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MINIMIZATION OF MACHINING PROCESS SEQUENCE BASED ON ANT COLONY ALGORITHM AND CONVENTIONAL METHOD

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Abstract

Machining airtime or non-productive time or airtime is a process of movement of the tool before shaping the workpiece. One of the methods to decrease the total machining time is by reducing airtime. Thus, in this study, an optimization of the sequence operation in machining was conducted using an Artificial Intelligence method, which is the Ant Colony algorithm. This algorithm was employed to decrease the machining airtime to enhance the effectiveness of the machining process. A three-dimensional model consisting of the drilling process and pocket milling process was developed using Solidworks software. Matlab software was used to develop the algorithm based on Ant Colony, which was then used to optimize the process sequence. Hence, the results of the optimization were implemented in MasterCAM software to run the machining simulation. Then, the results of machining time that used the tool path generated by the Ant Colony algorithm method was compared with the machining time that used tool paths generated by conventional methods. Based on the simulation, the Ant Colony algorithm method is, on average, 10.8% better than conventional methods in reducing machining time. It can be concluded that the Ant Colony algorithm is capable of reducing airtime machining and enhancing the machining process's performance.

Keywords: Ant colony algorithm, Machining sequence, MasterCAM.

1. Introduction

Lower machining time in the process of machining is essential to enhance the productivity of machining. To reduce machining time, several methods have been introduced based on conventional and non-conventional techniques [1, 2]. In the conventional method, an experimental approach and mathematical formulation are applied to determine the optimum parameters to produce a lower machining time.

For example, Vavruska et al. [3] conducted an optimization technique based on the experimental approach to propose a new strategy based on point milling that focus on tools with a circular cutting edge. This method can manage the feed rate and cutting speed to reduce machining time by handling the cutting parameters in the milling process. The method controlled the spindle speed to achieve a constant rate of speed as a result to monitor the feed rate.

Gadekula et al. [4] performed an experimental approach to minimize the cycle in machining operation. The optimization process was implemented in Computer Numerical Control Program (CNC) using R-parameters and subroutines. However, the main disadvantages of experimental work are that the process takes a longer time and must be done repetitively.

Besides experimental work, mathematical formulation is one of the conventional methods of optimization. For example, Leroy et al. [5] used a B-spline interpolation based on the mathematical formulation to improve the performance of tool paths in Mastercam software which are zig-zag, contour parallel, and spiral methods. Huang et al. [6] and Huang et al. [7] suggested and produced a technique to increase the performance of the spiral strategies path based on the medial axis (MA) transformation. This method focused on the machining pocket without islands that has no additional material inside the counter. This new method can lower the entire length of the path and consequently reduce the period of operation. Besides that, this method can improve both the typical contour-parallel technique and the current spiral tool path approach. It focused on reducing the total time by decreasing the entire length of the tool path. An experiment was performed to prove the improvements of the suggested method on machining productivity enhancement. However, the proposed technique only focused on the contour spiral tool path strategies. The limitation of the proposed mathematical formulation is that it does not consider the other criteria of machining such as surface roughens.

Non-conventional optimization techniques also are widely used in the machining process to enhance the machining performance. Debroy and Chakraborti [8] has performed a review study related to non-conventional method use in machining. In non-conventional optimization, the main purpose is to develop an objective function to decrease the time by obtaining the optimum parameter or reducing the tool path length based on several constraints. In a study by Karrupanan et al. [9], non-conventional optimization techniques were employed to reduce the distance of tool path in pocket milling by determining the connection of the segment. The result of Genetic algorithm (GA) has been compared with the result obtain by Particle Swarm. However, this method only focused on the contour parallel tool path. Besides that, GA also had been used by Farughi et al. [10] to propose a mathematical model as the objective function to minimize the tool switches in flexible machining operation. One of the parameters that influenced machining time is the length (ACO) of tool path. Hence, several researchers have applied the Ant colony algorithm to improve the total time or airtime by obtaining the optimum length of the path.

