**UNIVERSITI PUTRA MALAYSIA**

# GRAVITATIONAL SEARCH – BAT ALGORITHM FOR SOLVING SINGLE AND BI-OBJECTIVE OF NON-LINEAR FUNCTIONS

**IRAQ TAREQ ABBAS**

**FS 2019 27**

# GRAVITATIONAL SEARCH – BAT ALGORITHM FOR SOLVING SINGLE AND BI-OBJECTIVE OF NON-LINEAR FUNCTIONS

By

**IRAQ TAREQ ABBAS**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy**

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# DEDICATION

*I dedicate my dissertation work to my family.*

*In appreciation of their love, sacrifices, faith, and eternal goodness, I would like to dedicate my dissertation to my dear loving parents, Mariam and Ali*

*I will always appreciate all they have done, especially my wife Dr. Estabrak for helping me all the time throughout the entire doctoral program.*

*I dedicate this work and give special thanks to my best friends I mean my wonderful kids (Mariam, Ali, Hayder and Yahya) for being there for me throughout the entire doctorate program.*

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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**June 2018**

**Chairman : Associate Professor Mohd Rizam Abu Bakar, PhD**
**Faculty : Science**

In this thesis**,** in order to solve single objective optimization problem and bi-objective objective optimization problem in non-linear functions, two methods are created during the course of the present work. Firstly, a new strategy based on a combined method (i.e. single-objective Gravitational Search (GSA) with Bat Algorithm (BAT) (SOGS-BAT)) algorithm is proposed in which relies on the closed interval between 0 and 1 to avoid falling into local search. The lack of local optimum mechanism decreases the intensification of the search space, whereas diversity remains high. Secondly, two meta-heuristics, namely, Bi-Objective Gravitational Search Algorithm (BOGSA) and Bi-Objective Bat Algorithm (BOBAT), were combined to form a (BOGS-BAT) algorithm. Later, this algorithm was used to solve bi-objective Production Planning (PP) and Scheduling Problem (Sch.P).

The BOGS-BAT algorithm is based on three techniques. The first technique is to move or switch solution from single function to functions that contain more than one objective functions. The use of the BOGSA algorithm aims to create a new equation for the calculation of the masses of population individuals, as found in the theoretical work in the Strength Pareto Evolutionary Algorithm two (SPEAII) algorithm. The second technique is to solve bi-objective functions by using the BOBAT algorithm. The third technique is an integration of BOGSA with BOBAT to produce a BOGS-BAT algorithm. The gravitational search with BAT algorithm is used to balance exploitation and exploration, thereby resulting in efficient and effective (speed and accuracy) solution for the production planning model.

Finally, to verify the efficiency of the SOGS-BAT and BOGS-BAT and to demonstrate the effectiveness and robustness of the proposed algorithms, the numerical experiments based on benchmark test functions were performed. In addition, the simulation random data for were used to solve single and bi-objective optimization PP and Sch.P to improve the validation and verify the performance of the proposed algorithms. The results reveal that the proposed algorithms are promising and efficient.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**ALGORITMA PENCARIAN GRAVITI - BAT UNTUK PENYELESAIAN PENGOPTIMUMAN SATU DAN BI-OBJEKTIF DALAM MASALAH PERANCANGAN PENGELUARAN DAN PENJADUALAN**

Oleh

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Perancangan pengeluaran (PP) dan masalah penjadualan (Sch.P) adalah penting untuk sistem pengeluaran yang cekap. Dalam masalah sebenar PP dan Sch.P, nilai input atau nilai parameter, termasuk sumber, permintaan, dan kos, mungkin tidak tepat. Di samping itu, pertimbangan semua parameter dalam model PP dan Sch.P membuat penjanaan jadual pengeluaran induk sangat rumit, di mana data input atau parameter sering tidak tepat kerana maklumat yang tidak lengkap atau tidak dapat dikesan dan perubahan pola harian permintaan dan kapasiti pengeluar. Oleh itu, kajian ini cuba mencadangkan skema novel yang mampu menangani halangan-halangan dalam masalah PP dan Sch.P. Skema ini mengambil kira ketidakpastian dan membuat tukar ganti pelbagai objektif bertentangan pada masa yang sama. Teknik yang dicadangkan terdiri daripada dua langkah utama: pertama, beberapa keputusan kritikal mengenai penentukan kadar pengeluaran dan perancangan sumber manusia (data rawak) dipertimbangkan; seterusnya, keputusan mengenai kuantiti dan kaedah penyimpanan inventori dan pengedaran produk akhir kepada pelanggan.

