UNIVERSITI PUTRA MALAYSIA

HYBRID META-HEURISTIC ALGORITHM FOR SOLVING MULTI-OBJECTIVE AGGREGATE PRODUCTION PLANNING IN FUZZY ENVIRONMENT

BAYDA ATIYA KALAF

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HYBRID META-HEURISTIC ALGORITHM FOR SOLVING MULTI-OBJECTIVE AGGREGATE PRODUCTION PLANNING IN FUZZY ENVIRONMENT

By

BAYDA ATIYA KALAF

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

August 2017

DEDICATION

To my respectful father and a lovely mother who taught me the meaning of courage and always had confidence in me.
To my beloved husband (Hassan AL-Mansoor) for all his contribution, patience, and understanding throughout my Ph.D. studies. He supported me a lot and made it all possible for me.
To my kids (Ali, Mary, and Asef), who accompanied me through the different parts of my study. Their love has always been my greatest inspiration.
To my brothers and sisters.

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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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Chair: Associate Professor Mohd Rizam Abu Bakar, PhD
Faculty: Science

Aggregate production planning (APP) is considered as significant for efficient production systems. APP problems are considerably important in several manufacturing concerns. In actual APP problems, input data or parameter values, including resource, demand, cost, and objective functions, may be inaccurate. On the other hand, consideration of all parameters in an APP model makes the generation of a master production schedule deeply complicated especially in real-world APP problems, where input data or parameters are frequently imprecise (fuzzy) due to incomplete or unobtainable information and daily changes patterns of demand and manufacturers capacity (Sakalh et al., 2010). In addition, the APP problem based on the fuzzy environment becomes even more sophisticated as decision makers try to consider multi-objectives.

Therefore, this study attempts to propose a novel scheme which is capable of dealing with these obstacles in APP problem. This schema takes into account uncertainty and makes a trade-off among conflicting multi-objectives at the same time. In addition, the proposed technique comprises of two main steps: first, some critical decisions about determining production rate and human resource planning (fuzzy data) are considered; next, decision about quantity and method of holding inventory and distribution of end product to customers was made. During the course of the present work, two fuzzy methods (modified Zimmermanns approach and modified angelovs approach) and four meta-heuristics and hybrid meta heuristics including; simulated annealing (SA), modified simulated annealing (MSA), hybrid modified simulated annealing and simplex downhill (MSASD), hybrid modified simulated annealing and modified particle swarm

optimization (MSAPSO) were proposed. For these proposed approaches, this study adopted a hybridization of a fuzzy programming, modify simulated annealing, and simplex downhill (SD) algorithm called Fuzzy-MSASD to resolve multiple objective linear programming APP problems in a fuzzy environment. The proposed strategy is dependent on modified Zimmermanns approach for handling all inexact operating costs, data capacities, and demand variables. The SD algorithm is employed to balance exploitation and exploration in MSA, thereby resulting in efficient and effective (speed and quality) solution for the APP model.

Finally, the proposed approach was implemented in a real-world problem for Baghdad Soft Drinks Company to automate their APP. The findings showed that the proposed approach produced significant efficient solutions and achieved significantly low computational time for APP in large-scale problems.

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

ALGORITMA META-HEURISTIK HIBRID BAGI PENYELESAIAN PERANCANGAN PENGELUARAN AGREGAT BERBILANG OBJEKITF DALAM PERSEITARAN KABUR

Oleh

BAYDA ATIYA KALAF

August 2017

Pengerusi: Profesor Madya Mohd Rizam Abu Bakar, PhD
Fakulti: Sains

Perancangan pengeluaran agregat (APP) dianggap sebagai signifikan untuk sistem pengeluaran yang cekap. Masalah APP adalah jauh lebih penting dalam beberapa kebimbangan dalam pembuatan. Dalam masalah sebenar APP, data input atau nilai-nilai pembolehubah, termasuk sumber, permintaan, kos, dan fungsi objektif, mungkin tidak tepat. Sebaliknya, pertimbangan semua pembolehubah dalam model APP menjadikan penjanaan jadual pengeluaran induk amat rumit terutama masalah APP dalam dunia sebenar, dimana data yang dimasukkan atau pembolehubah kebiasaannya tidak tepat (kabur) disebabkan oleh maklumat yang tidak lengkap atau tidak dapat diperolehi dan perubahan pola harian permintaan dan keupayaan pengeluar (Sakalh et al., 2010). Di samping itu, masalah APP berdasarkan persekitaran kabur menjadi lebih canggih sebagai pembuat keputusan dan cuba untuk mempertimbangkan pelbagai objektif.