Abdullah et al. [2] and Abdullah et al. [11] performed a modification to basic ACO to reduce the path length in pocket machining. The modified algorithm was verified using experimental work. Based on Xin et al. [12], the main advantage of ACO search is influenced by searching efficiency and pheromone constructive feedback, thus produce shortest processing path. Therefore, a new algorithm had been proposed to improve the milling peripheral process method that contain multi-cavity based on ACO. Each cavity was considered as a point denoted by x, y, and z coordinates. Compared to the existing methods such as zigzag and peripheral, the ACO based tool path is capable of decreasing the time by obtaining the optimum path length. Ant colony optimization has been widely used in the optimization process. Besides ACO and GA, Cuckoo Search Optimization is also capable of producing better performance in reducing machining time [13].

Mellal and Edwards [14] performed a simulation using CS to decrease the whole manufacturing time of the process of milling. From the simulation, it was found that CS produced better results than other methods. Biogeography-Based Optimization is one of the nature-inspired metaheuristics that is capable of producing better performance in the minimization process. As such, Narooie et. al [15] applied this method to minimize the airtime motion in pocket milling. The length of the cutting path can also be decreased by considering the scallop heights criterion in the free-form surface process [16]. In this study, the surface was split into various areas depend on different intervals. These intervals made certain that the contact location at the surface had a higher value than the range of the cutting tool with an enhanced feed rate.

Simulation on CAD/CAM software can improve the performance of machining time. Mniwuka et al. [17] used Mastercam software to determine the appropriate combinations of cutting tool sizes by producing tool paths. In addition, several simulations can define the optimal parameters of machining used in the CNC milling process. The tool path length and parameters were determined by defining the best of sizes for cutting tools during the simulation achieved by utilising MasterCAM software. Besides that, Sumbodo et al. [18] performed several simulations for the milling process to determine lower machining time from various machine parameters, tool path strategy, and variations in cross-sectional shapes. CADCAM software has been used to optimize machining parameters in pocket roughing such as feed rate, cutting speed, and axial cut).

Based on the study by Conradie et al. [19], tool path strategies are an essential factor influencing production time and manufacturing cost. For the pocketing process, Abdullah et al. [20] performed a simulation using the Ant colony to minimize non-productive time to reduce the total time in machining. In this study, the method of contour parallel had been implemented in the pocketing process. The center of contour parallel was considered as the point to implement the Travelling Salesman Problem (TSP). At the same time, this research studied the effect of intervals in contour parallel machining strategies and found that the parameter of cutting strategies influences the total length and time of machining.

For a component with many types of processes, it is important to define the sequence to produce a lower machining time [21]. Several research have been done to study and minimize machining time in components that involve many operations. For example, Sing and Deb [22] used the basic ant algorithm to optimize the machining operation. Several operations were involved in this study, such as face milling, end milling, drilling, and boring. However, this research focused more on reducing the manufacturing cost by minimizing the quantity of cutting tools and time to setting up changes for an environment involve with single machine rather than machining time.

Liu et al. [21] also developed a mathematical formulation for planning the process by taking into consideration the machining constraint in reducing the machining cost. ACO was used to optimize the cycle operation. There are three processes of machining which are drilling, face, and slot milling. The computing results showed that ACO produced a better performance compared to Tabu Search and Genetic Algorithm. Similar with the study by Djurdjev et al. [23], optimization of operation sequencing was performed using Genetic Algorithm. Most of the previous research performed optimization to reduce the manufacturing cost in machining by considering tool changing, set up cost, and machining cost. In this research, the main objective is to minimize the path length in a machine component that has different types of machining operation which affects the time of machining and manufacturing cost. Simultaneously, in determining the optimum sequence operation, this study also considered and investigated the optimum tool path strategies on pocket machining.

In Mastercam, the sequence's representation depends on the operator handling the software and CNC machine. Hence, this will lead to a misleading optimal sequence, which sometimes will lead to a higher machining time. Therefore, in this present study, a sequence machining operation was minimized using an Artificial Intelligence method, ACO. A three-dimensional model with various machining processes had been developed in CAD software.

