

ARTIFICIAL IMMUNE SYSTEM FOR STATIC AND DYNAMIC PRODUCTION
SCHEDULING PROBLEMS

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*For my beloved parents, Hj Muhamad b. Deraman and Hjh. Salma bt. Setapa
my wife, Maziana bt. Mustaffar
my children, Afiq Rifqi, Auni Sahira and Amsyar Razin*

who have given me the strength and courage.

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ABSTRACT

Over many decades, a large number of complex optimization problems have brought researchers' attention to consider in-depth research on optimization. Production scheduling problem is one of the optimization problems that has been the focus of researchers since the 60s. The main problem in production scheduling is to allocate the machines to perform the tasks. Job Shop Scheduling Problem (JSSP) and Flexible Job Shop Scheduling Problem (FJSSP) are two of the areas in production scheduling problems for these machines. One of the main objectives in solving JSSP and FJSSP is to obtain the best solution with minimum total completion processing time. Thus, this thesis developed algorithms for single and hybrid methods to solve JSSP and FJSSP in static and dynamic environments. In a static environment, no change is needed for the produced solution but changes to the solution are needed. On the other hand, in a dynamic environment, there are many real time events such as random arrival of jobs or machine breakdown requiring solutions. To solve these problems for static and dynamic environments, the single and hybrid methods were introduced. Single method utilizes Artificial Immune System (AIS), whereas AIS and Variable Neighbourhood Descent (VND) are used in the hybrid method. Clonal Selection Principle (CSP) algorithm in the AIS was used in the proposed single and hybrid methods. In addition, to evaluate the significance of the proposed methods, experiments and One-Way ANOVA tests were conducted. The findings showed that the hybrid method was proven to give better performance compared to single method in producing optimized solution and reduced solution generating time. The main contribution of this thesis is the development of an algorithm used in the single and hybrid methods to solve JSSP and FJSSP in static and dynamic environment.

ABSTRAK

Semenjak beberapa dekad yang lalu, banyak permasalahan berkaitan pengoptimuman yang kompleks telah menarik minat para penyelidik untuk membuat kajian yang mendalam dalam bidang pengoptimuman. Permasalahan penjadualan pengeluaran adalah salah satu daripada masalah pengoptimuman yang telah menjadi tumpuan para penyelidik sejak tahun 60 an. Masalah utama dalam penjadualan pengeluaran adalah untuk memperuntukkan mesin bagi melaksanakan tugas-tugas. Masalah Penjadualan Pekerjaan Kedai (JSSP) dan Masalah Penjadualan Pekerjaan Fleksibel Kedai (FJSSP) merupakan dua masalah dalam permasalahan penjadualan pengeluaran berkaitan dengan mesin. Salah satu dari objektif utama dalam menyelesaikan JSSP dan FJSSP adalah untuk mendapatkan penyelesaian terbaik dengan meminimumkan jumlah masa pemrosesan. Oleh itu, kajian ini membangunkan algoritma bagi kaedah tunggal dan hibrid untuk menyelesaikan JSSP dan FJSSP dalam persekitaran yang statik dan dinamik. Dalam persekitaran yang statik, tiada perubahan yang diperlukan untuk penyelesaian yang dihasilkan tetapi perubahan terhadap penyelesaian yang diperlukan. Sebaliknya, dalam persekitaran yang dinamik, terdapat banyak aktiviti masa nyata seperti ketibaan pesanan baru secara tidak menentu atau masalah kerosakan mesin yang memerlukan kepada penyelesaian. Untuk menyelesaikan permasalahan dalam persekitaran statik dan dinamik ini, kaedah tunggal dan kaedah hibrid telah diperkenalkan. Sistem Imun Buatan (AIS) digunakan bagi kaedah tunggal, manakala AIS dan Pewarisan Kejiranan Berubah (VND) digunakan dalam kaedah hibrid. Pemilihan Algoritma Prinsip Pemilihan Klon (CSP) dalam AIS telah digunakan dalam kaedah tunggal dan hibrid yang dicadangkan. Di samping itu, untuk menilai kepentingan metod yang dicadangkan, eksperimen dan pengujian statistik Satu-Jalur ANOVA telah dilaksanakan. Dapatan kajian menunjukkan bahawa kaedah hibrid telah terbukti memberikan prestasi yang lebih baik berbanding dengan kaedah tunggal dalam menghasilkan penyelesaian yang optimum dan mengurangkan masa penjaanaan penyelesaian. Sumbangan utama kajian ini ialah membangunkan algoritma yang digunakan dalam kaedah tunggal dan hibrid untuk menyelesaikan JSSP dan FJSSP dalam persekitaran statik dan dinamik.