Di samping itu, teknik ini terdiri daripada dua langkah utama: pada langkah pertama; beberapa keputusan kritikal tentang menentukan kadar pengeluaran dan perancangan sumber manusia (data kabur) dipertimbangkan.; dalam langkah seterusnya, , keputusan tentang kuantiti dan kaedah inventori pegangan, pengedaran produk siap kepada pelanggan telah dibuat. Semasa kerja sekarang, dua kaedah kabur (mengubah suai kaedah Zimmermann dan mengubah suai kaedah Angelov) dan empat meta-heuristik dan heuristik meta berhibrid termasuk; penyepuhlindapan simulasi (SA), mengubah suai penyepuhlindapan simulasi (MSA), berhibrid mengubah suai penyepuhlindapan simulasi dan algoritma simpleks menurun (MSASD), berhibrid berhibrid mengubah suai penyepuhlindapan simulasi dan mengubah suai zarah swarm pengoptimunan (MSAPSO) telah dicadangkan. Bagi pendekatan yang dicadangkan, kajian ini mencadangkan suatu penghibridan pengaturcaraan kabur, mengubah suai penyepuhlindapan simulasi, dan algoritma simpleks menurun (SD) yang dipanggil kabur-MSASD

untuk menyelesaikan model pengaturcaraan linear pelbagai objektif untuk menyelesaikan masalah APP di dalam persekitaran yang kabur. Strategi yang dicadangkan adalah bergantung kepada pendekatan Zimmermann untuk mengendalikan semua kos operasi, kapasiti data, dan pembolehubah permintaan yang tidak tepat. Algoritma SD telah digunakan untuk mengimbangi antara eksploitasi dan pemeriksaan teliti di MSA, dengan itu penyelesaian kepada APP model adalah cekap dan berkesan (kelajuan dan kualiti).

Akhirnya, pendekatan yang dicadangkan telah dilaksanakan untuk masalah sebenar bagi syarikat Baghdad Soft Drinks untuk mengautomasikan APP mereka. Penemuan menunjukkan bahawa pendekatan yang dicadangkan telah menghasilkan penyelesaian yang signifikan cekap dan mencapai masa pengiraan APP yang signifikan rendah dalam masalah skala besar.

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BAYDA ATIYA KALAF

2017

I certify that a Thesis Examination Committee has met on 24 August 2017 to conduct the final examination of Bayda Atiya Kalaf on his thesis entitled "Hybrid Meta-Heuristic Algorithm for Solving Multi-Objective Aggregate Production Planning in Fuzzy Environment" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

APP	Aggregate Production Planning
NFL	No-Free-Lunch
SA	Simulated Annealing algorithm
SD	Simplex Downhill algorithm
GA	Genetic Algorithms
TS	Tabu search
PSO	Particle Swarm Optimization
HS	Harmony Search
MSA	Modified Simulated Annealing algorithm
MSASD	Modified Simulated Annealing and Simplex downhill
MSAPSO	Modified Simulated Annealing and Modify Particle Swarm Optimization
DM	Decision Maker
LP	Linear Programming
GP	Goal Programming
FLP	Fuzzy Linear Programming
FGP	Fuzzy Goal Programming
FMOLP	Fuzzy Multi-Objective Linear Programming

CHAPTER 1

INTRODUCTION

1.1 Overview

Aggregate Production Planning (APP) is a prominent method that gathers all the information related to production before determining the best way to satisfy the predicted demand through the use of available physical resources. Aggregating the information being processed is vital because it is usually impossible to take into consideration every detail related to the production process while still maintaining a long planning horizon. APP is considered a planning technique with medium-term capacity. It is able to identify the optimum level for production, inventory, workforce, backlog, and subcontracting to meet requirements of the fluctuating demand over a specified time frame that ranges from 3 to 18 months even with limited resources and capacity (Al-e et al. (2012), and Wang and Yeh (2014)).

APP can even help in maintaining the effectiveness and responsiveness of supply chains. Thus, it is imperative to have proper planning. A multi-criteria APP covers several costs, for example: product purchasing costs, inventory costs, manpower maintenance costs, manufacturing costs, back ordering, or extra subcontracting costs. Because aggregate plannings ultimate output is the preparation of a master production plan, future master scheduling can be significantly affected by discrepancies that may take place in the planning stage as in Figure 1.1.