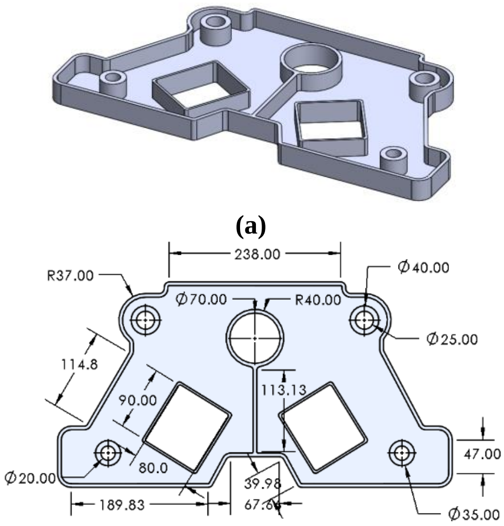
2. Methodology

In this study, there are three parts of the methodology. For the first step, a three-dimensional sugar cane crusher was developed using Solidworks software. Then, Matlab software was used in developing Ant Colony Algorithm. This algorithm is used to obtain the optimum operation sequence in machining process. Subsequently, for the third step, Mastercam was used to implement and verify the results of the algorithm.

2.1. Development of three-dimensional model

To analyse the practice sequence that obtain by Artificial Intelligence method, the model of a sugar cane crusher had been developed based on Mniwuka et al. [17]. Figure 1 shows the three-dimensional model and top view using Solidworks software.

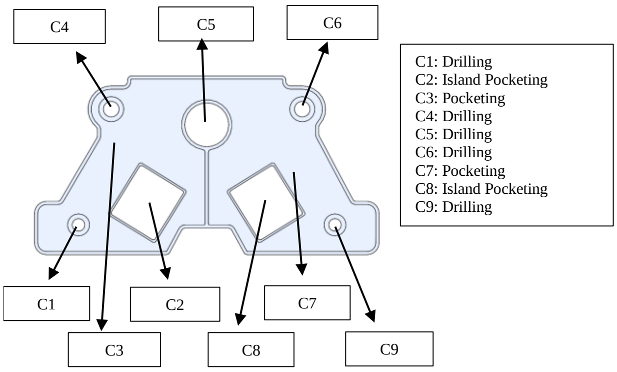
The model of a sugar cane crusher was designed with complex pockets and islands, as presented in Fig. 2. In minimizing the process sequence, each process had been denoted with point numbers as shown in Fig. 2. In this component, there are three processes involved which are drilling, pocketing, and island pocketing. Each point of center (C) of the process was denoted by a coordinate in the x- and y-axis. These coordinates were used as the input parameter in the Ant Colony Algorithm.



(a)

(b)

Fig. 1. Model of sugar cane crusher
(a) Three-dimensional view (b) Top view [17].



(b)

Fig. 2. Machining process in the component sugar crane crusher.

The Ant Colony algorithm was developed to determine the sequence of the process. The points shown in Fig. 2 are variables in the ACO algorithm that represent the centre of the operation machining.

2.2. Ant colony optimization

In minimizing the sequence of machining processes in the sugar crane crusher component, Matlab software was used to develop the algorithm of the Ant Colony Optimization. The objective function is to minimize the sequence operation by determining the length of the path as shown in Eq. (1).

$$f(x,y,z) = \sum_{i=1}^{n-1}\sum_{j=2}^{n}\sqrt{\left(x_j - x_i\right)^2 + \left(y_j - y_i\right)^2} + \sum_{k=1}^{n} z_k \qquad (1)$$

where, x and y are absolute coordinates of centre for each operation, and z is the z-axis tool movement at each point. The variables of coordinates (x, y) depend upon the number of operations for the machining process. The function is subjected to a constraint where the calculation of the optimum length must start from the first point, C1. In ACO, some parameters have to be defined, such as the coordinates of the centre for each process, weight of pheromone (σ), weight of visibility (β), and weight of trail. In the ACO, the ants were placed at the first point. In this study, the first point is referred to as Point 1, as demonstrated in Fig. 1. Next, the choice to the following point is affected by the probability formula. Once the movement of ants is completed, all the points have been visited, the movements have been stored in a matrix length, and the non-productive length is calculated. Then, the pheromone will be updated to determine the shortest distance. The flow process of ACO is shown in Fig. 3.

From this algorithm, the results of optimum sequence operation were obtained. Following that, the sequence was implemented in Mastercam. However, the ACO developed was just to optimize the process plan for one part at a time and could not handle the problem for two or more parts of a component. In Mastercam, there are several parameters that need to be defined and this is going to be clarified in the next part.

