HYBRID ARTIFICIAL BEE COLONY ALGORITHM WITH BRANCH AND BOUND FOR TWO–SIDED ASSEMBLY LINE BALANCING

SALEM ABDULSALAM ELTERIKI

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In the name of

ALLAH

Most Gracious,

Most Merciful

To my **Mother**.

To my **Wife**.

To my **Sons** and **Daughter**.

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ABSTRACT

The two-sided assembly-line balancing (2SALB) is widely used in various production systems especially in high-volume large-size products. However, not many types of research are focused on the study of the 2SALB problem. Recently, the artificial bee colony (ABC) algorithm was used in the solution process where it was considered as a very useful, effective and well-known algorithm. Nevertheless, the ABC is also known to be a slow converging method in achieving an optimal solution. This research is intended to improve the ABC performance in solving the 2SALB problem with the objectives to hybrid ABC algorithm with branch and bound concept and to evaluate the performance of this algorithm in minimizing idle time and number of the workstation . The two-sided assembly line data was tested in modified spreadsheet model which is equipped with random priority rules in order to get multi-solution of ABC approach for balancing two-sided assembly line. The feasible number of workstations was determined with the minimum idle time of every mated station and maintains the minimum one in each cycle. This was done by calculating the partial fitness of the mated station. The branch and bound concept was applied by using mated workstations to overcome the slow convergence of the ABC algorithm and solve the problem optimality. The visual basic application software was used to generate different solutions with the various partial fitness of the proposed approach. The modified ABC algorithm was tested with the 2SALB problems involving P9, P12, P16, P24, P44 and P65 tasks. The results were tested by comparing hybrid ABC with pure ABC, where it was found that hybrid ABC had less number of workstation with minimum partial fitness value. In addition, the comparison was done with other research on ABC with full constraints and the proposed approach shows improvement by reduction of two workstations in sixteen task problem and reduction of one workstation at nine, twenty four and sixty five task problem sizes. As a conclusion, the proposed hybrid of ABC with Branch and Bound concept has increased the effectiveness of 2SALB solutions through the evaluation of many alternative mated stations results before going to assign to next mated stations to obtain minimum workstations with given cycle time solution.

ABSTRAK

Penyeimbangan barisan pemasangan dua sisi (2SALB) banyak digunakan secara meluas dalam pelbagai sistem pengeluaran terutamanya melibatkan produk bersaiz besar serta berskala tinggi. Walau bagaimanapun, tidak banyak jenis penyelidikan tertumpu kepada kajian masalah yang melibatkan 2SALB. Kini, algoritma koloni lebah buatan (ABC) telah digunakan dalam proses penyelesaian di mana ia dianggap sebagai algoritma yang sangat berguna, berkesan dan terkenal. Walau bagaimanapun, ABC juga dikenali sebagai kaedah yang perlahan untuk mendapatkan penyelesaian yang optimum. Kajian ini adalah bertujuan untuk meningkatkan prestasi ABC dalam penyelesaian masalah yang melibatkan 2SALB dengan objektif untuk menghibrid algoritma ABC dengan konsep *branch and bound* serta menilai prestasi algoritma ini dalam meminimumkan masa terbiar dan bilangan stesen kerja. Data barisan pemasangan dua sisi telah diuji di dalam model *spreadsheet* yang telah diubahsuai dan dilengkapi dengan peraturan keutamaan secara rawak bagi membentuk pelbagai pendekatan penyelesaian ABC untuk mengimbangi barisan pemasangan dua sisi. Bilangan stesen kerja yang sesuai telah ditentukan dengan masa terbiar yang minimum bagi setiap pasangan stesen dan mengekalkan nilai minimum dalam setiap kitaran. Ini dilakukan dengan mengira *fitness* separa pasangan stesen. Konsep *branch and bound* digunakan terhadap stesen kerja berpasangan untuk mengatasi sifat perlahan algoritma ABC bagi mendapatkan penyelesaian yang optimum. Perisian *Visual Basic for Application* telah digunakan untuk membentuk pelbagai penyelesaian dengan tahap *fitness* separa yang berbeza melalui kaedah yang dicadangkan. Algoritma ABC diubahsuai dan diuji dengan masalah 2SALB yang melibatkan saiz tugas P9, P12, P16, P24, P44 dan P65. Hasil daripada ujikaji telah membandingkan ABC hibrid dengan ABC tulen, di mana ianya mendapati ABC hibrid mempunyai bilangan stesen kerja yang kurang dengan nilai *fitness* separa yang minimum. Di samping itu, perbandingan juga dilakukan dengan kajian lain terhadap ABC dengan kekangan yang penuh dan kaedah yang dicadangkan berjaya mengurangkan dua stesen kerja dalam saiz masalah P16 dan pengurangan satu stesen kerja pada P9, P24 dan P65. Kesimpulannya, kaedah ABC hibrid dengan *branch and bound* telah menunjukkan peningkatan keberkesanan dalam penyelesaian melibatkan 2SALB melalui penilaian pelbagai alternatif stesen berpasangan sebelum menetapkan tugas kepada stesen berpasangan seterusnya. Kaedah ini juga berjaya mendapatkan nilai minimum stesen kerja dalam penyelesaian kitaran masa yang ditetapkan.

