UNIVERSITI PUTRA MALAYSIA

HYBRID MULTIOBJECTIVE GENETIC ALGORITHM FOR INTEGRATED DYNAMIC SCHEDULING AND ROUTING OF JOBS AND AUTOMATED GUIDED VEHICLES IN FLEXIBLE MANUFACTURING SYSTEMS

UMAR ALI UMAR

FK 2014 162

HYBRID MULTIOBJECTIVE GENETIC ALGORITHM FOR INTEGRATED DYNAMIC SCHEDULING AND ROUTING OF JOBS AND AUTOMATED GUIDED VEHICLES IN FLEXIBLE MANUFACTURING SYSTEMS

By

UMAR ALI UMAR

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

November 2014

This thesis is dedicated to my beloved parents.

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

HYBRID MULTIOBJECTIVE GENETIC ALGORITHM FOR INTEGRATED DYNAMIC SCHEDULING AND ROUTING OF JOBS AND AUTOMATED GUIDED VEHICLES IN FLEXIBLE MANUFACTURING SYSTEMS

By
UMAR ALI UMAR

November 2014

Chair: Mohd Khairol Anuar bin Mohd Ariffin PhD
Faculty: Engineering

The dynamic continues trend of adoption and improvement inventive automated technologies is one of the main competing strategies of many manufacturing industries. Effective integrated operations management of Automated Guided Vehicle (AGV) system in Flexible Manufacturing System (FMS) environment results in the overall system performance. Routing AGVs was proved to be NP-Complete and scheduling of jobs was also proved to be NP hard problems. The running time of any deterministic algorithms solving these types of problems increases very rapidly with the size of the problem, which can be many years with any computational resources available presently. Solving AGVs conflict free routing, dispatching and simultaneous scheduling of the jobs and AGVs in FMS in an integrated manner is identified as the only means of safeguarding the feasibility of the solution to each sub-problem. Genetic algorithm has recorded of huge success in solving NP-Complete optimization problems with similar nature to this problem. The objectives of this research are to develop an algorithm for integrated scheduling and conflict-free routing of jobs and AGVs in FMS environment using a hybrid genetic algorithm, ensure the algorithm validity and improvement on the performance of the developed algorithm. The algorithm generates an integrated scheduling and detail paths route while optimizing makespan, AGV travel time, mean flow time and penalty cost due to jobs tardiness and delay as a result of conflict avoidance. The integrated algorithms use two genetic representations for the individual solution entire sub-chromosomes. The first three sub-chromosomes use random keys to represent jobs sequencing, operations allocation on machines and AGV

dispatching, while the remaining sub-chromosomes are representing particular routing paths to be used by each dispatched AGV. The multi - objective fitness function use adaptive weight approach to assign weights to each objective for every generation based on objective improvement performance. Fuzzy expert system is used to control genetic operators using the overall population performance history. The algorithm used weight mapping crossover (WMX) and Insertion Mutation (IM) as genetic operators for sub-chromosomes represented with priority-based representation. Parameterized uniform crossover (PUX) and migration are used as genetic operators for sub-chromosomes represented using random-key based encoding. Computational experiments were conducted on the developed algorithm coded in Matlab to test the effectiveness of the algorithm. First scenario uses static consideration, the second scenario uses dynamic consideration with machine failure recovery. Sensitivity analysis and convergence analysis was also conducted. The results show the effectiveness of the proposed algorithm in generating the integrated scheduling, AGVs dispatching and conflict-free routing. The comparison of the result of the developed integrated algorithm using two benchmark FMS scheduling algorithms datasets is conducted. The comparison shows the improvement of 1.1% and 16% in makespan of the first and the second benchmark production dataset respectively. The major novelty of the algorithm is an integrated approach to the individual sub-problems which ensures the legality, and feasibility of all solutions generated for various sub-problems which in the literature are considered separately.

