ARTIFICIAL IMMUNE SYSTEM FOR STATIC AND DYNAMIC PRODUCTION SCHEDULING PROBLEMS

AHMAD SHAHRIZAL BIN MUHAMAD

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Computer Science)

Faculty of Computing
Unversiti Teknologi Malaysia

JUNE 2017

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.

ACKNOWLEDGEMENT

In the name of Allah the Most Gracious and the Most Merciful, I thank You with all my heart for granting Your Servant immeasurable help during the course of this study and peace be Muhammad , upon him, the last messenger of Allah.

I would like to express my sincere thanks and gratitude to my supervisor, Dr. Zalmiyah binti Zakaria and Professor Dr. Safa'ai bin Deris for his encouragement and guidance that made this research possible and completed. He has corrected all my mistakes patiently and taught me everything that I needed to know, not only for successfulness of my study but also for my life and career. I also would like to thank all members of the Artificial Intelligence and Bioinformatics Research Group (AIBIG) for their continuous guidance in many aspects of this research. The completion of this work would never have been possible without persistent support from my wife Maziana binti Mutaffar. During the whole process she did everything to help me through my difficult time. I would like to appreciates her and my lovely kids Affiq Rifqi, Auni Sahira and Amsyar Razin for all the moral support. Finally, I would like to thank my beloved parents, Hj. Muhamad bin Deraman and Hjh. Salma binti Setapa for their everlasting wishes and also for all my family members.

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 pemprosesan. 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 penyelesaikan yang optimum dan mengurangkan masa penjanaan penyelesaian. Sumbangan utama kajian ini ialah membangunkan algoritma yang digunakan dalam kaedah tunggal dan hibrid untuk menyelesaikan JSSP dan FJJSP dalam persekitaran statik dan dinamik.

TABLE OF CONTENTS

CHAPTER	TITLE		PAGE
	DECLARATION		**ii**
	DEDICATION		**iii**
	ACKNOWLEDGEMENT		**iv**
	ABSTRACT		**v**
	ABSTRAK		**vi**
	TABLE OF CONTENTS		**vii**
	LIST OF TABLES		**xi**
	LIST OF FIGURES		**xiii**
	LIST OF ABBREVIATIONS		**xix**
	LIST OF APPENDIXES		**xxi**
1	**INTRODUCTION**		**1**
	1.1	Overview	1
	1.2	Background of Problem	4
	1.3	Motivation	7
	1.4	Problem Statement and Research Question	8
	1.5	Research Goal and Objective	10
	1.6	Thesis Outline	10
	1.7	Summary	11
2	**LITERATURE REVIEW**		**12**
	2.1	Introduction	12
	2.2	Production Scheduling	13
	2.3	The Solving Method for JSSP and FJSSP	15

	2.4	Exact Method for Solving Production Scheduling	23
	2.5	Variable Neigborhood Decent and Graph Theory	24
	2.6	Natural Immune System	26
	2.7	Artificial Immune System (AIS)	28
	2.8	Clonal Selection Principle	33
	2.9	Applying the AIS in Solving the JSSP and FJSSP	37
	2.10	Issues and Challenges	42
	2.11	Direction on JSSP and FJSSP	45
	2.12	Summary	46
3	**RESEARCH METHODOLOGY**		**47**
	3.1	Introduction	47
	3.2	Research Framework	47
		3.2.1 Initial Stage	49
		3.2.2 Phase 1: Single Method to Solve JSSP & FJSSP	55
		3.2.3 Phase 2: Hybrid Method to Solve JSSP & FJSSP	57
		3.2.4 Phase 3: Rescheduling for JSSP & FJSSP	60
	3.3	Experimental Design	61
	3.4	Result Validation and Analysis	64
	3.5	Summary	67
4	**APPLYING CLONAL SELECTION PRINCIPLE TO SOLVE JOB-SHOP AND FLEXIBLE JOB-SHOP SCHEDULING PROBLEMS**		**68**
	4.1	Introduction	68
	4.2	Initialisation	70
	4.3	Step 1: Generate Antibody Population	71

4.3.1 Antibody Population for JSSP 71
4.3.2 Antibody Population for FJSSP 75
4.4 Step 2: Calculate Antibody Affinity 77
4.5 Step 3: Cloning and Mutating the Antibody 78
4.5.1 Random Somatic Point and Heavy-Light Chain Somatic Point 79
4.5.2 Random Somatic Point Recombination and Heavy Chain Somatic Point Recombination 80
4.5.3 Gene Conversion 82
4.5.4 Gene Inversion 83
4.5.5 Gene Right-Shift and gene Left-Shift 84
4.5.6 Nucleotide Addition Right-Left and Nucleotide Addition Right-Right 85
4.6 Step 4: Calculating the Affinity of the Mutation of Clone and Updating Antibody Population 88
4.7 Step 5: Stop Criterion 91
4.8 Step 6: Find and Decode the Best Antibody 91
4.9 Experimental Results and Discussions 91
4.9.1 JSSP Experimental Results and Discussions 91
4.9.2 FJSSP Experimental Results and Discussions 104
4.10 Summary 110

5	**HYBRID CLONAL SELECTION PRINCIPLE AND VARIABLE NEIGHBOURHOOD DESCENT TO SOLVE JOB-SHOP AND FLEXIBLE JOB-SHOP SCHEDULING PROBLEMS**		**111**
	5.1	Introduction	111
	5.2	Disjunctive Graph and Critical Path	112
	5.3	The Hybrid Algorithm	116
	5.4	Experimental Results and Discussions	120
		5.4.1 JSSP Experimental Results and Discussions	120
		5.4.2 F JSSP Experimental Results and Discussions	137
		5.4.3 Comparison with the State-of-the-art in JSSP and FJSSP	145
	5.5	Summary	146
6	**RESCHEDULING OF JOB-SHOP AND FLEXIBLE JOB-SHOP SCHEDULING PROBLEM**		**148**
	6.1	Introduction	148
	6.2	Rescheduling for Machine Breakdown Factor	150
	6.3	New Orders Receive	154
	6.4	Experimental Resuts and Discussions	158
	6.5	Summary	163
7	**CONCLUSION AND DISCUSSION**		**164**
	7.1	Concluding Remarks	164
	7.2	Research Contributions	166
	7.3	Future Works	168
REFERENCES			**170**
Appendix A – B			190 – 194

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	Related Works for Production Scheduling Problem	20
2.2	Advantages of Each Methods	21
2.3	Disadvantages of Each Methods	22
2.4	Comparison of Genetic Algorithms and AIS	30
2.5	Mapping Between Real World Issue and Research Question	44
3.1	List of JSSP and FJSSP Problem	51
3.2	Experiment Parameter	63
3.3	List of Data Set for JSSP	64
3.4	List of Data Set for FJSSP	64
3.5	Previous Research for JSSP Result Comparison	66
3.6	Previous Research for FJSSP Result Comparison	66
3.7	Previous Research for Rescheduling Result Comparison	66
4.1	Parameter Setting for Expr. 1 to Expr. 3 using JSSP Instance	93
4.2	Parameter Setting for Expr. 4 to Expr. 6 using JSSP Instance	94
4.3	Mean of *makespan* for Each Problem	95
4.4	Summary of Confident Level and P-Value for Mutation Type Test	96
4.5	Comparison Min C_{max} and Mean C_{max} for Expr. 6	97
4.6	The Computational Result Comparison for abz5 – abz9	98
4.7	The Computational Result Comparison for ft6 and ft10	98
4.8	The Computational Result Comparison for la01 – la40	99

4.9	The Computational Result Comparison for orb01 – orb10	101
4.10	Parameter Setting for FJSSP Instance	105
4.11	mk01 – mk10 Result Comparison for Each Experiment	105
4.12	m01 – mk10 C_{max} Comparison for Lowest and Mean	106
4.13	% MRE Comparison for Each Experiment	106
4.14	The computational result comparison for mk01 – mk10	107
5.1	Mean of C_{max} for Experiment Result	121
5.2	Comparison between Min C_{max} and Mean C_{max} for Expr. 3	123
5.3	Comparison of Mean C_{max} between Single and Hybrid Method	124
5.4	Summary of Confident Level and P-Value for Different Method Test	125
5.5	Mean of Time for Single and Hybrid Method	126
5.6	Summary of Confident Level and P-Value for Time Test	126
5.7	The Computational Result Comparison for abz5 – abz9	127
5.8	The Computational Result Comparison for ft6 and ft10	127
5.9	The Computational Result Comparison for la01 – la40	128
5.10	The Computational Result Comparison for orb01 – orb10	130
5.11	mk01 – mk10 Comparison for Each Experiment using Hybrid Method	138
5.12	m01 – mk10 C_{max} Comparison for Lowest and Mean	138
5.13	% MRE Comparison for Each Experiment using Hybrid Method	138
5.14	MRE Comparison between Single and Hybrid Method	139
5.15	Time to Produce Solution Comparison between Two Method	140
5.16	The computational result comparison for mk01 – mk10	141
6.1	Situation and Strategy	157
6.2	Comparison Result for Rescheduling Process	163