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LIST OF SYMBOLS AND ABBREVIATIONS

NP	Non-deterministic Polynomial-time
ABC	Artificial Bee Colony
B&B	Branch and Bound
ALB	Assembly line balancing
OSALB	One-side assembly line balancing
2SALB	Two-sided assembly line balancing
Ct	Cycle time
Sk	Station operation time
BA	Bee algorithm
PSO	Particle Swarm Optimization
GA	Genetic Algorithm
DE	Differential Evolution
EA	Evolutionary Algorithm
TS	Tabu Search
SA	Simulated Annealing
P9	Problem size nine tasks
P12	Problem size twelve tasks
P16	Problem size sixteen tasks
P24	Problem size twenty four tasks
P44	Problem size forty four tasks
P65	Problem size sixty five tasks
CT	Cycle Time
SB	Scout Bee
EB	Employed Bee
OB	Onlooker Bee
P	Number of Employed Bee
J	Number of solution for Employed Bee
I	Number of mated workstations
K	Number of solution for Onlooker Bee
EBop	Optimal solution of Employed Bee
OBop	Optimal solution of Onlooker Bee
W/S	Work Station
n	Number of Work Station
f	Fitness value

CHAPTER 1

INTRODUCTION

1.1 Research Background

The flow assembly line is an important process in the manufacturing and production system. It is used to produce automobiles, transportation equipment, household appliances and electronic goods. The beginning of the assembly line can be traced back to the 19th century and the first flow assembly line was initiated to produce the steam engines at the factory of Richard Garrett & Sons in 1853. Henry Ford is most prominent for his contribution to the rise of mass production in the early 20th century. The assembly line developed for the Ford Model T began operation in December 1913 and it had a huge influence on the world.

Assembly line has been widely used in various production systems to produce high-volume standardised products. Assembly line balancing (ALB) is the term used to refer to the decision process of assigning tasks to workstations in a serial production line. The task consists of elemental operations required to convert raw material into finished goods. The task allocation of each workstation is achieved by assembly line balancing to increase assembly efficiency and productivity. The components are processed depending on the set of tasks for a given cycle time. Tasks are assigned to an ordered sequence of stations according to a given precedence relationship among them.

For any assembly line, an important decision is to have an adequate arrangement of the line. The decision problem of optimally assigning tasks to workstations is to guarantee continuous product flow, known as the assembly-line balancing problems. The main objective in line balancing is maximizing efficiency which could be understood as making the best use of resources such as time, capital and manpower. Many researchers have focused their efforts on solving the line balancing problem using mathematical models, heuristics methods, and other procedures. In recent technology improvement, production of complex products with hundreds of tasks has started to become possible. The large-scale of complex products, such as buses and trucks were produced in a simple assembly line having hundreds of stations. In addition, a huge manufacturing plant and several work-in-processes would be needed.

The two-sided assembly-line balancing (2SALB) problem was first studied by Bartholdi (1993). He presented the two-sided assembly line balancing and described the design and usage of a computer program which embodies a balancing algorithm. The two-sided assembly line has two parallel stations allocated on the left and right sided direction. Two-sided assembly line offers several advantages over a one-sided assembly line. For example, some task times might be shorter since the worker can avoid setup times, a two-sided line can be more space-efficient since the line length can be shorter, and not only will the cost of tools and fixtures be lowered but material handling and workers movement shall also be reduced.

The two-sided assembly line balancing (2SALB) problems can be classified based on the number of models produced in the line, the nature of task times are deterministic or probabilistic, and the nature of flow was straight-type or U-type

In the same assembly line, one or more models of a product may be assembled. If only a single model were assembled in the line, then the production system was defined as a single-model assembly system; otherwise, it was called a multi-model assembly system. The processing times of the tasks may be either deterministic or probabilistic. If the tasks were performed using all sophisticated tools and fixtures by highly skilled labours, then the processing times of the tasks may be approximated to deterministic quantity, because the variability in the processing times may be less under such situation. This was because of the facilitating nature of tools and availability of operators with required skills. But, normally, in assembly-type operations, the processing times will vary, which can be characterized in the form of some probability distribution. The arrangement of the workstations of the assembly line may be in a straight-line layout or in a U-shape layout.