Abstrak tesis yang dikemukan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

HIBRID ALGORITMA PELBAGAI OBJEKTIF UNTUK PENJADUALAN DAN PENGHALAAN TUGAS BERPANDU SERTA KENDERAAN AUTOMATIK BERSEPADU DALAM PERSEKITARAN PEMBUATAN

Oleh

UMAR ALI UMAR

November 2014

Pengerusi: Mohd Khairol Anuar bin Mohd Ariffin, PhD
Fakulti: Kejuruteraan

Trend penggunaan dan peningkatan rekacipta teknologi automatik yang dinamik dan berterusan adalah salah satu strategi utama dalam persaingan industri pembuatan. Pengurusan sistem operasi Kenderaan Automatik Berpandu (AGV) bersepadu yang berkesan dalam persekitaran Sistem Pembuatan Fleksibel (FMS) memberi impak terhadap keseluruhan prestasi sistem. Penghalaan AGVs telah terbukti menjadi NP yang lengkap dan penjadualan kerja juga terbukti menjadi masalah utama NP. Masa operasi yang diambil oleh algoritma terhadap masalah jenis ini meningkat, selari dengan saiz masalah yang mana boleh memakan masa bertahun-tahun jika menggunakan sumber pengkomputeran yang ada pada masa ini. Dengan menyelesaikan AGVs penghalaan bebas konflik, penghantaran dan penjadualan serentak daripada pekerjaan dan AGVs dalam FMS secara bersepadu, telah dikenalpasti sebagai satu-satunya cara untuk melindungi penyelesaian untuk setiap sub-masalah. Algoritma genetik telah mencatatkan kejayaan besar dalam menyelesaikan masalah pengoptimuman NP lengkap yang mana sifatnya hampir serupa dengan masalah ini. Objektif kajian ini adalah untuk membangunkan satu algoritma untuk penjadualan bersepadu dan tugasan routing bebas konflik dan AGV dalam persekitaran FMS dengan menggunakan algoritma genetik hibrid, serta memastikan kesahihan algoritma dan peningkatan kepada prestasi algoritma yang dibina. Algoritma ini menjana laluan dan penjadualan laluan terperinci yang bersepadu serta mengoptimumkan makespan, masa perjalanan AGV, aliran masa dan kos penalti kelewatan pekerjaan akibat daripada mengelakkan konflik. Algoritma bersepadu menggunakan dua representasi genetik bagi

penyelesaian secara individu untuk keseluruhan sub-kromosom. Untuk tiga sub-kromosom yang pertama, ia menggunakan kunci rawak untuk mewakili kerja-kerja penjujukan, pembahagian operasi pada mesin dan AGV penghantar, manakala sub-kromosom yang selebihnya mewakili laluan-laluan tertentu yang akan digunakan oleh setiap AGV penghantar. Fungsi berbilang objektif menggunakan pendekatan pemberat untuk metetapkan nilai pemberat kepada setiap objektif bagi setiap generasi berdasarkan objektif peningkatan prestasi. Sistem pakar yang fuzzy digunakan untuk mengawal pengendali genetik menggunakan rekod prestasi keseluruhan populasi. Algoritma yang menggunakan Pemetaan Pemberat Crossover (WMX) dan Pemasukan Mutasi (IM) sebagai pengendali genetik untuk sub-kromosom diwakili mengikut kaedah keutamaan. Parameterized Crossover yang seragam (PUX) dan pemindahan digunakan sebagai operator geneti k untuk sub-kromosom diwakili dengan menggunakan berasaskan rekod secara rawak. Kajian berkomputer telah dijalankan terhadap algoritma yang dibina dan telah dikodkan dalam program Matlab untuk menguji keberkesanan algoritma. Senario pertama menggunakan pertimbangan statik manakala senario kedua menggunakan pertimbangan dinamik dengan pemulihan kegagalan mesin. Analisis kepekaan dan analisis penumpuan juga telah dijalankan. Keputusan menunjukkan keberkesanan algoritma yang dicadangkan dalam menjana penjadualan bersepadu, AGVs penghantaran dan penghalaan bebas konflik. Perbandingan hasil daripada algoritma bersepadu yang dibangunkan dengan menggunakan dua set data algoritma penjadualan FMS sebagai penanda aras telah dijalankan. Keputusan perbandingan menunjukkan peningkatan sebanyak terhadap makespan untuk set data penanda aras pengeluaran pertama dan kedua masing-masing sebanyak 1.1% dan 16%. Pembaharuan utama algoritma yang dibina adalah ianya satu pendekatan sub-masalah individu bersepadu yang memastikan kesahihan, dan penyelesaian yang dihasilkan untuk pelbagai sub-masalah secara berasingan.