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
1.1	Example of JSSP	2
1.2	Example of FJSSP	4
1.3	Type of Schedules	5
2.1	Example of Solution for JSSP	16
2.2	Example of Solution for FJSSP	17
2.3	Example of Disjunctive Graph	26
2.4	How Human Immune System Work	27
2.5	Clonal Selection Principle	35
2.6	Integer String Encoding Antibody Generated Randomly	38
2.7	Integer String Encoding Antibody Generated using Library	39
2.8	Antibody Representation for Flexible Job-Shop using Approach 1	39
2.9	Antibody Representation for Flexible Job-Shop using Approach 2	39
2.10	Basic Flow for JSSP and FJSSP Solving Process using AIS	40
3.1	Research Framework	48
3.2	Initial Stage Process	50
3.3	ft06 JSSP Data Set	52
3.4	Data Set for Hurink la01 EData	52
3.5	ft06 JSSP Instance from Figure 3.6 Data Set	52
3.6	Hurink la01 EData FJSSP Instance from Figure 3.7 Data Set	53

3.7	Mapping JSSP into Integer String (Antibody)	54
3.8	Initial Algorithm to Generate Antibody Population	54
3.9	Algorithm for Mutation Type	54
3.10	First Phase Activity – Single Method to Solve JSSP and FJSSP	56
3.11	Statistical Test Process for Mutation Type Significant	57
3.12	Second Phase Activity – Hybrid Method to Solve JSSP and FJSSP	59
3.13	Statistical Test Process for Method Significant	59
3.14	Third Phase Activity – Rescheduling for JSSP and FJSSP	60
3.15	Algorithm to Calculate C_{max}	62
3.16	Transferred into Gantt Chart (Problem ft06)	65
3.17	Integer String, Machine List and Time List	65
4.1	The Proposed Algorithm to Solve JSSP and FJSSP using AIS Approach	69
4.2	Flow Chart for Proposed Model to Solve JSSP and FJSSP	70
4.3	Example of JSSP	71
4.4	Randomly Generate Antibody for JSSP	71
4.5	Formula to Calculate Number of Light-Chain	72
4.6	Generate Antibody from Library	73
4.7	Algorithm to Generate Antibody Randomly for JSSP	74
4.8	Algorithm to Generate Antibody using Library for JSSP	74
4.9	Algorithm to Generate Antibody using *Rule1* for FJSSP	75
4.10	Algorithm to Generate Antibody using *Rule2* for FJSSP	76
4.11	Example of FJSSP	76
4.12	Generate Antibody using *Rule1* for FJSSP	76
4.13	Generate Antibody using *Rule2* for FJSSP	76
4.14	Antibody Decoding for JSSP	77
4.15	Antibody Decoding for FJSSP	77
4.16	Random Somatic Point Mutation for JSSP	79
4.17	Random Somatic Point Mutation for FJSSP	79
4.18	Heavy-Light Chain Somatic Point Mutation JSSP	80

4.19	Heavy-Light Chain Somatic Point Mutation for FJSSP	80
4.20	Random Somatic Point Recombination for JSSP	81
4.21	Random Somatic Point Recombination for FJSSP	81
4.22	Heavy Chain Somatic Point Recombination for JSSP	81
4.23	Gene Conversion for JSSP	82
4.24	Gene Conversion for FJSSP	82
4.25	Gene Inversion for JSSP	83
4.26	Gene Inversion for FJSSP	83
4.27	Gene Right-Shift for JSSP	84
4.28	Gene Right-Shift for FJSSP	84
4.29	Gene Left-Shift for JSSP	85
4.30	Gene Left-Shift FJSSP	85
4.31	Nucleotide Addition Right-Left for JSSP	86
4.32	Nucleotide Addition Right-Left for FJSSP	86
4.33	Nucleotide Addition Right-Right for JSSP	87
4.34	Nucleotide Addition Right-Right for FJSSP	87
4.35	Mutate using Random Somatic Point Recombination for JSSP	88
4.36	Mutate using Random Somatic Point Mutation for JSSP	89
4.37	Mutate using Random Somatic Point Recombination for FJSSP	90
4.38	Mutate using Random Somatic Point Mutation fo FJSSP	90
4.39	Mean Relative Error Values by Different Methods for abz5 – abz9	103
4.40	Mean Relative Error Values by Different Methods for la01 – la40	103
4.41	Mean Relative Error Values by Different Methods for orb1 – orb10	104
4.42	MRE for Brandimarte Data over Best-Known Lower Bound	108
4.43	MRE for Hurink Data over Best-Known Lower Bound	108
4.44	Mean Relative Error (MRE) over Best-Known Lower Bound for Dauzére-Pérés and Paulli Data Set and Barnes and Chambers Data Set	109

5.1	Example of JSSP	113
5.2	Disjunctive Graph Represented the JSSP Represented	113
5.3	A Feasible Solution for the Disjunctive Graph in Figure 5.2	113
5.4	Algorithm to Give the Number to Each Node	114
5.5	A Feasible Solution with Each Node are Numbered	114
5.6	Calculate the *Head Value*	115
5.7	Calculate the *Tail Value*	115
5.8	Find the Critical Node (Operation)	116
5.9	The Proposed Algorithm for Hybrid Proposed Method to Solve JSSP and FJSSP	117
5.10	Basic Flow Chart for Hybrid Proposed Method to Solve JSSP and FJSSP	118
5.11	Antibody for JSSP in Figure 5.1	119
5.12	Clone for Antibody in Figure 5.11 after Mutation Process	119
5.13	Calculation of the Critical Path	120
5.14	New Antibody / Solution after Swap Critical Gene on Critical Path	120
5.15	Time Comparison between Single and Hybrid Method for abz5 – abz9	131
5.16	C_{max} Comparison between Single and Hybrid Method for abz5 – abz9	132
5.17	C_{max} Comparison between Single and Hybrid Method for ft06 & ft0	132
5.18	C_{max} Comparison between Single and Hybrid Method for orb1 – orb10	133
5.19	C_{max} Comparison between Single and Hybrid Method for la01 – la20	134
5.20	C_{max} Comparison between Single and Hybrid Method for la21 – la40	135
5.21	Mean Relative Error Values by Different Methods for abz5 – abz9	136

5.22	Mean Relative Error Values by Different Methods for la01 – la40	136
5.23	Mean Relative Error Values by Different Methods for orb1 – orb10	137
5.24	Analysis of Variance for Significance between Methods	139
5.25	Analysis of Variance for Method Significant (Time to Produce Solution)	140
5.26	Time Comparison to Get Result between Difference Methods	142
5.27	Comparison between Single and Hybrid Method for Brandimarte	143
5.28	MRE for Brandimarte Data over Best-Known Lower Bound	144
5.29	MRE for Hurink Data over Best-Known Lower Bound	144
5.30	Mean Relative Error (MRE) over Best-Known Lower Bound for Dauzére-Pérés and Paulli Data Set and Barnes and Chambers Data Set	145
5.31	Analysis of Variance for JSSP State-of-the-art	146
5.32	Analysis of Variance for FJSSP State-of-the-art	146
6.1	Flow Chart for Rescheduling Process	150
6.2	Job Shop Scheduling Problem	151
6.3	Antibody for JSSP	151
6.4	Schedule (Gantt Chart) for JSSP	151
6.5	Machine Breakdown	152
6.6	Random Function to Generate Machine Breakdown	153
6.7	Antibody for Machine Breakdown	153
6.8	New Schedule (Gantt Chart) after Machine Breakdown	153
6.9	New Jobs Arrive	155
6.10	Antibody for new Jobs	155
6.11	Rescheduling for New Job Arrival using Strategy 1 and Strategy 3	156
6.12	Rescheduling for New Job Arrival using Strategy 2	156
6.13	Rescheduling for New Job Arrival using Strategy 4	157
6.14	ft06 Data Set with New Job Arrival	158

6.15	ft06 Data Set Job Ordering on Machine for Current Solution	159
6.16	ft06 Data Set Job Ordering on Machine for New Solution	159
6.17	Data from Yang and Wu (2003)	161
6.18	Original Schedule for Benchmark Flexible Job-Shop Data	162
6.19	New Schedule after Rescheduling Process	162
6.20	Analysis of Variance for Rescheduling using Different Methods	163

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
HAIS	-	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 Neigbourhood Decent
VNS	-	Variable Neigbourhood Search

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	List of Publications	190
B	Data Set Validation	191

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
Job_1	O_1	6	6	∞
	O_2	∞	5	∞
	O_3	4	4	4
	O_4	∞	∞	∞
Job_2	O_1	∞	6	∞
	O_2	∞	5	7
	O_3	7	9	∞
	O_4	6	3	∞
Job_3	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.

