OPTIMIZATION OF PIPE SPOOL FABRICATION SHOP SCHEDULING USING GENETIC ALGORITHM

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I would like to dedicate this dissertation to my beloved father, Padar Mokhtari Moghadam, who taught me how to be strong and ambitious. It is also dedicated to my beloved mother, Arous Nasiri Rad, who taught me how to be patience and love people kindly.

I would like to dedicate this thesis to my dear brothers and sisters, whose positive energies always support me the best way.

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ABSTRACT

Spool fabrication shop is an intermediate phase in the piping process for construction projects. The delivery of pipe spools at the right time in order to be installed in the site, is very important. Therefore, effective scheduling and control of the fabrication shop has a direct effect on the productivity and successfulness of the whole construction projects. This research developed a genetic algorithm (GA) in order to generate a feasible and near-optimal schedule for the operational level of pipe spool fabrication shop based on the concepts and methods of job shop scheduling problems. In the proposed algorithm, an improved chromosome representation is used to conveniently represent a schedule for the fabrication shop. Operation-based global selection and Operation-based local selection are designed to generate high-quality initial population in the initialization stage. To adapt to the special chromosome structures and the characteristics of the problem, precedence order-based crossover (POX), two-point crossover, and uniform crossover are used. In addition, different mutation operators for operation sequence part and machine assignment part of the chromosome are used. The data which consist of operations processing time, and dimension of spools and stations are collected from an industrial fabrication shop. The proposed algorithm is applied by using the collected data to obtain a feasible and near-optimal schedule for the operational level of pipe spool fabrication shop. The results showed that the productivity of the fabrication shop by using the proposed algorithm for scheduling fabrication processes has increased to 178 percent.

ABSTRAK

Kedai fabrikasi kili adalah fasa perantaraan dalam proses paip untuk projek-projek pembinaan. Penghantaran kili paip pada masa yang betul untuk dipasang dalam tapak pembinaan adalah sangat penting. Oleh itu, penjadualan dan kawalan berkesan kedai fabrikasi mempunyai kesan langsung ke atas produktiviti dan kejayaan sesuatu projek pembinaan keseluruhan. Kajian ini membangunkan algoritma genetik (GA) untuk menjana jadual yang sesuai dan hampir optimum untuk peringkat operasi kedai fabrikasi paip kili berdasarkan konsep dan kaedah kerja kedai masalah penjadualan. Dalam algoritma yang dicadangkan itu, perwakilan kromosom yang lebih baik digunakan untuk mewakili jadual untuk kedai fabrikasi. Pemilihan global berasaskan Operasi dan Operasi berasaskan pemilihan tempatan berasaskan Operasi direka untuk menjana populasi awal yang berkualiti tinggi di peringkat pengawalan. Untuk menyesuaikan diri dengan struktur kromosom khas dan ciri-ciri masalah, keutamaan crossover berasaskan pesanan (POX), crossover tunda-mata, dan crossover seragam digunakan. Di samping itu, pengendali mutasi yang berbeza untuk bahagian operasi urutan dan bahagian mesin tugasan digunakan. Data yang terdiri daripada masa pemprosesan operasi, dan dimensi kili dan stesen diambil dari sebuah kedai fabrikasi industri. Algoritma yang dicadangkan dilaksanakan dengan menggunakan data yang dikumpul untuk mendapatkan jadual yang sesuai dan hampir optimum untuk peringkat operasi kedai fabrikasi paip kili. Hasil kajian menunjukkan bahawa produktiviti kedai fabrikasi dengan menggunakan algoritma yang dicadangkan bagi penjadualan proses fabrikasi meningkat kepada 178 peratus.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Since the occurrence of the industrial revolution, manufacturing and industrial construction are growing in size and complexity. Furthermore, timely delivering of products and services to customers is more significant during past decades. Therefore, in order to be more productive and profitable, the need for developing new principles, techniques, and research disciplines is remarkable to survive in this competitive market-place. Operation research (OR), as a systematic and analytical approach to decision-making and problem-solving, is one of the discipline that has been developed to respond to this challenge (Hillier and Lieberman, 2001). Over the years, many researchers used OR for improving factory layout design, facility location, utilization of resources, scheduling, inventory control etc. Among these topics, scheduling receives much attention from researchers due to the significant impact on productivity and successful of corporations in terms of reducing cycle time, reducing of cost (or increasing of profit), minimizing work in process (WIP), and so on (Rokni, 2010).