ACKNOWLEDGEMENTS

All praise and thanks are due to Allah, we thank and seek for His help. I wish to express my warm thanks and gratitude to my beloved parent Alhaji Ali Umar Misau and Hajiya Fatima Ali Umar. I will also wish to thank my brothers, Dr Muhammad Ali Pate, Dr Nisser Ali Umar and Dr Ahmad Fate Ali for their financial assistance, prayers and advice during the period of my studies. My special thanks and gratitude also go to my sisters Hajiya Fatima (Hajja), Hajiya Hafsat, Hajiya Ummi and my wife-to-be insha Allah Maryam for their help and support. I will also wish to thank Dr Shehu Abubakar Misau, Dr M.K Baru, Alhaji Wakili Abdu, Justice Muhammad El-Mainari.

I wish to express my thanks to my supervisory committee chairman Assoc. Prof. Dr. Mohd Khairol Anuar bin Mohd Ariffin for his guidance, and constructive criticism during the period of my study. I also wish to thank my supervisory committee members Prof. Datin Dr Napsiah Ismail and Assoc. Prof. Dr Tang Sai Hong. I will also like to express my very special thanks to all my friends and elders from UPM and beyond.

Finally, in order not to mistakenly forget about the remaining important individuals who contribute immensely towards completion of this research and my studies at large, I will refrain from attempting to list all of them, suffice is to say, I wish to express my thanks and gratitude to all my brothers and sisters, relatives, friends, and anybody who contributes with prayers, financial assistance, advice and guidance towards the completion of my studies. Thank you all.

APPROVAL

I certify that a Thesis Examination Committee has met on 26th November, 2014 to conduct the final examination of Umar Ali Umar on his thesis entitled "Hybrid Multiobjective Genetic Algorithm for Integrated Dynamic Scheduling and Routing of Jobs and Automated Guided Vehicles in Flexible Manufacturing Systems". In accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

Mohd Sapuan Salit, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Shamsuddin Sulaiman, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Norzima Zulkifli, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Abid Haleem, PhD
Professor
Faculty of Engineering and Technology
Jamia Millia Islamia, New Delhi
India
(External Examiner)

NORITAH OMAR, PhD
Associate Professor
Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

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

Mohd Khairol Anuar bin Mohd Ariffin, PhD,
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Napsiah Ismail, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Tang Sai Hong, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

BUJANG BIN KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by Graduate Student

I hereby confirm that:

- This thesis is my original work;
- Quotations, illustrations and citations have been duly referenced;
- This thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- Intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- Written permission must be obtained from the supervisor and the office of the Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- There is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature:_____Date: _____

Name and Matric No.: _____

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature:_____	Signature:_____
Name of Chairman of Supervisory Committee:_____	Name of Member of Supervisory Committee:_____
Signature:_____	Signature:_____
Name of Member of Supervisory Committee:_____	Name of Member of Supervisory Committee:_____

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDIX

LIST OF ABBREVIATIONS

FMS	Flexible Manufacturing System
AGV	Automated Guided Vehicle
GA	Genetic Algorithms
WMX	Weight Mapping Crossover
PUX	Parameterized Uniform Crossover
IM	Insertion Mutation
MOGA	Multi-objective Genetic Algorithms
MOP	Multi-objective Optimization Problems
GT	Group Technology
ASRS	Automated Storage and Retrieval System
LSH	Local Search Heuristics
CIM	Computer Integrated Manufacturing
CNC	Computer Numemerical Control
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing

CHAPTER 1
INTRODUCTION

1.1 Background

The attention toward automated control of system components to achieve the desired functionality is rapidly increasing in all application domains. This is due to the enormous benefits offered by proper implementation of automated technologies to any system. Increasing system efficiency, reducing operational cost and increasing task precision are some of the proven pledge of deployment of automation techniques. This results i n very rapid and continuous application of automation technologies in public amenities, agriculture, and ever-growing industrial automation.

Industrial automation is the biggest and the most prosperous area of application of automated technology. As a powerful tool toward operational process innovation, automation is a competing strength to many manufacturing and service industries globally. This makes adoption and continuously improving it as one of the success determining task in any industrial competing arena. Automating a production system always innovatively reduce significantly, the overall production cost, product lead time and significantly increase the production system output (Maffei, 2012). Currently, the area of industrial automation is witnessing a great attention in order to meet up with the adoption and improvement of automated systems design, management and maintenance.