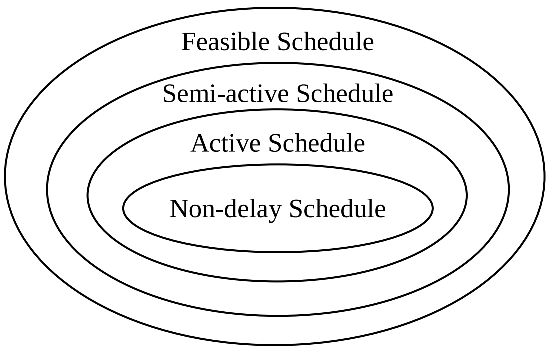

Figure 1.3: Types of Schedule

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.

REFERENCES

Abdollahpour, S., and Rezaeian, J. (2015). Minimizing Makespan for Flow Shop Scheduling Problem with Intermediate Buffers by using Hybrid Approach of Artificial Immune System. *Applied Soft Computing*. 28, 44-56.

Abreu, N., Ajmal, M., Kokkinogenis, Z., and Bozorg, B. (2011). Ant Colony Optimization. Retrieved June 18, 2014, from http://paginas.fe.up.pt/~mac/ensino/docs/DS20102011/Presentations/PopulationalMetaheuristics/ACO_Nuno_Muhammad_Zafeiris_Behdad.pdf.

Adams, J., Balas, E. and Zawack, D. (1988). The Shifting Bottleneck Procedure for Job Shop Scheduling. *Management Science*. 34, 391-401.

Adibi, M.A., Zandieh, M., and Amiri, M. (2010). Multi-objective Scheduling of Dynamic Job Shop using Variable Neighborhood Search. *Expert Systems with Applications*. 37, 282-287.

Afshari, M., and Sajedi, H. (2012). A Novel Artificial Immune Algorithm for Solving the Job Shop Scheduling Problem. *International Journal of Computer Applications* (0975 – 888). 48(14), 46-53.

Aickelin, U. (2004). Artificial Immune Systems (AIS) - A New Paradigm for Heuristic Decision Making. Invited Keynote Talk. *Annual Operational Research Conference 46*, York, UK.

Aickelin, U., Burke, E., and Din, A.M. (2004). Investigating Artificial Immune Systems For Job Shop Rescheduling In Changing Environments. *6th International Conference in Adaptive Computing in Design and Manufacture. Bristol*, United Kingdom.

Alvarez-Valdes, R., Fueters, A., Tamarit, J.M., Gimenez, G., and Ramos, R. (2005). A heuristic to Schedule Flexible Job-Shop in a Glass Factory. *European Journal of Operational Research*. 165(1), 525-534.

Amirghasemi, M. (2015). An Effective Asexual Genetic Algorithm for Solving the Job Shop Scheduling Problem. *Computers and Industrial Engineering*. 83, 123-138.

Amirghasemi, M., and Zamani, R. (2015). An Effective Asexual Genetic Algorithm for Solving the Job Shop Scheduling Problem. *Computers & Industrial Engineering. 83*, 123-138.

Applegate, D., and Cook, W.(1991). A Computational Study of the Job-Shop Scheduling Instance. *ORSA Journal on Computing*. 3, 149-156.

Atay, Y., and Kodaz, H. (2014).Optimization of job shop scheduling problems using modified clonal selection algorithm. *Turkish Journal of Electrical Engineering & Computer Sciences*. 22, 1528-1539.

Ayara, M.J., de Lemos, T.R., and Forrest, S.(2005). Immunising Automated Teller Machines. *Proceedings of the 4th International Conference in Artificial Immune Systems (ICARIS 2005)*. Lecture Notes in Computer Science 3627. Berlin, Germany: Springer, 404-417.

Bagheri, A., Zandieh, M., Mahdavi, I., and Yazdani, M. (2010). An Artificial Immune Algorithm for the Flexible Job-Shop Scheduling problem. *Future Generation Computer Systems*. 26, 533-541.

Bai, Q. (2010). Analysis of Particle Swarm Optimization Algorithm. *Computer and Information Science*. 3(1), 180-184.

Baker, K. R. (1974). *Introduction to Sequencing and Scheduling*. New York: John Wiley.

Balaji, A.N., and Porselvi, S. (2014). Artificial Immune System Algorithm and Simulated Annealing Algorithm for Scheduling Batches of Parts based on Job Availability Model in a Multi-Cell Flexible Manufacturing System. *Procedia Engineering*. 97, 1524-1533.

Balas, E., Lenstra, J.K., and Vazacopoulos, A. (1995), One Machine Scheduling with Delayed Precedence Constraints. *Management Science*. 41, 94-109.

Baptiste, P. and Le Pape, C. (1996). A constraint-Based Branch and Bound Algorithm for Preemptive Job-Shop Scheduling. *Proceedings of the International Workshop on Production Planning and Control*. Mons, Belgium.

Barker, J.R. and McMahon, G.B. (1985). Scheduling the General Job-Shop. *Management Science*. 31(5), 594-598.

Barnes J.W. and Chambers J.B. (1996). Flexible Job Shop Scheduling by TabuSearch. *Graduate Program in Operations Research and Industrial Engineering*. Technical Report ORP 9609, University of Texas, Austin.

Bean, J., Birge, J.R., Mittenthal, J., and Noon, C.E.(1991). Matchup Scheduling with Multiple Resources, Release Dates and Disruptions. *Operations Research*. 39(3), 470-483.

Berlung, B., Karltun, J. (2005). Human, Technological and Organizational Aspects Influencing the Production Scheduling Process. *18th International Conference on Production Research*. 31 July to 4 August 2005. Fisciano, Italy.

Bersini, H. (1991). Immune Network and Adaptive Control. In Bourgine, P., and Francisco, V. (Ed.) *Proceedings of the first European Conference on Artificial Life*. Bradford Books: MIT Press, 217-226.

Bersini, H., and Varela, F.J. (1990). Hints for Adaptive Problem Solving Gleaned from Immune Networks. *Parallel Problem Solving from Nature.Lecture Notes in Computer Science*. Berlin: Springer Berlin Heidelberg, 343-354.

Bersini, H., and Varela, F.J. (1991). The Immune Recruitment Mechanism: A Selective Evolutionary Strategy. In Belew, R., and Booker, L. (Ed.) *Proceedings of the International Conference on Genetic Algorithm*. San Francisco, CA, USA: Morgan Kaufmann Publishers Inc, 520-526.

Bilgen, B., and Çelebi, Y. (2013). Integrated Production Scheduling and Distribution Planning in Dairy Supply Chain by Hybrid Modelling. *Annal Operational Research*. 211, 55-82.

Blazewiez, J., Ecker, K., Schmidt, G., and J. Weglarz. (1994). *Scheduling in Computer and Manufacturing Systems*, New York: Springer.

Blazewiez, J., Pesch, P., and Sterna, M. (2000). The Disjunctive Graph Machine Representation of the Job Shop Scheduling Problem. *European Journal of Operational Research*. 127, 317-331.

Bmcker, P., Jurisch, B., and Sievers, B. (1992). Job-shop (Ccodes). *European Journal of Operational Research*. 57, 132-133.

Bmcker, P., Jurisch, B., and Sievers, B. (1994). A Branch and Bound Algorithm for the Job-shop Scheduling Problem. *Discrete Applied Mathematics*. 49, 107-127.