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LIST OF ABBREVIATIONS

ABC	-	Ant Bee Clony
AI	-	Artificial Intelligence
AIS	-	Artificial Immune System
ANT	-	Ant Colony Optimization
CMA-ES	-	Covariance Matrix Adaptation Evolution Strategy
CSP	-	Clonal Selection Principle
CTF	-	Continuous Time Formulation
DTF	-	Discrete Time Formulation
Expr.	-	Experiment
FJSSP	-	Flexible Job-Shop Scheduling Problem
GA	-	Genetic Algorithm
GRASP	-	Greedy Randomized Adaptive Search Procedure
HAI	-	Hybrid Artificial Immune System
HGA	-	Hybrid Genetic Algorithm
HGATS	-	Hybrid Genetic Algorithm and Tabu Search
JSS	-	Job-Shop Scheduling
JSSP	-	Job-Shop Scheduling Problem
FJSSP	-	Flexible Job-Shop Scheduling Problem
MRE	-	Mean Relative Error
PR	-	Path Relinking
PSO	-	Practical Swarm Optimization
SA	-	Simulated Annealing
SBI	-	Shifting Bottleneck Procedure I
SBII	-	Shifting Bottleneck Procedure II
SSP	-	Stage Shop Problem
TGA	-	Tabu-based Genetic Algorithm

TS	-	Tabu Search
TSAB	-	Taboo Search Algorithm with Back Jump Tracking
TSSB	-	Tabu Search with Shifting Bottleneck
VND	-	Variable Neighbourhood Decent
VNS	-	Variable Neighbourhood Search

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CHAPTER 1

INTRODUCTION

1.1 Overview

Scheduling can be defined as a process of completing activities or tasks by distributing limited resources alongside all of the other constraints in a given period of time (Baker, 1974). Scheduling can also be considered as a search for, or an optimisation of a problem, with the goal of finding the best schedule. Production scheduling is among the most usual and significant problems commonly encountered by the manufacturing industry. One problem that often arise in production scheduling involves scheduling jobs on a machine (or a set of machines) to optimise a specific objective function such as total weighted completion time or total weighted tardiness.

Hermann (2006) stated that there are three important perspectives for production scheduling; namely problem-solving, decision-making, and organisational perspectives. Problem solving perspective looks into the scheduling as an optimisation problem. The formulation of scheduling works as a combinatorial optimisation, isolated from the control system place as well as the manufacturing planning. From the perspective of the decision maker, scheduling is one decision to be made by the corresponding personnel. Schedule maker would use official and informal information to finish up one schedule by fixing some to-do-tasks in that schedule. Organisational perspective views scheduling as one complex information flow and decision maker must decide on production planning and system control.

Usually, the system is divided into various modules that will be performing different functions.

In production scheduling, there are three types of scheduling problem as commonly faced by industry:

- i. Open Shop Scheduling Problem (OSSP), where there is no ordering constraints on operations;
- ii. Job Shop Scheduling Problem (JSSP), whereby the operations of a job are fixed in a predetermined order;
- iii. Flow Shop Scheduling Problem (FSSP), this occurs where every machine in each job is assigned to one operation, and all jobs will go through all of the machines in the same manner.

In most industries, job shop scheduling (JSS) is important because it will determine process maps and process capabilities (Roshanaei *et al.*, 2009). There are many techniques or methods that are applicable in order to solve the production scheduling problem especially for JSSP. All of these techniques or methods can be broken down into two categories: exact methods and approximate methods.

	Machine			Processing Time		
	O_1	O_2	O_3	O_1	O_2	O_3
Job ₁	1	2	3	4	3	2
Job ₂	2	1	3	1	4	4
Job ₃	3	2	1	3	2	3
Job ₄	2	3	1	3	3	1

Figure 1.1: Example of JSSP

JSSP consists of a set of n jobs $\{j_1, j_2, \dots, j_n\}$ with a number of m machines $\{m_1, m_2, \dots, m_m\}$. In each job there is a series of operations $\{o_1, o_2, \dots, o_i\}$, with each

operation having a processing time of $\{\tau_{i1}, \tau_{i2}, \dots, \tau_{im}\}$. All operations are required to be completed on a specific machine and at a particular time, one machine can only address one operation. The goal of job shop scheduling is to produce a scheduling that minimises the total time taken to complete all activities. The process constraints will influence the finding of the best schedule and determining its employment will either be very easy or very difficult (Pinedo, 2002). Figure 1.1 illustrates the JSSP. In many industries, JSS is significant in deciding process maps and capabilities (Roshanaei *et al.*, 2009). The most ideal possible solution for n jobs on single machine is $n!$. When m machines are exists, the number of possible solutions is $(n!)^m$.