Automated guided vehicle (AGV) system is a flexible material handling device that is automatically guided to perform it task. Barrett Electronics first invented AGVs in the year 1953 (Ullrich, 2015). Since then, there are tremendous improvements in both hardware and associated control system software. As application domain and operational needs keep changing with time, the operational control system of AGVs became more and more complicated. AGVs can be designed to travel on the guide path marked with magnetic tape or hidden wire on the flow. AGVs can also be designed to guide its movement by identifying a preferred path while detecting and avoiding an obstacle, the AGV designed with this capability is termed free ranging AGV.

The control system of AGV can either be centrally controlled or linked distributed controlled. Whenever a material handling request is generated an AGV dispatching decision is made and a schedule is generated for the AGVs, a corresponding detail routing is generated for the whole travel duration. AGVs are currently very widely used in automated warehouses, container terminals and production systems. Diverse production industries are using AGVs to serve their material handling requirements, ranging from automotive, semiconductor fabrication, foods and beverages, electronics and many more. Automating a production system will always be incomplete

without automating the movement of work-in-process and complete product or parts. In many automated production systems where there is demand for a very flexible means of automated material movement, the usage AGVs remains the only appropriate option.

Flexible Manufacturing System (FMS) is an automated manufacturing system which is automatically adaptable to some variety of changes in products, routing and schedule (Groover, 2014). The components of FMS are automated workstations, automated material handling system and associated control system. The necessary condition for an automated manufacturing system to qualify as a flexible manufacturing system are capability of producing a variety of products simultaneously, and adaptability to schedule changes in terms of addition of new jobs or operation sequence.

FMS is considered as an automated group technology (GT) cell, where a group of products or parts are produced simultaneously at the workstations of the manufacturing cell (Groover, 2014). In compliance with the GT manufacturing principle, workstations in FMS are capable of executing different operations on the work-in-process jobs. FMS attribute of variable pattern of material movement between workstations need automated material handling that is easily adaptable to the system operations requirement. Flexibility and adaptability to schedule change of AGVs system makes its usage in FMS environment a reality.

Meta-heuristics prove to be an efficient tool of solving tough optimization problems that practically cannot be solved using exhaustive deterministic optimization techniques due to large computational time. This is realized by systematic searching of the solution space to get an acceptably better solution to a problem under consideration, rather than searching all the solution space which is infeasible for many optimization problems. Nature inspired meta-heuristics with learning capability such as genetic algorithm has been applied and effectively solved a variety of hard optimization problems.

Genetic algorithm (GA) is a meta-heuristic that is searching the solution space based on the concept of natural selection in genetics. GA is a powerful solver of many search and optimization problems (Jones et al., 2002; Talbi et al., 2012). Representing a problem appropriately in a genetic form is the first and the most important stage toward providing a precise solution to a particular problem. The algorithm work with populations of candidate solution that runs generation by generation until the termination criteria is satisfied. At each generation a group of eligible candidate solutions is selected for genetic operations of crossover and mutation. The candidate solutions are evaluated based on the fitness measures of the problem being

solved. The algorithms can be hybridized with other heuristics or other optimization techniques to improve the performance. Currently, the genetic algorithm was successfully applied in many operations, design and maintenance problems. The past research is very helpful in meeting the objectives of this research in the area of identifying the gap that exist currently in the literature and in area of algorithm validation by comparing the results of the algorithm in the literature with the result of the developed algorithm.

1.2 Problem Statement

Material handling cost was estimated to account for between 15 to 70% of the total production cost (Tompkins et al., 2010). Flexibility and adaptability to schedule change of AGVs system makes its usage in FMS environment a reality due to the FMS operational requirements of high flexibility and automated operations. In order to effectively run a manufacturing system consisting of an automated guided vehicle system, there must be an efficient means of managing AGVs conflict-free routing through the guide path network, scheduling simultaneously the machines and AGVs, and dispatching an AGV to a task. Initially, the schedule of the jobs and machine are determined, at each instant the material handling request is generated and AGV is dispatched to the request. The detail paths segment to be used for AGV routing of each request at each instant of time is allocated in the guide path network.