Several researchers have presented alternative approaches to solve the 2SALB problem using different algorithms. Heuristic Swarm intelligent algorithms were applied to the 2SALB problem to get an optimal solution. Although practical mathematical models were functioned on the problem, the studies of the two-sided assembly line are still limited (Sivasankaran & Shahabudeen, 2014). The steps of execution for balancing the line is not clear.

1.2 Problem Statement

The problem statement in this research addresses two issues; first is the challenges in solving two-sided assembly line balancing problem, and the second is the low convergence of Artificial Bee Colony algorithm. The optimal solution of 2SALB need heuristic algorithm, ABC is suitable for optimization problems but it have low convergence. The hybrid ABC being important work to accelerate local optima solutions of ABC.

1.2.1 Challenges of Solving Two-sided Assembly Line Balancing (2SALB)

The two-sided assembly line balancing (2SALB) problem is to determine the assignments of tasks to an ordered sequence of mated stations. The sequence dependency of tasks at stations and preferred operation direction of tasks should be determined. As well as which task should be assigned to a left or a right side station or can be performed at either side of the assembly line. There are some of the constraints considered of balancing two-sided assembly lines such as cycle time, precedence and task direction constraints. Therefore, the assembly line balancing problems fall into a non-deterministic polynomial-time (NP) hard class of combinatorial optimization problems.

In recent years, most of the researchers have tried to model the more realistic problems of two-sided assembly line balancing. There are many studies suggesting heuristics algorithms and techniques models in solving assembly line problems. However, many researchers described that the intention to minimize number of workstation in two-sided assembly line balancing is a very challenging problem (Kim et al. (2000); Lee *et al*. (2001); Baykasoglu & Dereli (2008); Hu, *et al*. (2008); Wu *et al*. (2008); Ozcan & Toklu (2009a); Ozcan & Toklu (2009b); Ozcan & Toklu (2009c); Simaria & Vilarinho (2009); Ozbakir & Tapkan (2011); Tapkan, P., Ozbakir, L. & Baykasoglu, A. (2012); Janardhanan *et al*. (2018); Li, Tang & Zhang (2017)). The contributions of these researchers were to solve two-sided assembly line balancing optimality by heuristic algorithms and hybrid algorithms. Consequently, the studies on two-sided assembly line balancing are still too limited. Among the recent two-sided assembly line balancing studies was the work of Tapkan *et al*. (2012) which utilized Artificial Bee Colony algorithm to solve 2SALB. A mathematical programming model for fully constrained (fc2sALB) proposed to describe the problem formally due to the complexity of the problem. The objective of the study was to solve large-sized 2sALB problems including different types of constraints which are position, zoning, synchronous, preceding and cycle time constraints. Hence, it should be simplify the 2SALB problem and clarify the steps of assigning tasks to workstations.

Hence, this research focuses on balancing two-sided assembly line by using spreadsheet model in which the random priority rule was developed to generate multi-solution. The solutions can be visualised in the spread sheet by assigning the tasks to workstations.

1.2.2 Local optima slow convergence of Artificial Bee Colony algorithm

The Artificial Bee Colony (ABC) algorithm contains three groups of bees; employed bees, onlooker bees, and scout bees search for food sources randomly. ABC algorithm is one of the most recently presented optimization algorithms simulates the intelligent foraging behaviour of a honey bee swarm. The accelerating convergence speed and avoiding the local optima have become most important and interesting goals in ABC research.

Despite its ability to obtain good solutions, the ABC algorithm at its original character is known to have a slow convergence performance for local optima (Karaboga *et al*. 2014). It is well known that both exploration and exploitation are necessary for a population based optimization algorithm. In practice, the exploration and exploitation contradicts to each other. In order to achieve good performances on problem optimizations, the two abilities should be well balanced. Karaboga *et al*. (2014), also observed that the solution search equation of ABC algorithm which is used to generate new candidate solutions based on the information of previous solutions, is good at exploration but poor at exploitation, which results in a slow local optima convergence performance. This is the reason to many hybrid efforts done in order to improve the ABC performance inclusive the works of Jatoth & Rajasekhar (2010), El- Abd (2011), Sharma & Pant (2011) and Li & Jian (2011). Karaboga *et al*. (2014) concluded that ABC is suitable to be applied for optimization in dynamic and uncertain environment provided that it is combined with another algorithm to improve its performance.

Branch and bound algorithms are based on enumerating feasible solutions by successively assigning tasks or subsets of tasks to workstations. The enumeration tree uses to demonstrate the nodes and branches of feasible solutions and it is known to be huge with big number of tasks. Many hybrid studies on ABC focused on combination with an evolutionary algorithm, tabu search, simulated annealing, particle swarm, genetic algorithm, bacteria forging and local search (Hu *et al*. , 2010).