Bożejko, W., Pempera, J., and Smutnicki, C. (2009). Parallel Simulated Annealing for the Job Shop Scheduling Problem. *Computational Science, Lecture Notes in Computer Science*. Berlin: Springer Berlin Heidelberg, 631-640.

Brandimarte P. (1993). Routing and scheduling in a flexible job shop by tabu search. *Annals of Operations Research*. 41, 157 - 183.

Brucke, P., and Thiele, O. (1996). A Branch & Bound Method for the General-Shop Problem with Sequence Dependent Setup-times. *Operations Research Spektrum*. 18(3), 145-161.

Brucker, P., and Krämer, A. (1995). Shop Scheduling Problems with Multiprocessor Tasks on Dedicated Processors. *Annals of Operations Research*. 57(1), 13–27.

Brucker, P., and Neyer, J. (1998). Tabu-search for the multi-mode job-shop problem. *Operations-Research-Spektrum*. 20(1), 21-28.

Bruker, P., and Schlie, R. (1990) Job Shop Scheduling with Multi Purpose Machine. *Computing*. 45(4), 369-375.

Burnet, F.M. (1978). Clonal Selection and After. In Bell G. I., Perelson A. S. and Pimbley Jr. G. H. (Ed.). *Theoretical Immunology*. Marcel Dekker Inc: New York, 63-85.

Cai, B., Wang, S., and Hu, H. (2011). Hybrid Artificial Immune System for Job Shop Scheduling Problem. *International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering*. 5(11), 1606-1611.

Carlier, J. (1978). Ordonnancements a Contraintes Disjonctives. R.A.I.R.O. Recherech Operationelle. *Operational Research*. 12, 333–351.

Carlier, J. (1982). The One-machine Sequencing Problem. *European Journal of Operational Research*. 11(1), 42-47.

Carlier, J. and Pinson, E. (1989). One Machine Problem. *European Journal of Operational Research*. 11, 42-47.

Carlier, J. and Pinson, E. (1990). A Practical use of Jackson's Preemptive Schedule for Solving the Job-shop Problem. *Annals of Operations Research*. 26, 269-287.

Carlier, J. and Pinson, E. (1994). Adjustments of Head and Tails for the Job-shop Problem. *European Journal of Operational Research*. 78, 146-161.

Carlier, J. and Pinson, E., (1989). An Algorithm for Solving The Job-Shop Problem. *Management Science*. 35(2), 164-176.

Castro, L.N.D., and Zuben, F.J.V. (2000). The Clonal Selection Algorithm with Engineering Applications. *Genetic and Evolutionary Computation Conference (GECCO'00)*. 8 – 12 July 2000. Las Vegas, Nevada, USA.

Cervante, L., Xue, B., Shang, L., and Zhang, M. (2012). A Dimension Reduction Approach to Classification Based On Particle Swarm Optimisation and Rough Set Theory. *25nd Australasian Joint Conference on Artificial Intelligence. Lecture Notes in Computer Science*. 7691, 313–325.

Chambers, J.B. and Barnes, J.W. (1996). Flexible Job Shop Scheduling by Tabu Search. The University of Texas, Austin, TX, Technical Report Series ORP96-09, Graduate Program in Operations Research and Industrial Engineering.

Chandrasekaran, M., Asokan, P., Kumanan, S., Balamurugan, T., and Nickolas, S. (2006). Solving job shop scheduling problems using artificial immune system. *The International Journal of Advanced Manufacturing Technology*. 31(5-6), 580-593.

Chang, H.C., Chen, Y-P., Liu, T.K., and Chou, J-H. (2015). Solving the Flexible Job Shop Scheduling Problem With Makespan Optimization by Using a Hybrid Taguchi-Genetic Algorithm. *IEEE Access*. September 2015.

Chen H., Ihlow J., and Lehmann C. (1999). A Genetic Algorithm for Flexible Job-shop Scheduling. *IEEE International Conference on Robotics and Automation*. 10-15 May 1999. Detroit, MI: IEEE, 1120-1125.

Chryssolouris, G., and Subramaniam, V.(2001). Dynamic Scheduling of Manufacturing Job Shops using Genetic Algorithms. *Journal of Intelligent Manufacturing*. 12, 281-293.

Chueh, C.H. (2004). An Immune Algorithm for Engineering Optimization.Doctor of Philosophy, Tatung University.

Coello, C. A.C., Rivera, D.C., and Cortes, N.C.(2003). Use of An Artificial Immune System for Job Shop Scheduling. *Artificial Immune Systems, Second International Conference*. 1 - 3 September 2003. Edinburgh, UK, 2787, 1-10.

Costa, A.M., Vargas, P. A., Von Zuben, F.J., and Frabca, P.M.(2002). Makespan Minimization on Parallel Processors: An Immune-Based Approach. *Proceedings of the 2002 Congress on Evolutionary Computation*. 12 - 17 May 2002. Honolulu, HI:IEEE Press, 920-925.

Dasgupta, D., Yu, S., and Nino, F. (2011). Recent Advances in Artificial Immune Systems: Models and Applications. *Applied Soft Computing*. 11, 1574-1587.

Dausset, J. (1980). The Major Histocompatibality Complex InMan - Past, Present and Future Concepts. Nobel Lecturer. University of Paris.

Dauzére-Pérés S., and Paulli J. (1997). An Integrated Approach for Modeling and Solving the General Multiprocessor Job-Shop Scheduling Problem using TabuSearch. *Annals of Operations Research*. 70, 281 - 306.

Dauzére-Pérés, S. and Paulli, J. (1994). Solving the General Multiprocessor Job-Shop Scheduling Problem. Technical report, Rotterdam School of Management, Erasmus Universiteit Rotterdam.

Dauzére-Pérés, S., Roux, J., and Lasserre, J. B. (1998). Multi-Resource Shop Scheduling with Resource Flexibility. *European Journal of Operational Research*. 107(1), 289-305.

Davarzani, Z., Staji, S., and Dabaghi-Zarandi, F. (2015). Job Shop scheduling by Using the Combinational Viruses Evolutionary and Artificial Immune Algorithms in Dynamic Environment. *International Journal of Hybrid Information Technology*. 8(12), 191-204.

de la Puente, P., Muz, B., Gilson, R.C., Azab, F., Luderer, M., King, J., Achilefu, S., Vij, R., and Azab, A.K. (2015). 3D Tissue-engineered Bone Marrow as a Novel Model to Study Pathophysiology and Drug Resistance in Multiple Myeloma. *Biomaterials*. 73, 70-84.

Demir, Y., and İşleyen, S. K. (2014). An Effective Genetic Algorithm for Flexible Job-Shop Scheduling with Overlapping in Operations. *International Journal of Production Research*. 52(13), 3905-3921.

Deo, N. (1974). *Graph Theory with Applications to Engineering and Computer Science*. Englewood Cliffs : Prentice-Hall.

Diana, R.O.M, Franca Filho, M.F., de Sauza, S.R., and de Almeida Vitor, J.F. (2015). An Immune-inspired Algorithm for an Unrelated Parallel mMachines' Scheduling Problem with Sequence and Machine Dependent Stup-times for makespan minimisation. *Neurocomputing*. 163, 94-105.

Dirk, C., M., and Christian, B.(2004). An Efficient Genetic Algorithm for Job Shop Scheduling with Tardiness Objectives. *European Journal of Operational Research*. 155, 616 – 630.

Dong, Y. Sun, Z., and Jia, H. (2006). A Cosine Similarity-Based Negative Selection Algorithm For Time Series Novelty Detection. *Mechanical Systems and Signal Processing*. 20(6), 1461-1472.

Dreher, H. (1995). *The Immune Power Personality*. USA: Penguim Books.

Drexl A., and Kimms A. (Ed.) (1998). *Beyond Menufacturing Resource Planning (MRPII)*. Berlin: Springer.

Driss, I., Mouss, K.N., and Laggoun, A. (2015). An Effective Genetic Algorithm for the Flexible Job Shop Scheduling Problems. *11e Congrès International de Génie Industriel – CIGI2015*. 26 – 28 October 2015. Ville de Québec, Canada.

Du, H., Liu, D., and Zhang, M-H. (2016). A Hybrid Algorithm Based on Particle Swarm Optimization and Artificial Immune for an Assembly Job Shop Scheduling Problem. *Mathematical Problems in Engineering*. 2016, 1-10.