Firstly, routing of AGV system through the guide path network in manufacturing facility was proved to be Non-deterministic polynomial time (NP)-Complete problem (De Guzman et al., 1997). NP-complete is type of decision problem where the running time of any algorithms solving it increases very rapidly with the size of the problem, which can be many years with any computational resources available presently. Satisfying the demand for the shortest path to be used by AGV to deliver the material handling request, while avoiding conflict and deadlock at the fastest possible time is an essential quality of any production control system consisting of AGV. Due to the obvious limitations of the exhaustive search algorithms in solving NP-Complete problems, an approximate algorithm is used to find an optimal solution to the problem under consideration. Previous approximate algorithms attempts to solve AGV routing problem includes lagrangian relaxation approach (Nishi et al., 2007; Zhang et al., 2008), dynamic programming approach (Langevin et al., 1996), hybrid mixed integer programming approach (Corréa et al., 2007; Nishi et al., 2011), and Q-learning approach (Jeon et al., 2011). The common attribute of all the approximate algorithms based AGVs routing are finding optimal solutions toward a single objective and unable to integrate, dispatching and

scheduling of jobs and AGVs which are system parameters of interest that can render the optimality of the solution ineffectual.

Secondly, scheduling of jobs to machines either in job shop or FMS environment is proved to be NP-Hard problem (Soukhal et al., 2005). NP-Hard problem is a problem that is at least as hard as hardest NP problem which is not solvable in polynomial time. Simultaneously scheduling of machines and AGV is the only means of ensuring the validity of all the individual schedules (Vis, 2006). Algorithms in the literature that simultaneously schedule jobs and AGVs includes single objective approach (Blazewicz et al., 1991; Chaudhry et al., 2011; Deroussi et al., 2008; Lacomme et al., 2013) and multiple objective approach (Jerald et al., 2006; Reddy & Rao, 2006) .

Thirdly, due to the complexity of AGV routing and scheduling, the approach to the problems using approximate algorithms is necessary for realizing the desired integrated system functionality. However, according to survey of this research, significant studies consider only dispatching in isolation to scheduling and routing. Studies that present approximate algorithms for only AGV dispatching include (Kim & Hwang, 2001, 1999; Lin et al., 2006; Naso & Turchiano, 2005). Desaulniers et al., (2003) present an algorithm that combine dispatching and conflict-free routing. The only study that attempt to a little extend integrate scheduling, routing and dispatching of AGV is by (Langevin et al., 1996). However the study considers only two AGVs in a simple production system layout and did not include scheduling of jobs.

Fourthly, majority of real life optimization problem comprise of parameters of interest that require multiple objectives to get the appropriate optimal solution to the problem. Currently, all the studies of AGV conflict-free routing and dispatching are in single objective, like minimizing travel time (Jeon et al., 2011; Sarker & Gurav, 2005; Wu & Zhou, 2007), total job tardiness (Buyurgan et al., 2007; Corréa et al., 2007; Nishi et al., 2011), shortest travel distance (Sarker & Gurav, 2005; Wu & Zhou, 2007), and jobs completion time (Lin et al., 2006). Multi objective genetic algorithm is one of the most powerful stochastic solution domain searching algorithms that superbly solve similar problems. Aytug et al., (2003) present detail prospects of genetic algorithm for solving similar operations problem. Multi-objective genetic algorithm (MOGA) constitute majority of meta-heuristics approach for solving multi-objective optimization problems (Jones et al., 2002; Talbi et al., 2012). In search for a means to solve problems in the best possible means meta-heuristic algorithms like genetic algorithms is hybridized with other meta-heuristics, heuristic or an exact algorithm. This provide a means of combining constituent algorithms strength in solving problem (Blum et al., 2011).

Fifthly, according to the review of the relevant literature conducted in this study, all studies on AGV management consider either only one or two of the highly interrelated problems of scheduling, routing, dispatching or traffic control (Le-Anh & De Koster, 2006; Qiu et al., 2002; Vis, 2006). In reality an excellent solution of one or some of the problems may result in a very poor, infeasible or illegal solution to another related problem. Integrating and solving the problems together is the only appropriate means of getting the desired functionality traits of the overall system. Gen et al., (2009) presents a detail study of significance of integrating manufacturing system elements and the prospects of evolutionary algorithms, which includes genetic algorithms in solving integrated systems similar to this problem.

This research developed an algorithm for conflict-free AGVs routing that integrate dispatching and simultaneous scheduling of jobs and AGVs using multi objective genetic algorithms (MOGA). In order to obtain the desired searching balance between exploration and exploitation of solution domain, the algorithms was hybridized with fuzzy logic control systems. Numerical experimentation shows the effectiveness of the algorithms.