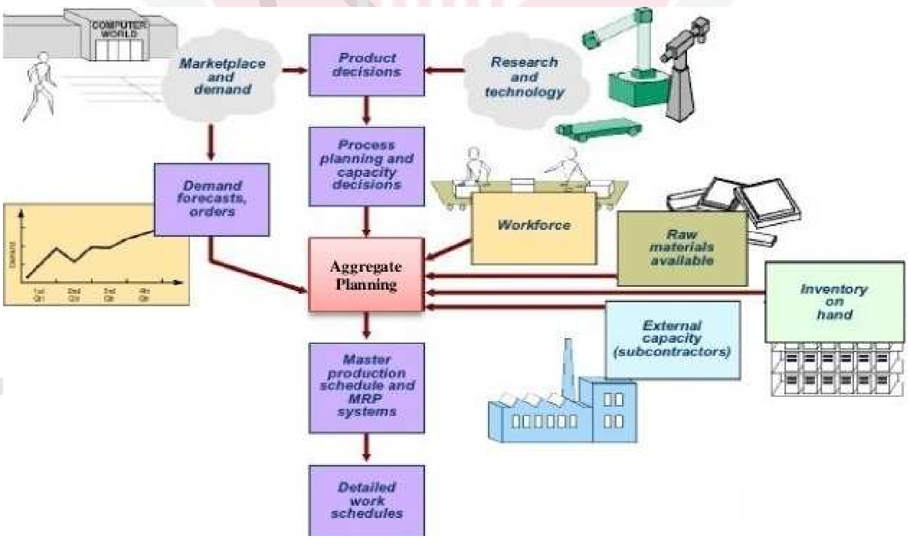

Figure 1.1: Aggregate Operations Planning, (Russell and Taylor, 2006)

Since the 1950s, numerous APP model and techniques have been launched involved different levels of complexity. Based on the number of objective functions, Al-e et al. (2012) classified APP models into three categories as: single-objective models (Wang and Yeh, 2014), bi-objective models (Mirzapour Al-E-Hashem et al. 2011; and Goh et al. 2007), and multi-objective models (Wang and Fang, 2001b).

Among these models, the approach to solving APP problems is to consider multiple objectives. Multi-objective models separately consider individual objectives, thus allowing a decision maker to examine different alternative solution sets. In addition, many companies aim at achieving several objective functions for a flexible production planning system. Such objectives can be identified by taking costs, inventory investment, profits, customer service, changes in workforce levels, changes in production rates and plant and equipment utilization into consideration. This makes multi-objective programming (MOP) a standard approach in solving APP problems (Sadeghi et al., 2013).

Meanwhile, Saad (1982) presented the traditional approaches used to solve these problems. Such methods can be categorized according to six classifications: decision rule (Holt et al., 1955), linear programming (Singhal and Adlakha, 1989), transportation method (Bowman, 1956), management coefficient approach (Bowman, 1963), simulation (Byrne and Bakir, 1999), and search decision rule (Taubert, 1968).

Although these methods were used to solve a number of APP problems, several researchers pointed the disadvantages of using traditional APP techniques in industry. Vollman (1992) put forward the reasons for the failure include:

1. Uniform rates have been assumed for different products. This assumption does not reflect reality in organizations producing various products.
2. It is so difficult for the general managers to grasp and understand the mathematical methods used in available techniques. Hence, the lack of interest on their parts in utilizing those techniques.
3. used in the above techniques require deterministic and certain data that the collection and quantification of these data is difficult requiring extra costs such as for employment and training of new staffs, etc.

Furthermore, Gilgeous (1989) has stated the following disadvantages:

1. Methods are rooted in their own specific qualifications. Hence, they are appropriate for a definite rage of variables.
2. The real world problems face a definite range of planning variables. Therefore, none of the available techniques can produce optimal or near-optimal solutions of plans. Other limitations of the current techniques are as follow:

a. Functions used by the current techniques do not appropriately reflect real cost functions in organizations.

b. Models of a case cannot directly be used in other cases.