Fabio, F., and Maurizio, R. (2006) Comparison of Artificial Immune Systems and Genetic Algorithms in Electrical Engineering. *Computation and Mathematics in Electrical and Electronic Engineering*. 25(4), 792-811.

Farashahi, H. G., Baharudin, B.T.H.T, Shojaeipour, S., and Jaberi, M. (2011). Efficient Genetic Algorithm for Flexible Job-Shop Scheduling Problem Using Minimise Makespan. *Communications in Computer and Information Science*. 135, 385-392.

Farmer, J.D., Packard, N.H., and Perelson, A.S. (1986). The Immune Systems, Adaptation and Machine Learning. *Physica D: Nonlinear Phenomena*. 22, 187-204.

Fattahi, P., Jolai, F., and Arkat, J. (2009).Flexible Job Shop Scheduling with Overlaping in Operations. *Applied Mathematical Modelling*. 33(1), 3076-3087.

Fisher, H., and Thompson, G.L. (1963). *Probabilistic Learning Combinations of Local Job-Shop Scheduling Rules*. In Muth, J.F. and Thompson G.L. (Ed.) *Industrial Scheduling* (225 - 251). Englewood Cliffs, New Jersey: Prentice Hall.

Florian, M., Trtpant, P., and McMahon, G. (1971). An Implicit Enumeration Algorithm for the machine sequencing problem. *Management Science*. 17, 782-792.

Forrest, S., Perelson, A.S., Allen, L., and Cherukuri, R. (1994). Self–nonself Discrimination in a Computer. *IEEE Symposium on Research in Security and Privacy*. 16 - 18 May 1994. Oakland, California.

French, S. (1982). *Sequencing and Scheduling (Mathematics and its Applications).* United Kingdom: Ellis Horwood Ltd.

Ge, H.W., Sun, L., Liang, Y.C., and Qian, F. (2008). An Effective PSO and AIS-Based Hybrid Intelligent Algorithm for Job-Shop Scheduling. *IEEE*

Transactions on Systems, Man, and Cybernetics – Part A: System and Humans. 38(2), 358 - 368.

Gen, M., Tsujimura, Y., and Kubota, E. (1994). Solving Job-Shop Scheduling Problem Using Genetic Algorithms. *Proceedings of the 16th International Conferences on Computer and Industrial Engineering*. 7 – 9 March 1994. Ashikaga, Japan, 576-579.

Giffler, B., and Thomson, G., (1960). Algortihms for Solving Production Scheduling Problems. *Operations Research*. VIII, 487-503.

Gonçalves, J.F., Mendes, J.J.M., and Resende, M.G.C. (2005). A Hybrid Genetic Algorithm for the Job Shop Scheduling Problem. *European Journal Operational Research*. 167(1), 77 - 95.

Gonz´alez, M.A., Vela, C.R., and Varela, R. (2013). An Efficient Memetic Algorithm for the Flexible Job Shop with Setup Times. *Proceedings of the Twenty-Third International Conference on Automated Planning and Scheduling*. 10 - 14 June 2013, Rome, Italy.

González, M. A., Camino, R. Vela, González-Rodríguez, I., and Varela, R. (2013). Lateness Minimization with TabuSearch for Job Shop Scheduling Problem with Sequence Dependent Setup Times. *Journal of Intelligent Manufacturing*. 24(4), 741-754.

Gutiérrez, C. (2014). Overlap Algorithms in Flexible Job-shop Scheduling. *International Journal of Artificial Intelligence and Interactive Multimedia*. 2(6), 41-47.

Hansen P., and Mladenovi´c´N. (2003). *Variable Neighborhood Search*. In: Glover, F. and Kochen-berger G. (Ed.), *Handbook of Metaheuristics* (145-184). Netherlands: Kluwer Academic Publisher.

Hart, E., and Timmis,J. (2008). Application Areas of AIS: The Past, The Present and The Future. *Artificial Immune Systems.Lecture Notes in Computer Science*, 3627.(483-497). Berlin: Springer Berlin Heidelberg.

Hart, E., and Ross, P. (1999). *An Immune System Approach to Scheduling in Changing Environments*. In Banzhaf, W., Daida, J., Eiben, A.E., Garzon, M.H., Honavar, V., Jakiela, M., and Smith, R.E. (Ed.) *Proceeding of the GECCO 1999* (1559 – 1565). San Francisco: Morgan Kaufmann Publishers Inc.

Hart, E., and Ross, P. (1999). *The Evolution and Analysis of a Potential Antibody Library for Job-Shop Scheduling*. In Dorigo, M. and Glover, F. (Ed.) *New Ideas in Optimisation* (185-202). London: McGraw-Hill.

Hart, E., and Timmis, J., (2008). Application Areas of AIS: The Past, ThePresent and The Future. *Applied Soft Computing*. 8(1), 191 - 201.

Hart, E., Ross, P., and Nelson, J. (1998). Producing Robust Schedules Via An Artificial Immune System. *Proceeding of the ICEC '98*. 4-9 May 1998. Anchorage, AK: IEEE, 464-469.

He, L., Liu, Y., Xie, H., and Zhang, Y. (2008). Job Shop Dynamic Scheduling Model Based on Multi Agent. *Control and Decision Conference*. 2-4 July 2008. Yantai, Shandong: IEEE, 829 - 833.

Hermann, J., W. (2006). Improving Production Scheduling: Integrating Organizational, Decision-Making, and Problem-Solving Perspectives. *Industrial Engineering Research Conference*. May 2006. Orlando, Florida.

Ho N.B., and Tay J.C. (2004). GENACE: An Efficient Cultural Algorithm for Solving the Flexible Job-Shop Problem. *IEEE international Conference on Robotics and Automation 2004*. 19-23 June 2004. New Orleans, Louisiana, USA: IEEE, 1759 - 1766.

Ho, N.B., Tay, J.C., and Lai, E.M.K. (2007). An Effective Architecture for Learning and Evolving Flexible Job-Shop Schedules. *European Journal of Operational Research*. 179(2), 316-333.

Hoffman, G.W. (1986). A Neural Network Model Based on the Nalogy with the Immune System. *Journal of Theoretical Biology*. 122, 33-67.

Hoitomt, D.J., Luh, P. B., and Pattipati, K. R. (1993). A Practical Approach to Job-Shop Scheduling Problems. *IEEE Transactions on Robotics and Automation*. 9(1), 1-3.

Holloway, C.A., and Nelson, R.T. (1974). Job Shop Scheduling with Due Dates and Variable Processing Times. *Management Science*. 20(9), 1264 - 1275.

Hu, X., Liu, L., Hu, R., Zhao, G., and Wang, S. (2015). A Hybrid PSO-GA Algorithm for Job Shop Scheduling in Machine Tool Production. *International Journal of Production Research*. 53(19), 5755-5781.

Huang, C-C., Tsai, H-W., Lee, W-Y. Lin, W-W., Chen, D-Y., Hung, Y-W., Chen, J-W., Hwang, S-M, Chang, Y., and Sung, H-W. (2013). A Translational Approach in Using Cell Sheet Fragments of Autologous Bone Marrow-derived

Mesenchymal Stem Cells for Cellular Cardiomyoplasty in a Porcine Model. *Biomaterials*. 34, 4582-4591.

Huang, C-C., Tsai, H-W., Lee, W-Y., Lin, W-W., Chen, D-Y., Hung, Y-W., Chen, J.W., Hwang, S-M., Chang, Y., and Sung, H.W. (2013). A Translational Approach in Using Cell Sheet Fragments of Autologous Bone Marrow-derived Mesenchymal Stem Cells for Cellular Cardiomyoplasty in a Porcine model. *Biomaterials*. 34, 4582-4591.

Hurink J., Jurish B., and Thole M. (1994). TabuSearch for the Job Shop Scheduling Problem with Multi-Purpose Machines. *OR-Spektrum 1994*. 15, 205-215.

Ishida, Y. (1990). Fully Distributed Diagnosis by PDP Learning Algorithm: Towards Immune Network PDP Model. *Proceedings of the International Joint Conference on Neural Networks*. 17-21 June 1990. San Diego, CA, USA, 777-782.

Ishida, Y. (1993). An Immune Network Model and Its Applications to Process Diagnosis. *Systems and Computers in Japan*. 24(6), 646-651.

Izadinia, H., Sadeghi, F., and Ebadzadeh, M.M. (2009). A Novel Multi-epitopic Immune Network Model Hybridized with Neural Theory and Fuzzy Concept. *Neural Networks*. 22, 633-641.