Semasa menjalankan kerja ini, dua kaedah dicipta. Pertama, strategi baru berdasarkan kaedah gabungan (iaitu Algoritma Pencarian Graviti Objektif Tunggal dengan Algoritma Bat (SOGS-BAT)) dicadangkan untuk menyelesaikan masalah pengoptimuman tunggal, yang bergantung pada selang tertutup antara 0 dan 1 untuk mengelakkan terjatuh ke dalam carian tempatan. Kekurangan mekanisme optimum tempatan menurunkan intensifikasi pencarian, sedangkan kepelbagaian masih tinggi.

Kedua, kombinasi antara dua meta-heuristik: Algoritma Pencarian Graviti Bi-Objektif (BOGSA) dan Algoritma Bi-Objektif BAT (BOBAT) untuk membentuk algoritma BOGS-BAT. Kemudian, algoritma ini digunakan untuk menyelesaikan pelbagai masalah pengaturcaraan linear PP dan Sch.P. Algoritma (BOGS-BAT) ini berdasarkan tiga teknik. Teknik pertama adalah untuk memindahkan atau menukar penyelesaian dari fungsi tunggal ke fungsi yang mengandungi lebih daripada satu fungsi objektif. Tujuan menggunakan algoritma BOGSA adalah untuk membentuk persamaan baharu yang digunakan untuk mengira massa individu individu, seperti yang didapati dalam kerja teori dalam Algoritma Kekuatan Pareto Evolusi Algoritma dua (SPEAII). Teknik kedua adalah untuk menyelesaikan fungsi pelbagai oleh algoritma BOBAT. Teknik terakhir adalah integrasi BOGSA dan BOBAT, untuk menghasilkan BOGS-BAT. Pencarian Graviti dengan Algoritma BAT (GSA-BAT) digunakan untuk mengimbangi eksploitasi dan eksplorasi, sehingga menghasilkan penyelesaian yang efisien dan berkesan (kecepatan dan ketepatan) untuk model perancangan produksi.

Akhir sekali, untuk mengesahkan kecekapan SOGS-BAT dan BOGS-BAT, eksperimen berangka berdasarkan fungsi ujian tanda aras telah dilakukan untuk menunjukkan keberkesanan dan keteguhan algoritma yang dicadangkan. Di samping itu, untuk meningkatkan pengesahan dan untuk mengesahkan prestasi algoritma yang dicadangkan, data rawak simulasi untuk perancangan pengeluaran digunakan untuk menyelesaikan masalah pengoptimuman bi-objektif PP dan Sch.P. Keputusan menunjukkan bahawa algoritma yang dicadangkan adalah memberangsangkan dan cekap.

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**2018**

This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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| | |
|---|---|
| GSA | Gravitational Search Algorithm |
| BAT | Bat Algorithm |
| NFL | No-Free-Lunch |
| TS | Tabu Search |
| GA | Genetic Algorithm |
| OR | Operations Research |
| ACO | Ant Colony Optimization |
| EA | Evolutionary Algorithm |
| FJS | Flexible Job Shop |
| MPS | Master Production Scheduling |
| BOM | Bill Of Material |
| MRP | Material Recruitment Production |
| APP | Aggregate Production Planning |
| TSP | Travelling Sales man Problem |
| PO | Purchase Order |
| HS | Harmony Search |
| FL | Fuzzy Logic |
| LK | Lin Kernighan |
| BA | Bat Algorithm |
| MBA | Modify Bat Algorithm |
| EBA | Enhanced Bat Algorithm |
| HBA | Hybrid Bat Algorithm |
| ELD | Economic Load Dispatch |
| SPGSA | Strength Pareto Gravitational Search Algorithm |
| MGBPSO | Mean $G_{Best}$ Particle Swarm Optimization |
| BOPSO/D | Bi- Objective Particle Swarm Optimization Decomposition |
| NSBATII | Non-Sorting Bat Algorithm Two |
| NSGAII | Non-Sorting Genetic Algorithm Two |
| SPEAII | Strength Pareto Evolutionary Algorithm Two |
| BOO | Bi-Objective Optimization |