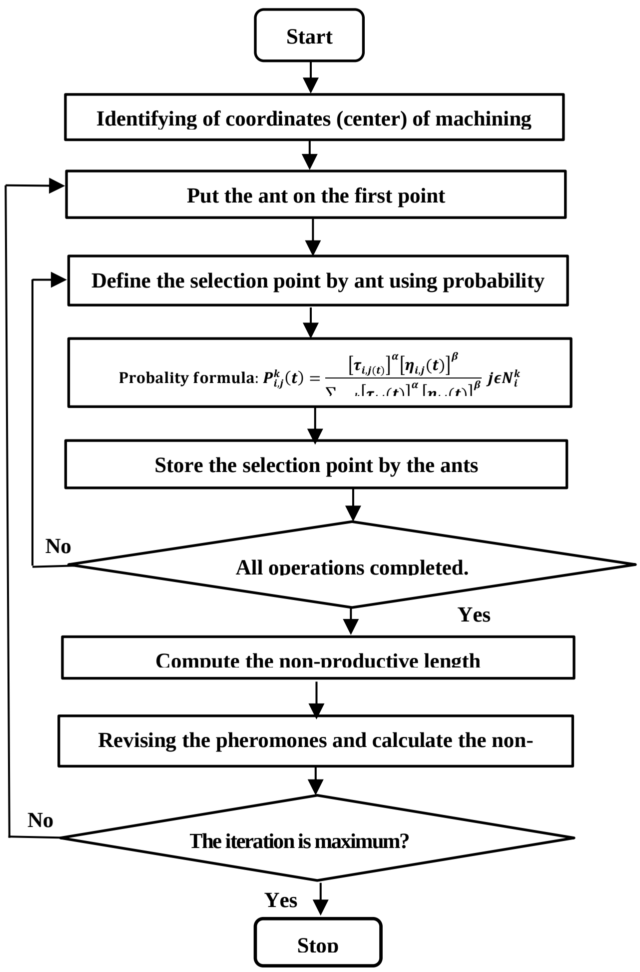


Fig. 3. The process of ACO

2.3. MasterCAM Simulation

To observe the performance of the ACO, the optimal sequence of machining operation obtained based on Matlab software had been implemented in MasterCam software. For the machining tool path, two processes were involved, namely the drill and pocket process. For the pocket island and pocketing process, seven types of machining strategies were used: Zig-Zag, Parallel Spiral, Morph Spiral, True Spiral, Clean Corner, Constant Overlap Spiral, High Speed, and One Way as shown in Fig. 4. In Mastercam, there are two types of tool path generation: tool path based on Mastercam default and tool path generation, where the sequence of processes is defined by a simulation of ACO. Mastercam by default refers to the sequence defined by the operator of the machine. Table 1 illustrates the machining parameters that were employed in the tool path production.

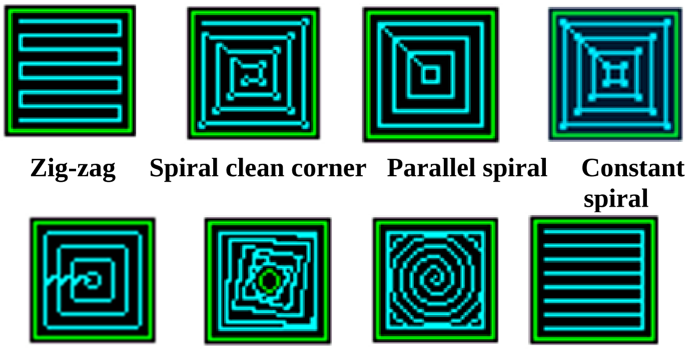


Fig. 4. Machining process in sugar cane crusher.

Table 1. Machining parameters are defined in MasterCam [24].

Operation	Spindle Speed	Cutting Feed
Drill 1 (25mm)	5000	950
Drill 2 (20mm)	5000	950
Drill 3 (30mm)	5000	950
Pocket island1	5000	950
Pocket island 2	5000	950
Pocket	9000	1800

3. Results of Path Length and Discussion

There are two sections for the results of minimization, which are non-productive path length established by ACO and the results of path generation in Mastercam.