Flexible job shop scheduling problem (FJSSP) is an extension to the conventional JSSP that enables an operation to be processed by any machine from a given set of available machines. Similar to the job shop, flexible job shop still consists of a set of n jobs $\{j_1, j_2, \dots, j_n\}$ with a number of m machines $\{m_1, m_2, \dots, m_m\}$. In each job J_i lies a series of operations $\{o_{i1}, o_{i2}, \dots, o_{in}\}$ with each operation having a processing $\{\tau_{i1}, \tau_{i2}, \dots, \tau_{im}\}$. As for the job shop, each operation can only be processed on one machine. But for the flexible job shop, each operation o_{ij} , i.e. the operation j of job i can be processed on any among a subset $M_{ij} \subseteq M$ of compatible machines. Figure 1.2 illustrates the FJSSP. The symbol ∞ in the Figure 1.2 indicates that a particular machine is unable to carry out the corresponding operation. In other words, it does not fall into to the subset of compatible machines for that operation or no operation j of job i . Bruker and Schlie (1990) were among the earliest to deliberate on FJSSP.

Artificial Immune System (AIS) is one of the methods to solve JSSP and FJSSP. AIS is a set of techniques, which algorithmically mimic natural immune systems conduct (Hart, 2008). This particular method is normally used in diagnosis, pattern recognition, fault detection, and other areas, including optimisation (Costa *et al.*, 2002). AIS can also be defined as a computational system based on metaphors borrowed from the biological immune system. The work in the field of AIS was initiated by Farmer *et al.* (1986). They introduced a dynamic model of the immune

system that was simple enough to be simulated on a computer. In their research, the *antibody – antibody* and *antibody – antigen* reactions were simulated via complementary matching strings. There are several basic traits of immune model and algorithm such as Bone Marrow Models, Clonal Selection Principle, Negative Selection Algorithms, Immune Network Models and Somatic Hypermutation. In this thesis intended for the solving of JSSP and FJSSP, the main algorithm to be used would be the Clonal Selection Principle (CSP). There two main reasons for using AIS to solve JSSP and FJSSP: (i) antibody population represents the feasible solution; (ii) evolutionary selection mutation.

		Operation	Machine		
			M_1	M_2	M_3
Job₁	O_1	6	6	∞	
	O_2	∞	5	∞	
	O_3	4	4	4	
	O_4	∞	∞	∞	
Job₂	O_1	∞	6	∞	
	O_2	∞	5	7	
	O_3	7	9	∞	
	O_4	6	3	∞	
Job₃	O_1	5	3	3	
	O_2	4	∞	∞	
	O_3	∞	∞	∞	
	O_4	∞	∞	∞	

Figure 1.2: Example of FJSSP

1.2 Background of Problem

The main problem in job shop and flexible job shop scheduling is to obtain the best schedules with the optimal solution. The solution for any optimisation problem is evaluated by an objective function. Objectives are associated with cost, resources and minimised time. There are several objective functions within JSSP and FJSSP as the measurements. The common measurements are maximum completion

time, flow time, lateness, tardiness and earliness. The *maximum completion time* is also known as ‘*makespan*’ and shows the completion time for the last job to be completed. The maximum completion time is important when having a finite number of jobs; and is closely related to the throughput objective. *Flow time* is the sum of the total completion time for all of the jobs that have been scheduled. This objective minimises the average number of jobs in the system. *Lateness* refers to the difference between the job completion time and the due date, $L_j = C_j - d_j$, and it may take a positive or a negative value. *Tardiness* indicates the time in which the job j is completed after its due date. Therefore, tardiness is regarded as positive lateness and is equal to $T_j = \max\{0, C_j - d_j\}$. *Earliness* is the time with which the job j is completed before its due date, $E_j = \max\{0, d_j - C_j\}$. As pointed out by French (1982), in examining minimum *makespan*, at least one of the most favourable solutions to a job shop scheduling problem is semi active. A schedule can be classified into four types of condition: feasible schedule, semi-active schedule, active schedule and non-delay schedule. The optimal schedule exists in the set of active schedules as shown in Figure 1.3.

