duration for the welding machine has decreased from 1.0333 hours in the existing process to 0.7850 hours in the new process. The hand-grinding machine's duration has slightly increased from 0.4242 hours to 0.0617 hours. The new milling machine in Table 8 has a Time Duration of 0.3975 Hours.

Table 6
Energy consumption for an existing process.

Equipment Used	Brand And Model	Volts (V)	Amps (A)	Watt Produce (KW)	Time Duration (Hrs)	Energy (Kwh)(Theory Calculation)	Cost Demand
Welding Machine	Welding Machine Miller XMt 350VS	415	30	12.45	1.0333	12.8650	4.89
Hand-Grinding Machine	BOSCH GWS 060	240	2.9	0.696	0.4242	0.29522	0.11
						Total Cost	RM 5.00

Table 7
Energy consumption for new additional processes.

Equipment Used	Brand And Model	Volts (V)	Amps (A)	Watt Produce (Kw)	Time Duration (Hrs)	Energy (Kwh)(Theory Calculation)	Cost Demand (RM)
Milling Machine	C.K.S MF-450VS	415	20	8.3	0.3975	3.29925	1.25
Welding Machine	Welding Machine Miller XMt 350VS	415	30	12.45	0.7850	9.77325	3.71
Hand-Grinding Machine	BOSCH GWS 060	240	2.9	0.696	0.0617	0.04294	0.02
						Total Cost	RM 4.98

Moreover, the energy consumption for the welding machine has decreased from 12.8650 (kWh)/theory in the existing process to 9.77325 (kWh)/theory in the new process due to pre-welding process operation. The hand-grinding machine's energy consumption has decreased from 0.29522 (kWh)/theory to 0.04294 (kwh)/theory. The additional process of the milling machine in Table 8 has an energy consumption of 3.29925 (kWh)/theory. Then, the cost demand for the welding machine decreased from RM4.89 in the existing process to RM3.71 in the new process. The hand-grinding machine's cost demand has reduced from RM0.11 to RM0.02. The alternative milling machine in Table 8 has a cost demand of RM1.25. In addition, the total cost for the existing process in Table 7 is RM5.00, while the total cost for the new process in Table 8 is RM4.98, indicating a slight reduction in overall cost. Thus, the new process introduces a milling step, reducing energy consumption and cost. However, the energy consumption and costs associated with the welding and hand-grinding machine have decreased in the new process compared to the existing process, potentially due to process improvements or optimisation.

Conclusions

The impact of milling process has been recognised. By adding milling process, it can reduce the number of material used. It also overcomes the repeated process (duplicate work) that occurred during the existing process. The new process introduces the endmill bit and exhibits changes in the average quantities or lengths used and variations in the total costs associated with specific tools, making the endmill tool costly. The additional process of the new milling machine reveals lower Watt, less time duration for the welding machine, reduced energy consumption for a hand-grinding machine, and lower cost demand for the welding machine than the existing process. In addition, the total cost of added milling process shows a slight reduction in overall cost and is associated with energy consumption.

Acknowledgement

This research was supported by the Industrial Grant (M115) and Matching Grant (Q273), and facilities provided by Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia. Special thank you to Intec Precision Engineering Sdn. Bhd. as a research collaborator.

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