3.1. Minimization of non-productive tool path length

ACO had been implemented to minimize the process sequence in the sugar cane crusher component by determining the non-productive length of the path of the cutting tool. Table 2 indicates the findings of the non-productive path length obtained established on the optimization process. The shortest distance is referred to as the optimum process sequence of the machining. Based on Table 2, the shortest length is 865.95 mm, and this value produces the optimum process sequence.

Table 2. Results of non-productive length on process.

No. of Run	Length	No. of Run	Length
1	891.2304	11	865.9548
2	865.9548	12	891.2304
3	865.9548	13	865.9548
4	891.2304	14	891.2304
5	865.9548	15	865.9548
6	891.9548	16	865.9548
7	865.9548	17	865.9548
8	910.642	18	865.9548
9	865.9548	19	865.9548
10	865.9548	20	865.9548

From Fig. 5, the optimum sequence starts at C1, then proceeds to C2, followed by C3 and C4. Next, the operation proceeds to points C5, C6, C7, C8, and ends at C9. This sequence was used in Mastercam to produce the tool path for the sugar cane crusher. It started with the drilling process and proceeded to the second process, island pocketing, and pocketing machining. This process continued until the last point, and then the whole process was completed. In this optimization, it had been assumed that the time of changing the cutter is ignored. Furthermore, the tool retraction on each process was also dismissed.

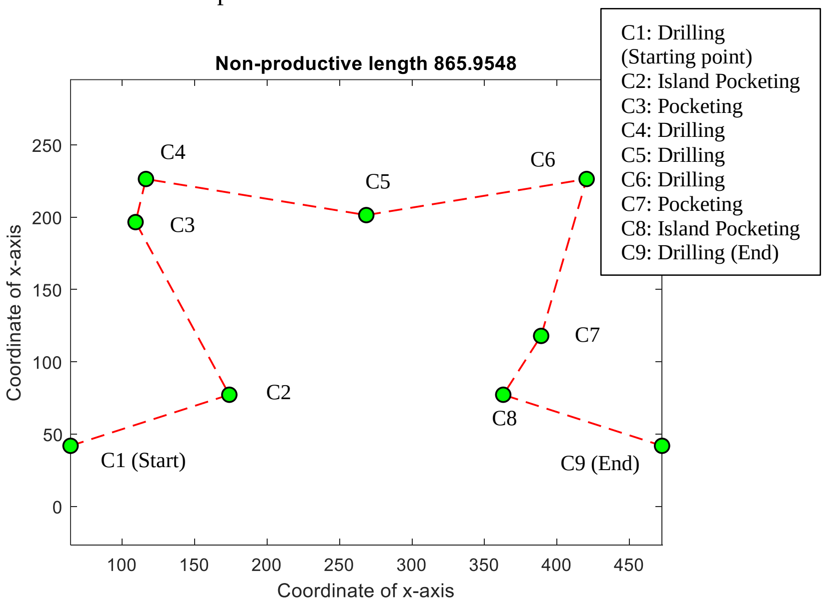


Fig. 5. Optimum sequence operation based on ACO.

3.2. Tool path generation in Mastercam

To observe the productivity of ACO, in minimizing the sequence of the machining process, an evaluation on the path length between the default Mastercam and Mastercam-ACO was performed. For the first series of simulations, the cutting tool's path was produced using the default setting. The default setting refers to the sequence of the machining process operation based on the operator's set. While for Mastercam-ACO, the sequence of the machining operation was determined by optimization using the ACO method. The default operation sequence in Mastercam is shown in Fig. 6. For the starting point, the process started with drilling (1) and then followed by the process of drilling (2). The process is considered completed once the main pocket, which is Point 9, completes the machining process. For the pocketing process, which is Point 6, Fig. 4 indicates the machining operation is based on Zig-Zag, Parallel Spiral, Morph Spiral, True Spiral, Clean Corner, Constant Overlap Spiral, High Speed, and One Way.