Janeway, C.A. (1992). The Immune System Discriminates Infectious Non-self From Non Infectious Self. *Immunology Today*, 13(1), 11-20.

Jansen, L.E., Birch, N.P., Schiffman, J.D., Crosby, A.J., and Peyton, S.R. (2015). Mechanics of Intact Bone Marrow. *Journal of the Mechanical Behavior of Biomedical Materials*. 50, 299–307.

Jansen, T., and Zarges, C. (2015). Analysis of Randomised Search Heuristics for Dynamic Optimisation. *Evolutionary Computation*. 23(4), 513-541.

Jensen, K., Mastrolilli, M., and Solis-Oba, R. (1999). Approximation Algorithms for Flexible Job-Shop Problems. *Proceedings of Latin American Theoritical Informatics*. Lecture Notes in Computer Science (68-77). Berlin: Springer.

Jensen, M.T. (2003). Generating Robust and Flexible JobshopSchedules using Genetic Algorithms. *IEEE Transactions on Evolutionary Computational*. 7(3), 275-288.

Jerne, N.K. (1973). The Immune System. *Scientific American*. 229(1), 52-60.

Jia H.Z., Nee A.Y.C., Fuh J.Y.H., and Zhang Y.F. (2003). A Modified Genetic Algorithm for Distributed Scheduling Problems. *International Journal of Intelligent Manufacturing*. 14, 351 - 362.

Jones, A., and Rabelo, L.C. (1998). Survey of Job Shop Scheduling Techniques. Unpublished note, National Institute of Standards and Technology (NISTIR).

Kacem, I. (2003). Genetic Algorithm for Flexible Job-Shop Scheduling Problem. *IEEE International Conference on Systems, Man and Cybernatics*. 4(1), 3464-3469.

Kacem, I., Hammadi, S., and Borne, P. (2002). Approach by Localization and Multiobjective Evolutionary Optimization for Flexible Job-shop Scheduling Problems. *IEEE Transactions on Systems, Man and Cybernetics*. 32(1), 1-13.

Kassu, J., and Eshetie, B. (2015). Job Shop Scheduling Problem for Machine Shop with Shifting Heuristic Bottleneck. *Global Journal of Researches in Engineering: J General Engineering*. 15(1), 20 - 26.

Khalid, M.N.A., and Yusof, U.K. (2015). An Artificial Immune Approach for Optimizing Crowd Emergency Evacuation Route Planning Problem. *Proceedings of the International Conference on Agents and Artificial Intelligence (ICAART-2015)*. 10 - 12 January 2015. Lisbon, Portugal. 503-508.

Komaki, G.M., Teymourian, E., and Kayvanfar, V. (2015). Minimising Makespan in the Two-stage Assembly Hybrid Flow Shop Scheduling Problem using Artificial Immune Systems. *International Journal of Production Research*. 54(4), 963-983.

Kunnathur, A.S., and Sampath, S. (1996). Dynamic Rescheduling of A Job Shop: A Simulation Study. *Proceedings of the 1996 Winter Simulation Conference*. 1091-1098.

Kurdi, M. (2016). An Effective New Island Model Genetic Algorithm for Job Shop Scheduling Problem. *Computers & Operations Research*. 67, 132-142.

Lakshmi, K. and Vasantharathna, K. (2014). Gencos Wind–thermal Scheduling Problem using Artificial Immune System Algorithm. *Electrical Power and Energy Systems*. 54, 112–122.

Land, A.H., and Doig, A.G. (1960). An Automatic Method of Solving Discrete Programming Problems. *Econometricca*. 28(3), 497-520.

Lau, H.Y.K., and Qiu, X. (2014). An Artificial Immune Systems (AIS)-based Unified Framework for General Job Shop Scheduling. 19th World Congress

The International Federation of Automatic Control. 24 - 29 August 2014. Cape Town, South Africa, 6186-6191.

Lawrence. S. (1984). Resource Constrained Project Scheduling: An Experimental Investigation of Heuristic Scheduling Techniques (Supplement). Unpublished note, Graduate School of Industrial Administration, Carnegie-Mellon University, Pittsburgh, Pennsylvania.

Ledesma, S., Aviña, G., and Sanchez, R. (2008). Practical Considerations for Simulated Annealing Implementation, Tan, C.M. (Ed.). Simulated Annealing (401-420). *In-Teh, I-Tech Education and Publishing KG*, Vienna, Austria.

Li, D., Meng, X., Li, M. and Tian, Y. (2016). An ACO-BasedIntercell Scheduling Approach for Job Shop Cells with Multiple Single Processing Machines and One Batch Processing Machine. *Journal of Intelligent Manufacturing*. 27(2), 283-296. First Online: 05 January 2014.

Liang, Y. C., Ge, H. W., Zhou, Y. andGuo, X. C. (2005). A Particle Swarm Optimization-Based Algorithm For Job-Shop Scheduling Problems. *International Journal of Computational Methods*. 2(3), 419-430.

Lin, L. andXi, Y. (2006). A Hybrid genetic Algorithm for Job Shop Scheduling Problem to Minimize Makespan. *Intelligent Control and Automation*. 1, 3709-3713.

Lin, S-W., Chen, S-C. (2009). Psolda: A Particle Swarm Optimization Approach for Enhancing Classification Accuracy Rate of Linear Discriminant Analysis. *Applied Soft Computing*. 9(3), 1008-1015.

Lin, T.L., Horng, S.J., Kao, T.W., Chen, Y.H., Run, R.S., Chen, R.J., Lai, J.L. and Kuo I.H. (2010). An Efficient Job-Shop Scheduling Problem Algorithm Based on Practicle Swarm Optimization. *Expert Systems with Applications*. 37, 2629-2636.

Liu, Q., L., Kozan, E., (2016). Parallel-identical-machine Job-shop Scheduling with Different Stage-dependent Buffering Requirements. *Computer & Operations Research*. 74. 31-41.

Loukil, T., Teghem, J., and Fortemps, P. (2007). A Multi-Objective Production Scheduling Case Study Solved by Simulated Annealing. *European Journal of Operational Research*. 159(1), 258-263.

Luh, G.C., and Chueh, C.H. (2007). Job Shop Optimization Using Multi-Modal Immune Algorithm. In Okuno, H.G. and Ali, M. (Ed.) *IEA/AIE 2007. Lecture Notes In Computer Science* (1127-1137). Berlin: Springer.

Lukaszewicz, P.P. (2005). Metaheuristics for Job Shop Scheduling Problem, Comparison of Effective Methods. Master Thesis. Department of Accounting, Finance and Logistics. Aarhus School of Business.

Mantila Roosa, S.M., Liu, Y., and Turner, C.H. (2011). Gene Expression Patterns in Bone following Mechanical Loading. *Journal of Bone and Mineral Research*. 26, 100-112.

Markowitz, H. M., and Manne, A. S. (1957). On the Solution of Discrete Programming Problems. *Econometvica*. 25(1), 84- 110.

Mastrolilli M., and Gambardella L.M. (1996). Effective Neighbourhood Functions for the Flexible Job Shop Problem. *Journal of Scheduling*. 3, 3-20.

Mati, Y., Rezg, N., and Xie, X. (2001). An Integrated Greedy Heuristics for a Flexible Job Shop Scheduling Problem. *IEEE International Conference on Systems, Man and Cybernetics*. 491, 2534-2539.

McMahon, G., and Florian, M. (1975). On Scheduling with Ready Times and Due Dates to Minimize Maximum Lateness. *Operations Research*. 23, 475-482.

Mencía, C., Sierra, M.R., and Varela, R. (2013). Depth-first Heuristic Search for the Job Shop Scheduling Problem. *Annals of Operations Research*. 206(1), 265-296.

Metzger, T.A., and Niebur, G.L. (2016). Comparison of Solid and Fluid Constitutive Models of Bone Marrow During Trabecular Bone Compression. *Journal of Biomechanics*. 49(14), 3596-3601.

Metzger, T.A., Shudick, J.M., Seekell, R., Zhu, Y., and Niebur, G.L. (2014). Rheological Behavior of Fresh Bone Marrow and the Effects of storage. *Journal Mech. Behav. Biomed. Mater*. 40, 307-313.

Mladenovi´c N., and Hansen P. (1997). Variable Neighborhood Search. *Computers & Operations Research*. 24(11), 1097-100.