Moreover, Jamalnia and Soukhakian (2009) and Liang et al. (2011) pointed that traditional mathematical programming techniques are not suitable to solve real-world APP problems. Input data or parameters are often inaccurate in real-world APP problems. This is because some information might be unobtainable or incomplete (Sakallı et al., 2010). Given that the current demand patterns and manufacturers capacity change daily, there are difficulties in handling uncertainties while designing a successful APP plan. The process thus becomes complex and ambiguous.

Hence, stochastic mathematical programming (SMP) based on probability programming (Kazemi Zanjani et al. 2013; and Mirzapour Al-e Hashem et al. 2013) and fuzzy mathematical programming (FMP) based on fuzzy set theory (Iris and Cevikcan 2014; and Liang et al. 2011) are employed for handling the fuzzy parameters in APP problems. SMP approaches can satisfactorily handle a number of probabilistic uncertainties in decision making. They are useful when system component values fluctuate at wide intervals with probabilistic descriptions (Huang 1994; Bitran and Yanasse 1984; Silva Filho 2001; Yong-quan et al. 2006; and Hahn et al. 2012) are known.

The APP problems solved through stochastic programming techniques are based on theories, concepts, and methodologies of randomness theory. Therefore, the approach can only consider the restricted form of a given probability distribution function. Thus, it cannot contribute significantly to decision-making in actual situations (Tang et al. 2000; and Wang and Liang 2005a).

Specifically, when historical data is lacking, FMP is more appropriate than stochastic programming approach and can provide alternative models for imprecisions and uncertainties (Tavakkoli-Moghaddam et al., 2007). Fuzzy set theory provides appropriate approach to deal with imprecise coefficients, objectives and constraints quantitatively and it has been extensively applied in several fields (Rommelfanger (1996), and Liang (2007)). In these studies, goals are defined as fuzzy values, and fuzzy models are resolved through their transformation into classically crisp mathematical programming problems (Baykasoglu and Gocken, 2010). In addition, this approach may limit FMP utility of the crisp linear equivalent of a given fuzzy model may not be obtained easily in several situations (Baykasoğlu and Göçken, 2006). In recent decades, large-scale APP problems acquired characteristics of high complexity and NP-hard problems, which could not be tackled with mathematical programming solvers.

Thus, research community use metaheuristic algorithms to solve complex problems (Raa et al. 2013; Fahimnia et al. 2008; and Jiang et al. 2008).Despite successful use of metaheuristic algorithms in attacking complex APP problems, we cannot adopt one algorithm for all real-world APP problems. In fact, no standard algorithm cover all problems based on No-Free-Lunch theorem (NFL) (Wolpert and Macready, 1997).

1.2 Problem Statement

The 21st century has brought many industrial changes that have altered the global economic and the industrial perspective. A majority of the industries produce a wide variety of products and the companies are striving to produce new products every day depending on the market requirements. This has led to many challenges and newer logistic problems for the product manufacturers. APP is known to be an essential tactical-level of planning in the production-based management system that is generally dependent on the parameters having an uncertain value in the manufacturing environment. Although aggregate production planning problem is a multiple-objective decision-making problem, the majority of APP models developed to address the problem focused on it as a single objective. Besides Baykasoglu (2001) stated that this might be the reasoned for the difficulty in solving the aggregate production planning problem. Furthermore, Makui et al. (2016) illustrated that the complexity of the multi-product APP problem makes it strongly NP-hard and complex problem.

Thus, the research community seeks to resolve complicated problems by using metaheuristic and hybrid metaheuristic algorithms (Ramezanian et al. 2012; and Wang and Yeh 2014). Nevertheless, metaheuristic and hybrid metaheuristic algorithms are based on the assumption that, inexact parametric values are deterministic, however, this produce useless and impractical results (Yaghin et al., 2012). Therefore, Ning et al. (2006); and Chakrabortty et al. (2015) adopted a fuzzy approach for handling inaccuracies in metaheuristic and hybrid algorithm to solve the APP problems. However, their models for resolving APP problems are related to single objectives.

As result, several researchers used fuzzy approach with meta-heuristic or hybrid meta-heuristic algorithms to solve multi-objective APP problems (Aliev et al. 2007; Baykasoğlu and Göçken 2006; Baykasoglu and Gocken 2010; and Chakrabortty and Hasin 2013b). However, only two types of products were considered in their case studies. This means that all presented methods are generally focused on solution algorithms for small firms but do not considering generalized large scale App problems. Moreover, these methods are incompatible with actual production environment and also inefficient in terms of accuracy and runtime. Therefore, the present study proposed a general and comprehensive algorithm to solve multiple objective APP problems given the fuzzy environment, by taking into account large-scale problems.