| | |
|---|---|
| SOO | Single-Objective Optimization |
| BOGSA | Bi-Objective Gravitational Search Algorithm |
| BOBAT | Bi-Objective Bat Algorithm |
| BAST | Bat Algorithm Scheduling Tool |
| BOOP | Bi-Objective Optimization Problem |
| BOPSO | Bi-Objective Practice Swarm Optimization |
| BOGWO | Bi-Objective Grey Wolf Optimization |
| BOJSSP | Bi-Objective Job Shop Scheduling Problem |
| JSSP | Job Shop Scheduling Problem |
| PFSP | Permutation Flow Shop Scheduling Problem |
| WMS | Workload Management System |
| DBC | Deadline Budget Constraint |
| HFS | Hybrid Flow Shop |
| HMS | Holonic Manufacturing System |
| FJSP | Flexible Job-Shop Problem |
| BOABC | Bi-Objective Artificial Bee Colony |
| BOLP | Bi-Objective Linear Programming |
| SOLP | Single-Objective Linear Programming |
| VND | Variable Neighbourhood |
| HMS | Holonic Manufacturing System |
| PSE | Process Systems Engineering |
| MIP | Mixed Integer Programming |
| QAP | Quadratic Assignment Problem |
| GVP | Great Value Priority |
| MRP | Material Requirements Planning |
| SPV | Position Value Rule |
| BGA | Breeder Genetic Algorithm |
| BFO | Bacterial Foraging Optimization |
| TFT | Total Flow Time |
| FA | Firefly Algorithm |
| KP | Knapsack Problem |
| IPPS | Integration of Production Planning and Scheduling Problem |

| | |
|---|---|
| ORPD | Optimal Reactive Power Dispatch |
| AFSO | Artificial Fish Swarm Optimization |
| FIS | Fuzzy Inference System |
| MHPSO | A MOdified Hybrid Particle Swarm Optimization |
| RRHC | Random-Restart Hill Cli |
| BOEA/D | Bi-Objective Evolutionary Algorithm with Decomposition. |
| SOGS-BAT | Single-Objective Gravitational Search Algorithm with Bat Algorithm |
| BOGS-BAT | Bi-Objective Gravitational Search Algorithm with Bat Algorithm |
| DPSO | Discrete Particle Swarm Optimization |
| TOPSIS | Technique for Order Performance by Similarity to Id Solution |
| SPX | Simplex Crossover |
| DFR | Distribution Feeder Reconfiguration |
| AMGSA | Accelerated Bi-Gravitational Search Algorithm |
| SAMBA | Self-Adaptive Bodification Bat Algorithm |

# CHAPTER 1

# INTRODUCTION

## 1.1 Research Background and Motivations

Classical optimization algorithms do not provide a suitable solution for optimization problems with a high-dimensional search space because of the exponential increase in the search space with the increase in the problem size. Therefore, solving such problems using exact techniques, such as comprehensive research is impractical (Alatas, 2010).

The increasing interest in algorithms over the last decade is inspired by naturalistic phenomena (Dorigo, Maniezzo, & Colorni, 1996), various heuristic algorithms have been proposed and show an efficient and effective performance, such as ant colony search algorithm by Dorigo et al. (1996), artificial bee colony (ABC) algorithm by Ning, Liu, Zhang, and Zhang (2018), genetic algorithm by Tang, Man, Kwong, and He (1996), bat algorithm (BAT) by X.-S. Yang (2011), particle swarm optimization (PSO) by Kennedy (2011), simulated annealing by Kirkpatrick, Gelatt, and Vecchi (1983) and gravitational search algorithm (GSA) by Rashedi et al. (2009).