1.3 Objectives of the Thesis

The main objective of this research is to develop an algorithm for integrated scheduling and conflict-free routing of jobs and AGVs in FMS environment. The individual sub-objectives set for the thesis are:

1. To develop a multi-objective genetic algorithm for integrated AGVs conflict-free routing, dispatching and simultaneous dynamic scheduling of Jobs and AGVs that will consider time and make span while predicting and avoiding routes conflict.
2. To hybridize the developed algorithm with local search and fuzzy logic controller for improvement of the algorithm performance in the exploration and exploitation of solutions space.
3. To evaluate and validate the performance of the developed algorithm using computational experimentation.

1.4 Scope of the Thesis

The scope of the thesis is development of conflict-free routing and dispatching of AGVs, and also simultaneous scheduling of jobs and AGVs in the flexible manufacturing system (FMS) environment. The study considers an AGVs guided throughout the travel time along the bidirectional guide path network. The algorithm validation is carried out using hypothetical production data in the literature used by two researchers in the flexible manufacturing system scheduling.

1.5 Thesis Contributions

The main contribution of the thesis is the integration and synchronization of jobs dynamic schedules with AGVs schedules, AGVs conflict-free routes and

AGVs dispatching decisions in FMS environment, which in the literature are considered separately. The need for an integrated approach that provide solutions to each sub-problem in synchrony with the other sub problems has been identified in the literature as the only means of safeguarding the legality and feasibility of all sub-problems. The proposed multi-objective genetic algorithm first schedule the jobs, then in synchrony generates for every dispatched AGVs a schedule and a detail routing path free from dispatching and routes conflict for serving the material handling request related to the scheduled jobs. The integrated algorithm is optimizing the system objectives of makespan, AGV travel time, and penalty cost due to jobs tardiness and delay as a result of conflict avoidance. The hybridization of the developed algorithms with fuzzy logic controller for adaptive control of crossover and mutation rates, local search heuristics to improve the algorithm promising region exploitation further contributes to the effectiveness of the algorithm in providing better solutions to the problem. The algorithm adoption of a convergence model for determining algorithm termination point indicates that the algorithm will terminate with a good degree of certainty of providing an acceptably good solution to the integrated problem.

1.6 Thesis Outline

The thesis contains five chapters. The first chapter describes the background of the study. The problem statement in the context of gap identified in the literature and how to fill it is presented. The objectives of which the study is intended to achieve is also discussed in this section. Followed by the scope demarcated for the study. The main contributions of the study were also highlighted.

The second chapter contains the review of relevant literature. This includes flexible manufacturing system scheduling and AGVs management functions of dispatching, scheduling, routing and traffic control techniques. The chapter also reviews the relevant literature on multi objective genetic algorithms, the needs for algorithms hybridization and techniques to achieve them, complexity and material handling cost associated with automated guided vehicle usage.

The third chapter presents problem formulation, assumptions and limitation of the study. A detailed description of the proposed hybrid multi-objective genetic algorithms was explained, this includes the genetic representation used in this study, the genetic operators applied on the individual solutions, selection scheme, fitness evaluations and the mechanism used in the algorithm hybridization.

The fourth chapter describes the numerical experimentation conducted on

the developed algorithm. Firstly, the FMS system components used in the experimentation is presented. The first experimentation used static data sets from the literature while the second experimentation used dynamic data sets modified from the literature. Each section is followed by a discussion of the presented results of the numerical experimentation conducted. Algorithm validation with the existing algorithm is presented, followed by a detail algorithm convergence discussion.

The last chapter presents the summary of the thesis, the study conclusion in-line with the research established objectives and identified fertile ground for future research.

REFERENCES

Abdelmaguid, T. F., Nassef, A. O., Kamal, B. A., & Hassan, M. F. (2004). A hybrid GA/heuristic approach to the simultaneous scheduling of machines and automated guided vehicles. *International Journal of Production Research, 42*(2), 267–281. doi:10.1080/00207540320001235579

Arifin, R., & Egbelu, P. J. (2000). Determination of vehicle requirements in automated guided vehicle systems: A statistical approach. *Production Planning & Control*, *11*(3), 258–270. doi:10.1080/095372800232225

Arya, V., Garg, N., Khandekar, R., Meyerson, A., Munagala, K., & Pandit, V. (2004). Local Search Heuristics for k-Median and Facility Location Problems. *SIAM Journal on Computing*, *33*(3), 544–562. doi:10.1137/S0097539702416402