1.3 Research Objectives

The main aim of this research is to propose a general algorithm to solve multi-objective linear programming model for large-scale aggregate production planning problems under fuzzy environment. To achieve this aim, the following specific objectives will be considered:

(1) To explore the APP problems in the fuzzy environment, and to propose new methods to transform fuzzy data to crisp data for APP problems based on FMOLP approach.

(2) To develop Simulated Annealing (SA) to solve multi-objective model for APP problems.

(3) To modify Simulated Annealing (MSA) for multi-objective linear programming model for solving large-scale APP problems.

(4) To propose and verify new two hybridization for balancing the exploration and exploitation MSA algorithm to be efficient and effective (speed and quality) to solve the multi-objective model for large-scale APP problems; the first hybrid is to incorporate modified simulated annealing with local method namely namely (MSASD), while the second one is to hybridize modified simulated annealing with global search method (MSAPSO).

(5) To justify the proposition of the new method by illustrating the applicability in the real-world industrial.

1.4 Main Contributions

This research made several contributions, which are as follows:

- Proposed two new general methods; (1) Modified Zimmerman's approach by determining the tolerance levels for membership function in the fuzzy multi-objective linear programming (FMOLP). (2) Modified Angelov's approach by determining the rejection levels for non-membership function based on intuitionistic fuzzy optimization technique (IFO).

  These methods can be used by any decision maker to obtain similar 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.

- Introduced simulated annealing to solve multi-objective linear programming model for APP problem for the first time. Although SA is a popular and practical method for solving NP-hard and complex problems, such as scheduling, timetabling, and traveling salesman, etc., However to the best of the researcher knowledge, there is no study on the application for SA on multi-objective for APP problem

- Modified SA algorithm is proposed to expand search space and solve multi-objective linear programming model for APP problems.

  According to the proposed approach, initially, SA is allowed to search for global optimal for a given objective function. During the search process, it was found that SA solution did not improve fixed number of iterations, and SA was trapped into local optima. To improve performance and alleviate deficiencies in problem solving, we attempted to augment search space by starting with N solutions instead of from one solution.

- Enhanced the convergence speed of MSA algorithm by proposing two novel hybridization; one with simplex downhill algorithm and other with MPSO of (Wang and Yeh, 2014). MSA algorithm as any meta-heuristics algorithms contains two components; exploration and exploitation.

  Any successful meta-heuristic algorithm requires a good balance of these two important, seemingly opposite, components (Yang 2008, and Yang 2014). If the intensification is too strong, only a fraction of local space might be visited, and there is a risk of being trapped in a local optimum. On the other hand, if the diversification is too strong, the algorithm will converge too slowly with solutions jumping around some potentially optimal solutions (Yang, 2009). Therefore, two types of algorithm (global and local search algorithms) were chosen to balance the exploration and exploitation for MSA.

- Applied a novel technique, Fuzzy-MSASD in a real-world multi-objective APP problem, specifically to Baghdad Soft Drinks Company industry to automate their APP.

1.5 Thesis Outline

In order to achieve the aforementioned objectives, the thesis is divided into seven chapters, each chapter represent a different stage in the research process.

Chapter 1: Provides a general introduction about aggregate production planning, problem statement, objective and contributions of this thesis.

Chapter 2: Provides a more in-depth review of the literature relevant to this research, fuzzy multi-objective decision making, meta-heuristic algorithms and limitation.

Chapter 3: Comprises the modified Zimmermann's approach based on fuzzy set theory to solve APP problem, modified Angelov's approach based on intuitionistic fuzzy optimization to solve APP problem, comparative computational studies, summary of the results and conclusion.

Chapter 4: Provides simulated annealing and modified simulated annealing to solve multi-objective APP problems, given experimental results, and conclusion.

Chapter 5: Presents in details the two hybrid algorithms based on modify simulated annealing, experimental results which include results of test problems and simulation, and conclusion for this chapter.

Chapter 6: Covers the industrial application of the proposed Fuzzy- MSASD approach to APP problem in Baghdad Soft Drinks Company, which is one of the largest integrated manufacturers in Iraq.

Chapter 7: Presents the overall summary of the current study, the conclusion and future work.

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