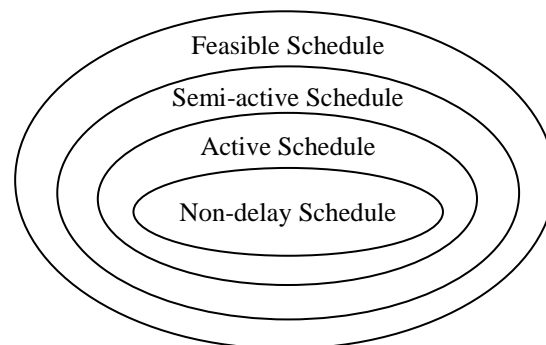


Figure 1.3: Types of Schedule

The FJSSP, as compared to JSSP, is much more complicated. This is due to the fact that it included all the strains and complexities of JSSP, which was first highlighted by Bruker and Schlie (1990). Motaghedi-larijani *et al.* (2010) divided FJSSP into two sub-problems:

- i. Routing sub-problem. It involves allocating each operation to a machine out of a set of potential machines.
- ii. Scheduling sub-problem. It refers to sequencing of the assigned operations on all chosen machines to obtain a feasible schedule with optimised objectives.

In FJSSP, it is difficult to choose the best machine from the given set of machines to ensure that the best schedule can be produced. Additionally, the total time taken to produce the best schedule must also be considered to ensure that any rush orders can be processed immediately.

Recently, in the dynamic environment of the manufacturing industry and with reference to job shop or flexible job shop problem, obtaining the best possible schedule with an optimal solution is not enough. Optimal solutions to problems are often failing to a great degree, hence a new solution must be produced in respond to any changes that occur alongside the original problem, however slight it might be. In the real-world, such alterations happen all the time. Therefore, there has been an outstanding deal of interest in the scheduling communities, especially in coming up with a robust, good enough schedules rather than optimal ones (Jensen, 2003). The most common changes of the current solutions are caused by machine breakdown or in receiving new order from customers. In the case of machine breakdown or new order received from customers, rescheduling of the current solution is probably needed and it depends significantly on the situation and when the changes happened. For example, if a new order is received while the machine is processing current jobs and the new job (order) is more important than the current jobs, the uncompleted operation for the current jobs needs to be rescheduled.

1.3 Motivation

In business, customer's satisfaction is very important. To ensure that the customers are satisfied with the service provided, all of their requirements must be fulfilled. In the manufacturing industries, producing the product according to time can ensure customer's satisfaction. One of the challenges of the manufacturing industry is to schedule the machine to ensure that the product required by customer can be produced on time or before the due date. Apart from that, the industry must also take into consideration the requirements from several other customers at the same time. Other problems to be considered by manufacturing industry are machine breakdown and rush order. In order to overcome the problems faced by manufacturing industries, a tool or technique must be developed to assist them in organising the schedule for their machines. Currently, there are several tools and techniques available in solving the scheduling problem in manufacturing industries. However, the existing tools and techniques are still inadequate in providing the optimum and robust solution to be used in today's dynamic environment.

Apart from manufacturing industries, other industries also significantly attain to the scheduling problem to ensure the satisfaction of their customers with the delivered service. Some of them employ the production scheduling problem solution methods to solve their scheduling problem by modelling their problems using production scheduling problems. For example transportation industries model their transport routing problem by using JSSP and FJSSP. The routes of transport are modelled as a 'job operation' and the starting point to the final destination are modelled as the 'job'. The segments in which the transport passed through are modelled as 'machine'. The route in each track segments are modelled as 'operation', with the time needed to pass each track segments is modelled as the 'operation time'. Therefore, the methods used to solve production scheduling problems can also be used to solve scheduling problems for transportation industries and any other industries. For some industries, apart from ensuring customer's satisfaction, operation cost and man-power can be reduced as well.

Hence today, many researchers are involved with the research on production scheduling to find the best techniques or methods to assist the players in manufacturing industries to solve their production scheduling problem to ensure that their customers are satisfied with the given services. The most popular method that is being used nowadays to solve scheduling problem is artificial intelligence. Therefore, an artificial immune system was used in this research to solve the production scheduling problem and it is one of the artificial intelligent techniques.