The term “industrial construction” involves a wide range of projects like petroleum refineries, petrochemical plants, power plants, and off-shore oil/gas production facilities (Barrie and Paulson, 1992). This type of construction project includes high volume of piping that conveys liquids, chemicals, mixtures, gases, vapors, and solids from one location to another (Hu and Mohamed, 2012).

Piping work can be categorized into four steps, include engineering design, pipe spool fabrication, module assembly, and field installation (Hu and Mohamed, 2012; Mosayebi *et al.*, 2012). Because of better production control management in the shop environment, as well as compacted schedule, and space constraints on the field, the main part of the piping works are doing on the shop fabrication (Song *et al.*, 2006; Hu and Mohamed, 2012). Spool shop fabrication is an intermediate phase in the piping process. This is considered to be crucial for delivering of pipe spools at a right time in order to be installed in the site. Therefore, excellent scheduling and control of the fabrication shop has a direct effect on the productivity and successfulness of the overall project (Hu and Mohamed, 2012). However, traditional management methods such as critical path method (CPM) and Program Evaluation and Review Technique (PERT) are not capable to model dynamic nature of these complex processes (Pritsker, 1986).

Because, most of the scheduling problems are well-known as NP-hard problem, i.e. there is no polynomial time algorithm for the problem, and the time, which is needed for solving the problem, is growing exponentially, when the number of machines or jobs increases. Therefore, a great deal of work has been devoted using approximate algorithms.

This thesis focuses on development of genetic algorithm as an approximate algorithm for scheduling and sequencing of pipe spool in the fabrication shop. In this chapter, first of all, the background of the study is explained. Then, the problem is defined in order to describe objectives of the thesis and which challenge of industrial construction, particularly pipe spool fabrication shop is going to be solved. After that, in the scope of the study, spool fabrication processes, techniques, research tools and software, used in the thesis are briefly introduced. Next, the goals and benefits that are expected to be achieved are addressed in order to reveal the significance of the research. Finally, the thesis organization is presented to understand how researcher is going to conduct research.

1.2 Background of the Study

According to the researchers, pipe spool fabrication shop as an important part of industrial construction project deals with low level of productivity and long process cycle time due to the high complexity, unique product, and uncertain work environment processes (Howell and Ballard, 1996; Tommelein, 1998; Wang *et al.* 2009). Furthermore, Business Roundtable reported that piping process is crucial for many industrial projects, but it is the most costly and least efficient within the construction industries ("Construction" 1982). Furthermore, current techniques of project scheduling such as CPM and PERT are not useful for decisions at the operational level of fabrication shop (Pritsker, 1986; Karumanasseri and AbouRizk, 2002), i.e. these techniques can be used as tools for scheduling presentation, not for developing an optimum scheduling in shop floor. Hence, this causes many productivity problems such as not delivering of the spool at the right time to install in the site, not having the right item or equipment when needed, using excess inventory to hide problems, inflexibility, and lack of responsiveness in fabrication processes (Huang and Tang, 1990). In order to solve these problems, researchers have attempted to improve pipe spool fabrication shop productivity by analyzing of some factors which are affected on the shop floor through implementing of a simulation model.

According to studies done before, in some cases, successful results have been achieved by conducting simulation model. Tommelein (2006) developed a simulation model to investigate the effects of standardized products. Her model showed a reduced cycle time. As another example of reduction in spool cycle time, Wang *et al.* (2009) developed a simulation model to test the effects of shop layout on the productivity. Song, Wang, and AbouRizk (2006) have proposed integrated model from the design, process planning, and shop fabrication by using a simulation model for estimating and scheduling of fabrication shop. In this regards, Sadeghi and Fayek (2008) also developed a simulation model for measuring the productivity of fabrication shop with less than 5% error. In order to find an optimization schedule for industrial shop, Rokni (2010) developed a multiple criteria scheduling framework by using a simulation model and fuzzy set theory. Hu and Mohammad (2011) used a simulation model and identified that different spool fabrication sequences affect the

productivity of shop. Their result for the best assembly sequence shows 10.09 % reduction of project completion time and reduction of material handling about 16.88%.

1.3 Problem Statement

In many countries, pipe spool fabrication shop as a crucial part of industrial construction project suffer from various problems such as; low productivity, long process cycle time, and high cost. Many studies show that good scheduling and sequencing of fabrication processes can effects on the productivity of the workshop. However, because of the dynamic working environment, complexity of processes and uniqueness products in pipe spool fabrication shop constructing appropriate schedule is somewhat difficult. Therefore, classical techniques of scheduling like CPM and PERT are quite useless in operational level, and they can be used as tools for scheduling presentation, not for developing an optimum scheduling in shop floor.