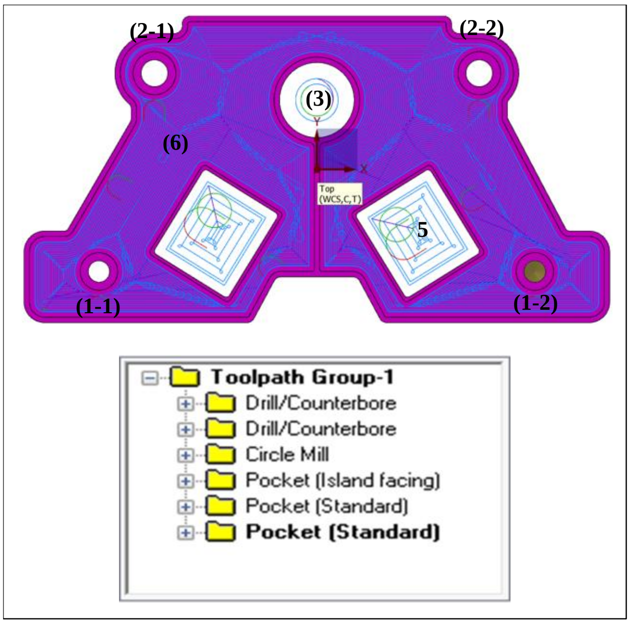


Fig. 6. Operation sequence based on default Mastercam (first series simulation).

The second series of simulations that implemented the optimal sequences of the machining operation obtained based on ACO minimization is shown in Fig. 7. This sequence was chosen based on the lowest of non-productive path length based on ACO. Like the default Mastercam, the generation of tool path based on ACO also used Constant Overlap Spiral, Zig-Zag, One Way, Parallel Spiral, Morph Spiral High Speed,Clean Corner, Parallel Spiral, and True Spiral for the pocketing operation.

To observe the performance of ACO implementation on the tool path generation, a comparison of the non-productive tool path length or known as rapid length, and total length in Mastercam is explained in Table 3. Based on Table 3, for all types of tool path strategies, the combination of Mastercam and ACO produced a lower total tool path length. The zig-zag method produced a lower path length compared to the other tool path methods for the pocketing process. The implementation of ACO shows that the Zigzag method produced the lowest rapid path length and total tool length for both tool paths generation, which is by default Mastercam and implementation of ACO. For the rapid length, ACO had decreased about 10.8% of the rapid length. Based on the study by Huang et al. [6], they developed an algorithm to improve the path strategies that applied in the pocketing machining, and the results were contrasted with the path in Mastercam. The percentage of reducing length was between 1.6% and 34.4%. Therefore, the percentage of the reduction for this study is considered effective and acceptable. On the other hand, Xin et al. [11] proposed a mathematical model which performed a simulation that implemented the ACO on a multi-cavity auronautical part to reduce the non-productive length and machining time. It was found that the basic of ACO can decrease the machining time of a sample by around 13%. This showed that the implementation of ACO in determining the optimal sequence of the operation had decreased the total length.

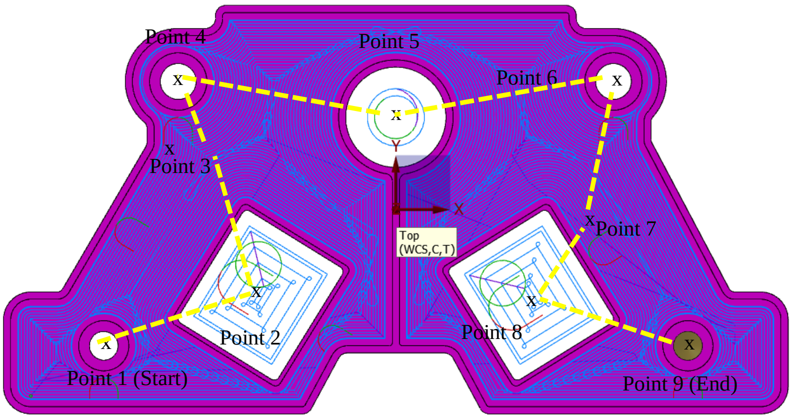


Fig. 7. Operation sequence based on minimization using ACO (second series simulation).

Table 3. Toolpath rapid length and different type of toolpath.