Many researchers have proven that these algorithms are well suited for solving complex computational problems, such as: objective function optimization (Du & Li, 2008); (Yao, Liu, & Lin, 1999), pattern recognition (Tang et al., 1996); (Y. Liu, Yi, Wu, Ye, & Chen, 2008), control objective (Baojiang & Shiyong, 2007) and (Karakuzu, 2009), image processing (Nezamabadi-Pour, Saryazdi, & Rashedi, 2006), filter Modelling (Kalinli & Karaboga, 2005); (Y.-L. Lin, Chang, & Hsieh, 2008), scheduling problem (Kan, 2012) and production planning problems (Karimi-Nasab & Ghomi, 2012).

In the meantime, the optimization problems in many industrial and academic research sectors generally have more than one objective. The involved optimization problems with conflicted and incommensurable objectives are called bi-objective optimization problems (BOPs). Given the high-dimensional search space in BOPs, traditional optimization algorithms using exact techniques (e.g. exhaustive search) are no longer suitable because the search space grows dramatically as problem size increases (Alatas, 2010).

Algorithms are gradually powered in different areas Wolpert and Macready (1997), Tripathi, Bandyopadhyay, and Pal (2007) and Rashedi et al. (2009) to solve various optimization problems. However, no specific algorithm is used to find the best solutions for all the problems in finite iterations, and certain algorithms exhibit better performance for particular problems than others. Thus, searching for new heuristic optimization algorithms is an open problem (Tripathi et al. (2007). For example, GSA is based on the movement of particles that are affected by the gravitational force. Moreover, GSA can be used to improve the convergence rates of BAT during iterations and enhance BAT behavior for high-dimensional problems.

"No-Free-Lunch Theorem" (Wolpert & Macready, 1997) indicates that no method can solve all problems optimally. For heuristic optimization algorithms, the hybrid technique has become an important tool to improve its performance. Hybridization of two algorithms is a common technique to take advantage of both algorithms while decreasing their disadvantages. By hybridization of algorithms, exploration and exploitation of the entire algorithm can be improved (S Sarafrazi, Nezamabadi-Pour, & Saryazdi, 2011). In particular, the lack of precision of an algorithm can be improved by hybridization with a local search procedure that refines the results.

In most cases, GSA achieves better performance than other heuristic optimization algorithms Rashedi et al. (2009), consequantly most GSA variants have been developed by combining GSA with other heuristic optimization algorithms and techniques to avoid some of these complexity. Han, Quan, Xiong, and Wu (2013) proposed a hybrid algorithm that combines the quantum-inspired binary gravitational search algorithm with the K-nearest neighbor method to solve the problem of feature selection could be treated as a problem of optimization in a search space. H.-C. Tsai, Tyan, Wu, and Lin (2013) presented the gravitational particle swarm (GPS) algorithm, which modified the velocity formula by combining PSO velocity with GSA acceleration to the outstanding performance and interesting concepts embodied in the GPS.

J.-S. Wang and Song (2017) inrodused four kinds of improved GSA-PSO hybrid algorithm by introducing a small constant updating mechanism, which adopts PSO strategy to optimize the velocity and position in the running process of the GSA. The simulation analysis results show that the improved hybrid algorithm greatly improves the function optimization convergence speed and optimization accuracy. Khajehzadeh, Taha, and Eslami (2014) a new hybrid algorithm combining an adaptive gravitational search algorithm (AGSA) with pattern search (PS) method is introduced and applied for bi-objective optimization of reinforced concrete RC retaining walls.