From the literature, no report was found on the hybrid effort related to ABC process and the concept of branch and bound to solve the two-sided assembly line balancing problem. Motivated by the work of Tapkan *et al*. (2012) and Wei *et al*. (2014), this research hybrid the ABC algorithm with the branch and bound concept specifically intended to solve the two-sided assembly line problem.

In this research, the ABC algorithm with the branch and bound concept are utilized to determine the feasible number of workstations by determining the minimum idle time of every mated station and maintain the minimum one in each cycle. This can be done by introducing the partial fitness of mated station to overcome the slow convergence of the ABC algorithm. Hence, this research proposed the hybridization of ABC algorithm with the branch and bound concept is introduced in order to increase the effectiveness of two-sided assembly line balancing solutions through the evaluation of alternative solutions of mated stations before going to the next mated stations.

1.3 Research Objectives

The objectives of this work are:

- To hybridize Artificial Bee Colony Algorithm with Branch and Bound concept to solve two-sided assembly line balancing problem.
- To evaluate the performance of the Artificial Bee Colony Algorithm with Branch and Bound concept in minimizing idle time and number of workstations.

1.4 Research Scope

The scope of this research is as the followings:

- The Branch and Bound Artificial Bee Colony method is developed using spreadsheet model with mated workstations.
- The research focuses on solving two-sided assembly line balancing problem.
- The performance of the hybrid Artificial Bee Colony with Branch and Bound method is tested on assembly line balancing problem consisting of 9, 12, 16, 24, 44 and 65 tasks.
- The assembly line data sample is obtained from the literature.
- The specific constraints considered in the two-sided assembly line are cycle time, precedence and task direction constraints.
- Visual Basic Application programming is applied to spread sheet to obtain the optimum solution.

1.5 Significance of the Research

The two-sided assembly line is typically used to produce high volume large-size products. Balancing two–sided assembly line has fallen into a non-deterministic polynomial-time (NP) hard class of combinatorial optimization problems. This research is important for balancing production lines in factories which assemble products using two-sided assembly line. Balancing of the assembly line is significant to reduce costs and increase efficiency. This research also contributes to provide reports to the field of two-sided assembly line balancing literatures.

In addition, this research also improve the convergence ability of the ABC for optimizing two-sided assembly line problem. Finally, this research also provides the method of using the spread sheet for visualizing and solving the two-sided assembly line balancing problem.

1.6 Thesis Organization

In this chapter, brief introductions about two-sided assembly line balancing (2SALB) problem, artificial bee colony (ABC) algorithm and Branch and bound (B&B) process were mentioned. The challenge issue of 2SALB and the low convergence of ABC were also elaborated. Moreover, additional information about this research such as the research objectives and scopes were also highlighted.

In chapter 2, some theories and significant contributions are discussed in relation to the 2SALBP, ABC, B&B concept, spreadsheet technique and Hybridization ABC algorithm with other algorithms. Additionally, some related studies that are significant to this research are also discussed.

The third chapter covers the general research methodology. In this chapter, the processes for conducting the research are explained. The research flowchart with a greater level of details is also provided.

In the fourth chapter, the methodology for constructing the solutions of the 2SALB problem by spreadsheet coverage mated-stations optimization is properly reported. Additionally, the steps for developing the ABC are also presented. The combined between ABC and B&B is explained and the Visual Basic application software is used in this chapter to obtain the solutions. This chapter also discusses all set of data tested on the proposed Branch and Bound ABC algorithm.

The performance of the proposed method was measured in Chapter 5. This chapter is also considered as the chapter for data analysis and discussion. The performance comparison is also considered as the validation process. Finally, chapter 6 provides a conclusion for this research and some recommendations for future works. Moreover, the contributions made by this research are also highlighted.

CHAPTER 2

LITERATURE REVIEW

This chapter focuses on the important theories and knowledge related to the research topics coverings the simple assembly line balancing, two-sided assembly line balancing, artificial bee colony algorithm, branch and bound algorithm, hybridization of artificial bee colony, and models and technique for balancing line. Besides that, it also presented the related works and models that are significant to this research. The critical findings in this chapter will be used as the foundation for developing the research methodology.

2.1 Assembly Line Balancing

The assembly line balancing is a matter of assigning tasks to workstations. It is categorized into two different classifications. The first is the simple assembly line balancing which contained one-sided workstations. The second is the two-sided assembly line which has workstations on both left and right side of the assembly line.

2.1.1 Simple Assembly Line Balancing

The meaning of simple line balancing is how to allocate tasks to sequence stations. This assembly line consists of a number of workstations arranged along the transportation device or conveyor belt which moves the part within same speed in order

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