An observation from previous relevant studies in spool fabrication shop results in two categories, Firstly, identification of factors which are affected the shop productivity such as shop layouts, dispatching rules, buffer location, standardized products, and configuration of products by developing simulation model. Secondly, development of simulation based framework and use dispatching rules for scheduling of fabrication shop.

However, studies showed that scheduling and sequencing have a significant effect on the productivity of pipe spool fabrication shop, but few researches have been done to develop a feasible and optimal schedule for shop environment in the era of industrial construction. In addition, previous researchers have developed a simulation model for scheduling of shop floor based on the scheduling rules such as shortest processing time, random selection, most work remaining (MWR) and etc. to choose spools and assign them to the stations. However, these rules are not precise and accurate techniques and achieve low quality solutions in compare with meta-heuristic techniques (Pinedo, 2008). Therefore, the need for a comprehensive method

to solve scheduling and sequencing problem in pipe spool fabrication shop is more necessary. The problem, which is considered to be solved, is generating of feasible and near optimal schedule for pipe spool fabrication processes by using genetic algorithm.

1.4 Research Objective

The main objective of this thesis is to develop a genetic algorithm (GA) in order to generate a feasible and near optimum schedule for the pipe spool fabrication shop based on the concepts and methods of job shop scheduling problems.

To realize this objective, two specific sub objectives are identified as below:

(1) Develop a mathematical model for scheduling problems of pipe spool fabrication processes.

(2) Obtain a feasible and near-optimal schedule for the pipe spool fabrication shop by using genetic algorithm with the aims of minimizing the maximum completion times of all jobs (pipe spools).

1.5 Scope of the Study

The scope of study is listed as below:

(1) A case study in Iran is considered for collecting required data.
(2) Collected data consist of operation processing time of 30 spools (or jobs), which should be performed by 16 workforces (or machines).

(3) The dimension of spools (or jobs) and stations (or machines) are considered.

(4) Genetic algorithm will be used for solving the mathematical model and finding a feasible and near-optimal schedule for shop floor based on deterministic process time for each station.

(5) Matlab programming 2012 is used for coding the genetic algorithm.

1.6 Significance of Research Findings

The research findings will be necessary in implementing genetic algorithm for the scheduling problem in pipe spool fabrication shop based on job shop scheduling concepts. The most benefits to be expected from this study for the considered industrial fabrication shop are:

(1) Minimized maximum completion times of all jobs, i.e., makespan.

(2) Obtain a feasible and near-optimal schedule in the operational level.

(3) Maximize resource utilization and balance workload between machines (or workforces).

(4) Maximize fabrication process productivity.

This means that the research will help managers and planners to control shop floor system properly. Therefore, resources utilization will be increased and consequently, delivering of pipe spools to the site will be facilitated based on the feasible and near optimum scheduling for fabrication processes. In addition, it has significant effects on reduction of completion time and consequently cost of whole industrial construction projects. The findings also will prove that, through implementing of genetic algorithm, the spool fabrication process productivity can be improved dramatically.

1.7 Thesis Organization

The remainder of the thesis is divided into six chapters. In Chapter 2 of this thesis, firstly, production system, job shop, pipe spool fabrication shop, scheduling and sequencing concepts are described. Then this chapter is dedicated to fully reviewing what researchers have done before for implementing simulation and genetic algorithm in pipe spool fabrication shop and job shop scheduling problems respectively. The third chapter shows the structure of research methodology. Different phases toward implementation of genetic algorithm are briefly discussed in order to indicate how the author plans to conduct the study. Having defined different phases of the thesis in Chapter 3, the rest of the thesis is dedicated to conducting different phases. These phases are fully discussed in Chapters 4, 5, 6, and 7. The second phase is discussed in Chapter 4. This phase involves three steps, which include a full description of the case study, problem mathematical formulation, and data collection. Chapter 5 is dedicated to developing a genetic algorithm in Matlab programming to solve the mathematical model. Genetic algorithm results and discussions for the best allocation and sequencing of operations in the fabrication shop are presented in chapter 6. Finally, chapter 7 presents the final conclusions and future research potentials.

1.8 Conclusion

This chapter is mainly dedicated to thesis introduction. It aims at introducing the thesis objectives, the problems to be solved, the scope to which the thesis is limited, the expected significant results, and finally the structure in which the thesis is conducted.

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