Strategies	Mastercam		ACO-Mastercam	
	Rapid length	**Total length**	**Rapid length**	**Total length**
	22967.299	286678.13	20484.039	286562.49
	22115.75	316836.99	21236.44	316721.35
	21790.48	297674.9	20911.17	297559.168
	21790.48	331303.68	20911.17	331188.04
	22152.08	2110044.78	21272.78	2109929.14
	21363.35	290283.99	20484.039	290168.039
	429292.59	372597.504	428413.28	372481.86
	21409.074	1521926.3	20529.76	1521810.66

Figures 8 and 9 show a difference of rapid length and total length for tool paths generated using Mastercam and combination of ACO-Mastercam. Reffering to the results depicted in the table, it can demonstrated that the zig-zag technique produced the lowest rapid length of the tool path for both methods, Mastercam and combination of ACO-Mastercam, respectively. On the other hand, the one way method produced the highest rapid length. The results obtained by Prajapati et al. [25] also showed that the one way method produced a higher rapid length compared to other methods due to the increase of tool retraction. For the total length of the machining process, the method of morph spiral produced the longest total length for Mastercam and combination of ACO-Mastercam. The morph spiral produced a rotational movement and this consequently generated a lengthy circulation of the path machining so as to generate a higher time [18]. Similar results were also found by Navaneetham et al. [26] and Danesmand [27]. Although most of the previous reseach had discussed more about the influence of cutting path stategies on time of machining, it is undeniable that the significant parameter that influences the time is the length of tool path [28].

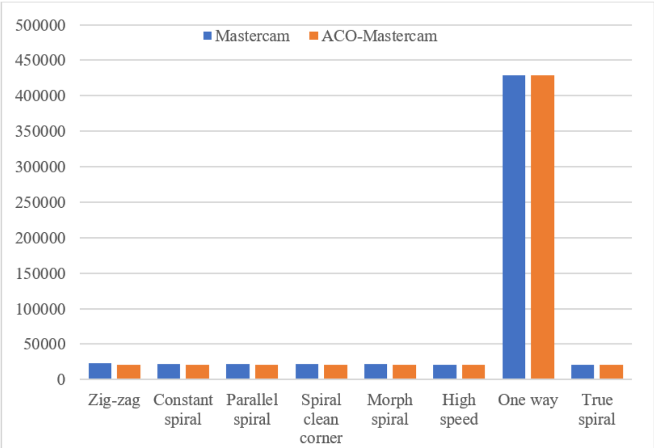


Fig. 8. Comparison of rapid length between the tool path using Mastercam and combination of ACO-Mastercam.

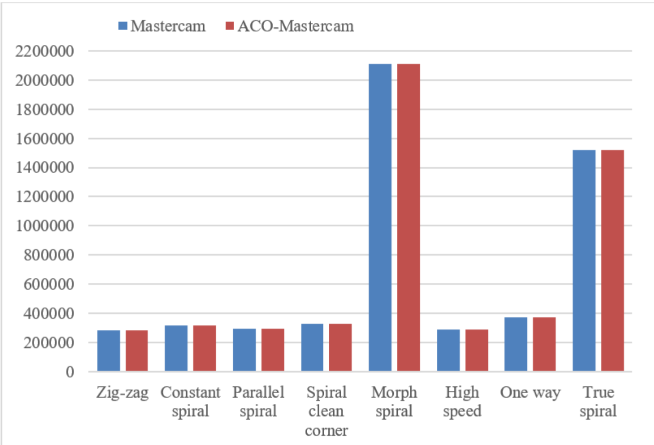


Fig. 9. Comparison of total length between the tool path using Mastercam and combination of ACO-Mastercam.

4. Conclusions

This research was conducted to minimize the sequence of machining operations to minimize the total path length in the machining operation. A three-dimensional model with three different machining operations was developed using CAD software. ACO had been implemented to optimize the sequence of the operation. Based on the simulation, it has been found that the determinations of operation sequence can reduce the total length by about 10.8%. It can be concluded that ACO is capable of minimizing the operation sequence to reduce the length and automatically reduce the machining time.

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Nomenclatures

L_k	Total length

Greek Symbols

α	Pheromone effect
β	Visibility effect
η_{ij}	$1/d_{ij}$ is the visibility
τ_{ij}	Intensity of trail on edge (*i*, *j*) at time *t*

Abbreviations

ACO	Ant Colony Optimization
CS	Cuckoo Search
GA	Genetic Algorithm
PSO	Particle Swarm optimization

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