Moin, N.H., Sin, O.C., and Omar, M. (2015). Hybrid Genetic Algorithm with Multiparents Crossover for Job Shop Scheduling Problems. *Mathematical Problems in Engineering*. 2015, 1-12.

Motaghedi-larijani, A., Sabri-lagaie, K., and Heydari, M. (2010). Solving Flexible Job Shop Scheduling with Multi Objective Approach. *International Journal of Industrial Engineering & Production Research*. 21(4), 197-209.

Muhamad, A.S., and Deris, S. (2013). An Artificial Immune System for Solving Production Scheduling Problems: A Review. *Artificial Intelligent Review*. 39(2), 97-108.

Murugesan, R., and Balan, K.S. (2012). Positive Selection Based Modified Clonal Selection Algorithm for Solving Job Shop Scheduling Problem. *Applied Mathematical Sciences*. 6(46), 2255-2271.

Najid, N. M., Dauzere-Peres, S., and Zaidat, A. (2002). A Modified Simulated Annealing Method for Flexible Job-Shop Scheduling Problem. *IEEE International Conference on Systems, Man and Cybernatics*. 5(1), 1-6.

Nakandhrakumar R. S., Seralathan S., Azarudeen A., and Narendran V. (2014) Optimization of Job Shop Scheduling Problem using Tabu Search Optimization Technique. *International Journal of Innovative Research in Science, Engineering and Technology*. 3(3), 1241-1244.

Nakandhrakumar R. S., Seralathan S., Azarudeen A., and Narendran V. (2014). Optimization of Job Shop Scheduling Problem using Tabu Search Optimization Technique. *International Journal of Innovative Research in Science, Engineering and Technology*. 3(3). 1241-1244.

Nandhini, M., and Kanmani, S. (2012). Multiobjective Combinatorial Problems Optimization Using Metaheuristic Algorithms: Literature Survey with the Case Study of Course Timetabling and Multi Job Shop Scheduling Problems. *Asian Journal of Computer Science and Information Technology*. 2(11), 316-322.

Nasiri, M.M.. (2015). A Modified ABC Algorithm for the Stage Shop Scheduling Problem. *Applied Soft Computing*. 28, 81–89.

Nicoară, E. S. (2012). Job Shop Scheduling using ACO Meta-heuristic with Waiting Time-based Pheromone Updating. *Journal of Emerging Trends in Computing and Information Sciences*. 3(8), 1265 - 1270.

Nof, S.Y. and Grant, F.H.(1991). Adaptive/predictive Scheduling: Review and a General Framework. *Production Planning and Control*. 2 (4), 298 - 312.

Nowicki, E. and Smutnicki , C. (1996). A Fast Taboo Search Algorithm for the Job Shop Problem. Management Science. 42, 797 - 813.

Nowicki, E., Smutnicki, C. (2005) An Advanced Tabu Search Algorithm for the Job Shop Problem. *Journal of Scheduling*. 8(2), 145-159.

Ohashi, H. and Igawa K. (2009). A Negative Selection Algorithm for Classification and Reduction of The Noise Effect. *Journal of Applied Soft Computing*. 9, 431-438.

Oliveira, A.C., Costa, T.A., Pena, P.N., and Takahashi, R.H.C. (2013). Clonal Selection Algorithms for Task Scheduling in a Flexible Manufacturing Cell with Supervisory Control. *2013 IEEE Congress on Evolutionary Computation*. 20 - 23 June 2013. Cancún, México, 982-988.

Ong, Z.X., Tay, J.C., and Kwoh, C.K. (2005). *Applying the Clonal Selection Principle to Find Flexible Job-Shop Schedules*. Artificial Immune Systems. *Lecture Notes in Computer Science*, (442-455), Berlin: Springer.

Orosz, G.C. (2001). An Introduction to Immuno-Ecology and Immuno-Informatics.In Segel, L.A., and Cohen, I. (Ed.) *Design Principles for the Immune Systems and other Distributed Systems* (125 - 150). London: Oxford University Press.

Pang, W., and Coghill. G.M. (2015). QML-AiNet: An Immune Network Approach to Learning Qualitative Differential Equation Models. *Applied Soft Computing*. 27, 148-157.

Paulli, J. (1995). A Hierarchical Approach for the FMS Scheduling Problem. *European Journal of Operational Research*. 86(1), 32-42.

Peng, B., Lü, Z., and Cheng, T.C.E. (2015). A Tabu Search/Path Relinking Algorithm to Solve the Job Shop Scheduling Problem. *Computer & Operations Research*. 53, 154-164.

Peng, Y., and Lu, B-L. (2015). Hybrid Learning Clonal Selection Algorithm. *Information Sciences*. 296, 128–146.

Perregaard, M., and Clansen, J. (1995). Parallel Branch and Bound Methods for the Job-shop Scheduling Problem. *Working Paper*, University of Copenhagen.

Pezzella, F., and Merelli, E. (2000). A TabuSearch Method Guided by Shifting Bottleneck for the Job Shop Scheduling Problem. *European Journal of Operational Research*. 120, 297 - 310.

Pezzella, F., Morganti, G., and Ciaschetti, G. (2008). A Genetic Algorithm for the Flexible Job-Shop Scheduling Problem. *Computer and Operation Research*. 35(10), 3202-3212.

Pinedo, M. (2012). *Scheduling: Theory, Algorithms, and Systems*. New York: Springer-Verlag.

Polat, O., Kalayci, C.B., Kulak, O., and Günther, H-O. (2015). A Perturbation Based Variable Neighborhood Search Heuristic for Solving the Vehicle Routing Problem with Simultaneous Pickup and Delivery with Time Limit. *European Journal of Operational Research*. 242(2), 369–382.

Potts, C.N. (1980). Analysis of Heuristic for One Machine Sequencing with Release Dates and Delivery Times. *Operations Research*. 28, 1436-1441.

Puente, P., Muz, B., Gilson, R.C., Azab, F., Luderer, M., King, J., Achilefu, S., Vij, R., and Azab, A.K. (2015). 3D Tissue-engineered Bone Marrow as A Novel Model to Study Pathophysiology and Drug Resistance in Multiple Myeloma. *Biomaterials*. 73, 70-84.

Qiu, X., and Lau, H.Y.K. (2014). An AIS-based hybrid algorithm for static job shop scheduling problem. *Journal of Intelligent Manufacturing*. 25(3), 489-503.

Reeves, C.R. (1995). A Genetic Algorithm for Flow Shop Sequencing. *Computer Operational Research*. 22, 5–13.

Roshanaei, V., Naderi, B., Jolai, F., and Khalili, M. (2009). A Variable Neighborhood Search for Job Shop Schedulin with Set-up Times to Minimize Makespan. *Future generation Computer Systems*. 25, 654-661.

Roy, B., and Sussmann, B. (1964). Les Problemes D'ordonnancement Avec Contraintes Disjonctives. Technical Report, *Note DS 9 bis*, SEMA, Paris.

Sadrzadeh, A. (2013). Development of Both the AIS and PSO for Solving the Flexible Job Shop Scheduling Problem. *Arabian Journal for Science and Engineering*. 38(12), 3593-3604.

Saidi-Mehrabad, M., and Fattahi, P. (2007).Flexible Job Shop Scheduling with Tabu Search Algorithms. *The International Journal of Adavnced Manufacturing Technology*. 32(8), 563-570.

Sampels, M., Blum, C., Mastrolilli, M., Rossi-Doria, and Olivia. (2002). Metaheuristics for Group Shop Scheduling. *Parallel Problem Solving from Nature — PPSN VII. Lecture Notes in Computer Science*. 2439, 631-640.

Scariaa, A., Georgeb, K., and Sebastiana, J. (2016). An Artificial Bee Colony Approach for Multi-objective Job Shop Scheduling. *Procedia Technology*. 25, 1030-1037.

Schuster, C. J. (2006). No-wait Job Shop Scheduling: Tabu Search and Complexity of Subproblems. *Mathematical Methods of Operations Research*. 63(3), 473-491.

Segel , L. A.(2001). Diffuse Feedback from Diffuse Informational Network: in the Immune System and another Distributed Autonomous Systems. Segel, L. A. and Cohen, I. (Ed.) *Design Principles for the Immune Systems and other Distributed Systems* (203 - 226). London: Oxford University Press.

Shen, J., Wang, J., and Ai, H. (2012). An Improved Artificial Immune System-Based Network Intrusion Detection by Using Rough Set. *Communications and Network*. 4, 41-47.