Aytug, H., Khouja, M., & Vergara, F. E. (2003). Use of genetic algorithms to solve production and operations management problems: A review. *International Journal of Production Research*, *41*(17), 3955–4009. doi:10.1080/00207540310001626319

Aytug, H., Lawley, M. A., McKay, K., Mohan, S., & Uzsoy, R. (2005). Executing production schedules in the face of uncertainties: A review and some future directions. *European Journal of Operational Research*, *161*(1), 86–110. doi:10.1016/j.ejor.2003.08.027

Bean, J. C. (1994). Genetic Algorithms and Random Keys for Sequencing and Optimization. *ORSA Journal on Computing*, *6*(2), 154–160. doi:10.1287/ijoc.6.2.154

Berman, S., & Edan, Y. (2002). Decentralized autonomous AGV system for material handling. *International Journal of Production Research*, *40*(15), 3995–4006. doi:10.1080/00207540210146990

Bilge, Ü., & Ulusoy, G. (1995). A Time Window Approach to Simultaneous Scheduling of Machines and Material Handling System in an FMS. *Operations Research*, *43*(6), 1058–1070. doi:10.1287/opre.43.6.1058

Blazewicz, J., Burkard, R. E., Finke, G., & Woeginger, G. J. (1994). Vehicle scheduling in two-cycle flexible manufacturing systems. *Mathematical and Computer Modelling*, *20*(2), 19–31. doi:10.1016/0895-7177(94)90203-8

Blazewicz, J., Eiselt, H. A., Finke, G., Laporte, G., & Weglarz, J. (1991). Scheduling tasks and vehicles in a flexible manufacturing system. *International Journal of Flexible Manufacturing Systems*, *4*(1), 5–16. doi:10.1007/BF01325094

Blum, C., Puchinger, J., Raidl, G. R., & Roli, A. (2011). Hybrid metaheuristics in combinatorial optimization: A survey. *Applied Soft Computing*, *11*(6), 4135–4151.

Boussaïd, I., Lepagnot, J., & Siarry, P. (2013). A Survey on Optimization Metaheuristics. *Inf. Sci.*, *237*, 82–117. doi:10.1016/j.ins.2013.02.041

Bozer, Y. A., & Srinivasan, M. M. (1992). Tandem AGV systems: A partitioning algorithm and performance comparison with conventional AGV systems. *European Journal of Operational Research*, *63*(2), 173–191. doi:10.1016/0377-2217(92)90024-4

Brest, J., Greiner, S., Boskovic, B., Mernik, M., & Zumer, V. (2006). Self-Adapting Control Parameters in Differential Evolution: A Comparative Study on Numerical Benchmark Problems. *IEEE Transactions on Evolutionary Computation*, *10*(6), 646–657. doi:10.1109/TEVC.2006.872133

Browne, J., Dubois, D., Rathmill, K., Sethi, S. P., & Stecke, K. E. (1984). Classification of flexible manufacturing systems. *The FMS magazine*, *2*(2), 114–117.

Buyurgan, N., Meyyappan, L., Saygin, C., & Dagli, C. H. (2007). Real-time routing selection for automated guided vehicles in a flexible manufacturing system. *Journal of Manufacturing Technology Management*, *18*(2), 169–181. doi:10.1108/17410380710722881

Buzacott, J. A., & Yao, D. D. (1986). Flexible manufacturing systems: a review of analytical models. *Management science*, *32*(7), 890–905.

Chaudhry, I. A., Mahmood, S., & Shami, M. (2011). Simultaneous scheduling of machines and automated guided vehicles in flexible manufacturing systems using genetic algorithms. *Journal of Central South University of Technology*, *18*(5), 1473–1486. doi:10.1007/s11771-011-0863-7

Chaudhry, S. S., & Luo, W. (2005). Application of genetic algorithms in production and operations management: a review. *International Journal of Production Research*, *43*(19), 4083–4101. doi:10.1080/00207540500143199

Chen, K. J., & Ji, P. (2007). A genetic algorithm for dynamic advanced planning and scheduling (DAPS) with a frozen interval. *Expert Systems with Applications*, *33*(4), 1004–1010. doi:10.1016/j.eswa.2006.08.025

Corréa, A. I., Langevin, A., & Rousseau, L.-M. (2007). Scheduling and routing of automated guided vehicles: A hybrid approach. *Computers & Operations Research*, *34*(6), 1688–1707. doi:10.1016/j.cor.2005.07.004