1.4 Problem Statement and Research Question

The job shop problem is a basic scheduling model. Real world applications usually lead to more complex situations. Some applications in real world such as robotic cell scheduling, multiprocessor task scheduling, railways scheduling and air traffic control use extended job shop scheduling problem as a model for their problem. For example, in multiprocessor task scheduling, one task can be modelled as an 'operation'; a computer program can be modelled as a 'job' and processor can be modelled as a 'machine'. Tasks are instructions of a computer program and these tasks are to be performed one after another by the processors.

By solving the JSSP and FJSSP, a variety of other scheduling problem can be solved by modelling their scheduling problem to job shop and flexible job shop scheduling problem. There are a few objectives that can be achieved by industries by solving their scheduling problems such as reduction of the operation cost, scaling down of man-power, customer satisfaction and other objectives related to time and resources. In order to obtain their objectives, the best schedule must be produced by applying relevant solution methods.

The current research trend in production scheduling is to solve the scheduling problem for flexible manufacturing system (FMS). As Bruker and Schlie (1990) said, FJSSP is applicable for FMS, the main objective is to obtain the fastest solution with

the minimum total completion time. The main problem in this area is to find the best technique that can produce the optimum solution for JSSP and FJSSP. In addition, the robustness of solution must also be considered to ensure that the solution can comply with the dynamic requirement of manufacturing industries such as rush order and machine breakdown. Consequently, the technique to solve JSSP and FJSSP must be able to produce an optimum and robust solution.

The main research question of this study is:

“Could an artificial immune system itself and hybrid method between an artificial immune system and variable neighbourhood descent be used to produce an optimum and robust solution for JSSP and FJSSP in static and dynamic environment?”

In order for the above research question to be answered, the following issues will be considered throughout the problem solving activity:

- i. How to model JSSP and FJSSP with the artificial immune system antibody?*
- ii. How can feasible solution be generated?*
- iii. How to design mutation type to produce variety type of mutation clone?*
- iv. How to choose the clone after mutation process to ensure that the clone can produce the best solution or close to the best solution?*
- v. How to produce an effective strategy for rescheduling process based on different situations?*

1.5 Research Goal and Objective

The goal of this research is to develop an algorithm to produce a better solution for JSSP and FJSSP using artificial immune system. In order to obtain a better solution, it has to minimise the total completion time for all activities. Additionally, the produce algorithm also must be able to solve the rescheduling problem in terms of JSSP and FJSSP. The main objectives of this research are:

- i. To design and develop an algorithm by using artificial immune system to solve job shop and flexible job shop scheduling problems;
- ii. To design and develop a hybrid algorithm by using artificial immune system and variable neighbourhood descent to solve job shop and flexible job shop scheduling problems;
- iii. To design and develop hybrid algorithm by using artificial immune system and variable neighbourhood descent to solve rescheduling problem for job shop and flexible job shop scheduling problems.

1.6 Thesis Outline

The thesis is organised in the following chapters:

- **Chapter 1:** A brief introduction to scheduling, job shop scheduling problem and flexible job shop scheduling problem. This chapter also discusses an overview of research background and research objective.
- **Chapter 2:** The relevant literature on current and existing works is presented. It deals with definitions and related keywords, contributions of previous

studies and provides the current trends and issues of job shop scheduling problems and flexible job shop scheduling problems.

- **Chapter 3:** This chapter presents the methodology in conducting the research such as the research design and operational framework during the research process. Various resources used in this research such as datasets, software and other related materials are also deliberated.
- **Chapter 4:** This chapter explains the algorithm developed using clonal selection principle in solving job shop and flexible job shop scheduling problem. The experimental results for proposed algorithm are also described.
- **Chapter 5:** This chapter explains the hybrid algorithm developed using clonal selection principle and variable neighbourhood descent in solving job shop and flexible job shop scheduling problem. The experimental results for proposed algorithm are also described.
- **Chapter 6:** This chapter discusses the techniques and strategies for the production rescheduling process to overcome the production scheduling problems in dynamic environment. The example of problems and examples of solution are also described in this chapter.
- **Chapter 7:** This chapter discusses the general conclusion of the results, major contribution and future plans in this active area of research.

1.7 Summary

This chapter gives an overview of the study by briefly describing job shop and flexible job shop scheduling problems and artificial immune system, problem background, and research goal and objectives. This study hopes to motivate researchers in multidisciplinary AIS research.

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