Moreover, X.-S. Yang (2010b) proposed a new optimization algorithm called BAT. This algorithm is inspired by the echolocation behaviour of bats.the echolocation behavior of bats shows their capability to find their prey and discriminate different types of insects even in complete darkness. Pure BAT has two featuers namly, exploration and exploitation are controlled by the equations X.-S. Yang (2010b). Exploration and exploitation, also referred to as diversification and intensification, are the two main aspects of the population-based heuristic algorithms; the balance between these features in any meta-heuristic algorithm is the performance measurement of its success in solving each given bi-objective optimization problem (BOP) (Hassanzadeh and Rouhani (2010). Exploration is the ability to search the space that allows the meta-heuristic algorithm to scan the expanding parts of the search space without falling into local optima. By contrast, exploitation is the ability to search locally in search space to provide accurate search and convergence (Rashedi, Rashedi, and Nezamabadi-pour (2018).

In view of the above, we note that researchers who have hybridized the algorithm of attraction with other algorithms and did not use it with the Bat algorithm, hence our basic idea to build a hybrid algorithm linking the gravity algorithm and the bat algorithm to inrodused single objective gravitational search with bat algorithm namly (SOGS-BAT).

Although population-based search algorithms achieve excellent performance results (Xiao, Li, Liu, and Ni (2018), none of the meta-heuristic algorithms can perform superiorly in solving all problems. In practice, the performance of an algorithm in solving BOPs may be controversial from one problem to another. Thus, developing a hybrid meta-heuristic algorithm by combining different meta-heuristic concepts can improve the quality of performance and satisfy the promising balance between diversity and convergence (H.-L. Liu, Chen, Deb, and Goodman (2017). To tackle the aforementioned issues and improve the balance between the diversity and convergence in BOPs, we propose a combined meta-heuristic algorithm called bi-objective gravitational search with BAT algorithm (BOGS-BAT).

## 1.2 Problem Statement

The success of any company depends on proper production planning and scheduling. International companies obtain critical success on a remarkable level on the basis of this idea. Production planning and scheduling problems have become quite complex and large scale. Most industries produce various products, and companies strive to provide new products everyday depending on the market requirements. This situation has led to many challenges and modern logistic problems for product manufacturers. Production planning and scheduling problems are essential in the tactical planning level of a production-based management system that is generally dependent on the parameters with an uncertain value in the manufacturing environment. Although production planning is a bi-objective decision-making problem, most models for this problem have focused on it as a single- objective. (Leung, Tsang, Ng, & Wu, 2007) stated that this consideration may be the reason for the difficulty in solving production planning problems. (Sadjadi, Makui, Dehghani, & Pourmohammad, 2016) illustrated that the complexity of the bi-product production planning problem makes it an NP-hard (i.e. non-deterministic polynomial-time hard problem as classified by (Garey & Johnson, 1979)) and complex problem.

Thus, the research community seeks to resolve complicated problems by using meta-heuristic and hybrid meta-heuristic algorithms (Sajadi & Rad, 2016); (G. Yang, Tang, & Zhao, 2017). Meta-heuristic and hybrid meta-heuristic algorithms are based on the assumption that inexact parametric values are deterministic; however, this assumption produces useless and impractical results (Yaghin, Torabi, & Ghomi, 2012). Although meta-heuristic algorithms have been successfully used to solve complex real-world production problem, an algorithm to solve all problems in optimization in a single run is unavailable (Wolpert & Macready, 1997).

As result, several researchers have used the heuristic approach with meta-heuristic or hybrid meta-heuristic algorithms to solve bi-objective production scheduling problems (Ponsignon & Mönch, 2012); (Wong, Chan, & Chung, 2012); (Karimi-Nasab & Aryanezhad, 2011); (Mehdizadeh, Niaki, & Rahimi, 2016); (Beheshti Fakher, Nourelfath, & Gendreau, 2017).

However, only two types of products are considered in the problem of these methods. In particular, these methods generally focus on solution algorithms for a company but ignore generalised large-scale production planning problems. These methods are also incompatible to the actual production environment and are inefficient in terms of accuracy and runtime. Therefore, the current study proposes a general and specific algorithm to solve large-scale and random single and bi-objective production planning and scheduling problems.