Shin, J.W., Buxboim, A., Spinler, K.R., Swift, J., Christian, D.A., Hunter, C.A., Leon, C., Gachet, C., Dingal, P.C., Ivanovska, I.L., Rehfeldt, F., Chasis, J.A., and Discher, D.E. (2014). Contractile Forces Sustain and Polarize Hematopoiesis from Stem and Progenitor Cells. *Cell Stem Cell*. 14, 81–93.

Shui, X., Zuo, X., Chen, C., and Smith, A.E. (2015). A Clonal Selection Algorithm for Urban Bus Vehicle Scheduling. *Applied Soft Computing*. 36, 36–44.

Sifaleras, A. and Konstantaras, I. (2015). Variable Neighborhood Descent Heuristic for Solving Reverse Logistics Multi-item Dynamic Lot-sizing Problems. *Computers & Operations Research*. Available online 23 October 2015.

Sipahioglu, A., and Aladag, A. (2012). An Artificial Immune System Approach for Flexible Job Shop Scheduling Problem. *Proceedings of the 2012 International Conference on Industrial Engineering and Operations Management*. 3 - 6 July 2012. Istanbul, Turkey, 729-735.

Song, S., Ren, J., and Fan, J. (2012). Improved Simulated Annealing Algorithm Used for Job Shop Scheduling Problems. *Advances in Intelligent and Soft Computing*. 139, 17-25.

Soves, C.P., Miller, J.D., Begun, D.L., Taichman, R.S., Hankenson, K.D., and Goldstein, S.A. (2014). Megakaryocytes are Mechanically Responsive and Influence Osteoblast Proliferation and Differentiation. *Bone*. 66, 111-120.

Sreeram K.Y. and Panicker, V.V. (2015). Clonal Selection Algorithm Approach for Multi-Objective Optimization Of Production-Distribution System. *XVIII Annual International Conference of the Society of Operations Management (SOM-14)*. Procedia - Social and Behavioral Sciences. 189, 48-56.

Stefansson, H., Sigmarsdottir, S., Jensson, P., and Shah, N. (2011). Discrete and Continuous Time Representations and Mathematical Models for Large Production Scheduling Problems: A Case Study from the Pharmaceutical Industry. *European Journal of Operational Research*. 215, 383-392.

Storer, R.H., Wu, S.D. and Vaccari, R. (1992). New Search Spaces for Sequencing Instances with Application to Job Shop Scheduling. *Management Science*. 38, 1495-1509.

Sun, L., Cheng, X. and Liang, Y. (2010).Solving Job Shop Scheduling Problem Using Genetic Algorithm with Penalty Function. *International Journal of Intelligent Information Processing*. 1(2), 65-77.

Surekha, P., and Sumathi, S. (2010). Solving Fuzzy based Job Shop Scheduling Problems using GA and ACO. *Journal of Emerging Trends in Computing and Information Sciences*. 1(2), 95 - 102.

Szetke, E., and Markus, G.(1994). A Cognitive Engineering Approach with AI Techniques to Reactive Scheduling in The Supervision of Dynamic Manufacturing Processes. Intelligent Systems Engineering. *Second International Conference on Intelligent Systems Engineering*. 5 - 9 September 1994. Hamburg-Harburg: IEE, 425-433.

Tamilarasi, A., and Kumar, T. A. (2010). An Enhanced Genetic Algorithm with Simulated Annealing for Job-Shop Scheduling. *International Journal of Engineering, Science and Technology*. 2(1), 144-151.

Tarlinton, D. (1998) Germinal Centers: Form and Function. *Current Operation in Immune*. 10, 245-251.

Tay J.C. and Ho, N.B. (2004). GENACE: An Efficient Cultural Algorithm for Solving the Flexible Job-Shop Problem. *Proceedings of the IEEE Congress of Evolutionary Computation*. 19 - 23 June 2004. 2, 1759-1766.

Taillard, E. (1993). Benchmarks for Basic Scheduling Problems. *European Journal of Operational Research*. 64, 278–285.

Thamilselvan, R., and Balasubramanie, P.(2012). Integration of Genetic Algorithm with Tabu Search for Job Shop Scheduling with Unordered Subsequence Exchange Crossover. *Journal of Computer Science*. 8 (5), 681 - 693.

Thamilselvan, R., and Balasubramanie, P. (2009). Integrating Genetic Algorithm, Tabu Search Approach for Job Shop Scheduling. *International Journal of Computer Science and Information Security*. 2(1).

Tomoyuki, M. (2003). An application of Immune Algorithms for Job-Shop Scheduling Problems. *Proceedings of the 5th International Symposium on Assembly and Task Planning*. 11 July 2003. Besancon, France, France , 146-150.

Ülker, E.D., and Ülker, S. (2012). Comparison Study fopr CLonal Selection Algorithm and Genetic Algorithm. *International Journal of Computer Science & Information Technology (IJCSIT)*. 4(4), 107-118.

Vaessens, R. J. M., Aarts, E. H. L., and Lenstra, J. K. (1994). Job Shop Scheduling by Local Search. *COSOR Memorandum 94-05*. Eindhoven University.

Wang, F., Sen, S., Zhang, Y., Ahmad, I., Zhu, X., Wilsond, I.A., Smiderd, V.V., Magliery, T.J., and Schultza, P.G. (2013). Somatic Hypermutation Maintains Antibody Thermodynamic Stability During Affinity Maturation. *Proceedings of the National Academy of Science of the United States of America*. 110(11), 4261-4266.

Wang, L., and Tsien, R.Y. (2006). Evolving Proteins In Mammalian Cells Using Somatic Hypermutation. *Nature Protocols*. 1, 1346–1350.

Wang, Y. M., Yin, H. L., and Qin, K. D. (2013). A Novel Genetic Algorithm for Flexible Job Shop Scheduling Problems with Machine Disruptions.The *International Journal of Advanced Manufacturing Technology*. 68(5-8), 1317-1326.

Weissman, I.L., and Cooper, M.D. (1993) How the Immune System Dvelops. *Scientific American*. 269(3), 33-40.

Wiers, V. (1997). Human-computer Interaction in Production Scheduling-Analysis and Design of Decision Support Systems for Production Scheduling Tasks. Netherlands: Ponsen&Looijen.

Winer, J.P., Janmey, P.A., McCormick, M.E., and Funaki, M. (2009). Bone Marrow-derived Human Mesenchymal Stem Cells Become Quiescent on Soft Substrates but Remain Responsive to Chemical or Mechanical Stimuli. *Tissue Engineering*. Part A 15, 147–154.

Xiangjing L., and Jin-KaoHao. (2016). Iteratedvariable Neighborhood Search for the Capacitated Clustering Problem. *Engineering Applications of Artificial Intelligence*. 56, 102–120.

Xiao, Y., Zhang, R., Zhao, Q., Kaku, I., and Xu, Y. (2014). A variable Neighborhood Search with an Effective Local Search for Uncapacitated Multilevel Lot-sizing Problems. *European Journal of Operational Research*. 235(1), 102-114.

Yamada, T. and Nakano, R. (1992). A Genetic Algorithm Applicable to Large-Scale Job-Shop Instances. Manner, R., Manderick, B. (eds.), *Parallel intance solving from nature 2*. North-Holland, Amsterdam, 281-290.

Yamamoto, M., and Nof, S.Y.(1985).Scheduling in the manufacturing operating system environment. *International Journal of Production Research*. 23(4), 705-722.

Yang, H., and Wu, Z. (2003). The application of Adaptive Genetic Algorithms in FMS dynamic rescheduling. *International Journal of Computer Integrated Manufacturing*. 16(6), 382-397.

Zhang, R. (2013). A Simulated Annealing-based Heuristic Algorithm for Job Scheduling to Minimize Lateness. *International Journal of Adavanced Robotic Systems*. 10 (214), 1-9.

Zhizhong, Z., Xinguo, Y., Kun, H., Wenqi, H., and Zhanghua, F. (2015). Iterated Tabu Search and Variable Neighborhood Descent for Packing Unequal Circles into a Circular Container. *European Journal of Operational Research*. 250(2), 615-627.

Ziaee, M. (2014). An Efficient Heuristic Algorithm for Flexible Job Shop Scheduling With Maintenance Constraints. *Applied Mathematics and Sciences: An International Journal (MathSJ)*. 1(1), 19-31.