## 1.3 Research Objectives

This study is conducted on the basis of the following objectives:

i. to propose a combination of single-objective gravitational search algorithm with bat algorithm (SOGS-BAT) for solving single objective optimization problems.
ii. to propose a combination of bi-objective gravitational search algorithm with BAT algorithm (BOGS-BAT) for solving BOPs.
iii. to investigate and validate the performance of SOGS-BAT in solving an SOP.
iv. to justify the use of BOGS-BAT in solving an BOP.
v. to determine the performance of BOGS-BAT by comparing it with other existing meta-heuristic approaches.
vi. to apply the proposed algorithms in an existing production planning and scheduling problem models.

## 1.4 Contributions

The contributions of this thesis are enumerated below.

- Proposed two new general methods; (1) single combination algorithm (SOGS-BAT) is introduced to solve single-objective optimization problems for PP and Sh.P issues. (2) A bi-objective combination algorithm (BOGS-BAT) is introduced to solve bi-objective optimization problems for PP and Sh.P issues.

  These methods can be used by any decision maker to obtain a good results from the same problem. In the past, the tolerance and rejection levels were subjectively chosen by decision makers depend on their experiences. Hence, there exist several implication from the outcomes of the present study.

- BOGS-BAT is used to solve the large-scale data for production planning and to demonstrate its capability in enhancing the performance.
- A create a new equation for the masses that belong to gravitational search algorithm (GSA) to expand the search space and transformation all the solution from single objective to bi-objective in the interval [0,1].
  On the basis of the proposed approach, GSA was initially allowed to search for the global optimal by using a given objective function. During the search process, the GSA did not improve the fixed number of iterations and was trapped in the local optima. So, we augmented the search space by starting with N solutions rather than one solution to improve the performance and alleviate the deficiencies in problem solving.
- The convergence speed of SOGS-BAT and BOGS-BAT are enhanced using two novel combinations, namely, GSA by Rashedi et al. (2009) with BAT algorithm by X.-S. Yang (2010b). As any meta-heuristic algorithms, SOGS-BAT and BOGS-BAT contain two components, namely, exploration and exploitation.
  Any successful meta-heuristic algorithm requires a good balance of the two important and opposite components intensification and diversification (Das, Chatterjee, & Goswami, 2015) (X.-S. Yang, Deb, & Fong, 2014). Only a fraction of local space may be visited when intensification is strong, and a trapping risk is observed in a local optimum. When diversification is strong, the algorithm slowly converges with solutions jumping around several potential optimal solutions (X.-S. Yang, 2009b). Therefore, two types of algorithm (global and local search algorithms) were utilised to balance the exploration and exploitation for SOGS-BAT and BOGS-BAT.

## 1.5 Thesis Outline

This thesis presents and discusses the production planning and scheduling problems in literature. New combination algorithms (SOGS-BAT and BOGS-BAT) are applied to solve these problems. **Chapter 1** describes the summary of the thesis and the introduction of production planning and scheduling problems. The problems in literature and their solutions are discussed. The importance of the proposed objectives is also presented. **Chapter 2** presents a detailed literature review on production planning scheduling and general swarm intelligence. Studies using general meta-heuristic algorithms for SOPs and BOPs, challenges and limitations are also reported. **Chapter 3** provides the methodology to solve SOPs and BOPs by using a proposed combination algorithm. The aims of the model to determine the optimal production limits and decrease the cost of production per item are discussed in details. **Chapter 4** investigates the benchmark problem instances. The experimental design and test problem are provided. Simulation and experimental results for benchmark SOPs and BOPs are presented. Lastly, **Chapter 5** elaborates the conclusions and possible future research.

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# LIST OF PUBLICATIONS

Iraq T. Abbas, Rizam Abu Bakar , Hassan A. AlSattar, A.A.Zaidan and B.B.Zaidan. (2018). A Novel Strength to Solve Bi-Objective Problems based BOGS-BAT algorithm using Strength Pareto. (Status: Accepted to Publishing). *Neural Computing and Application*.

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