Crauwels, H. A. J., Potts, C. N., & Van Wassenhove, L. N. (1998). Local Search Heuristics for the Single Machine Total Weighted Tardiness Scheduling Problem. *INFORMS Journal on Computing*, *10*(3), 341–350. doi:10.1287/ijoc.10.3.341

Dai, J. B., & Lee, N. K. S. (2012). Economic feasibility analysis of flexible material handling systems: A case study in the apparel industry. *International Journal of Production Economics*, *136*(1), 28–36. doi:10.1016/j.ijpe.2011.09.006

Deb, K., Pratap, A., Agarwal, S., & Meyarivan, T. (2002). A fast and elitist multiobjective genetic algorithm: NSGA-II. *IEEE Transactions on Evolutionary Computation*, *6*(2), 182–197. doi:10.1109/4235.996017

De Guzman, M. C., Prabhu, N., & Tanchoco, J. M. A. (1997). Complexity of the AGV shortest path and single-loop guide path layout problems. *International Journal of Production Research*, *35*(8), 2083–2092. doi:10.1080/002075497194741

Demirkol, E., Mehta, S., & Uzsoy, R. (1998). Benchmarks for shop scheduling problems. *European Journal of Operational Research*, *109*(1), 137–141. doi:10.1016/S0377-2217(97)00019-2

Deroussi, L., Gourgand, M., & Tchernev, N. (2008). A simple metaheuristic approach to the simultaneous scheduling of machines and automated guided vehicles. *International journal of production research*, *46*(8), 2143–2164.

Desaulniers, G., Langevin, A., Riopel, D., & Villeneuve, B. (2003). Dispatching and Conflict-Free Routing of Automated Guided Vehicles: An Exact Approach. *International Journal of Flexible Manufacturing Systems*, *15*(4), 309–331. doi:10.1023/B:FLEX.0000036032.41757.3d

Egbelu, P. J., & Tanchoco, J. M. A. (1984). Characterization of automatic guided vehicle dispatching rules. *International Journal of Production Research*, *22*(3), 359–374. doi:10.1080/00207548408942459

ElMaraghy, H. A. (2005). Flexible and reconfigurable manufacturing systems paradigms. *International journal of flexible manufacturing systems*, *17*(4), 261–276.

ElMekkawy, T. Y., & Liu, S. (2009). A new memetic algorithm for optimizing the partitioning problem of tandem AGV systems. *International Journal of Production Economics*, *118*(2), 508–520. doi:10.1016/j.ijpe.2009.01.008

Fanti, M. P. (2002). Event-based controller to avoid deadlock and collisions in zone-control AGVS. *International Journal of Production Research*, *40*(6), 1453–1478. doi:10.1080/00207540110118073

Fazlollahtabar, H., & Mahdavi-Amiri, N. (2013). Design of a neuro-fuzzy–regression expert system to estimate cost in a flexible jobshop automated manufacturing system. *The International Journal of Advanced Manufacturing Technology*, *67*(5-8), 1809–1823. doi:10.1007/s00170-012-4610-5

Feng, G. (2006). A Survey on Analysis and Design of Model-Based Fuzzy Control Systems. *IEEE Transactions on Fuzzy Systems*, *14*(5), 676–697. doi:10.1109/TFUZZ.2006.883415

Ficko, M., Brezocnik, M., & Balic, J. (2004). Designing the layout of single- and multiple-rows flexible manufacturing system by genetic algorithms. *Journal of Materials Processing Technology*, *157–158*, 150–158. doi:10.1016/j.jmatprotec.2004.09.012

Frazelle, E. H. (1986). *Material handling: A technology for industrial competitiveness*. Material Handling Research Center, Georgia Institute of Technology.

Gaur, D. R., Gupta, A., & Krishnamurti, R. (2003). A 53-approximation algorithm for scheduling vehicles on a path with release and handling times. *Information Processing Letters*, *86*(2), 87–91. doi:10.1016/S0020-0190(02)00474-X

Gen, M., Altiparmak, F., & Lin, L. (2006). A genetic algorithm for two-stage transportation problem using priority-based encoding. *OR Spectrum*, *28*(3), 337–354. doi:10.1007/s00291-005-0029-9

Gen, M., & Cheng, R. (2000). *Genetic Algorithms and Engineering Optimization*. John Wiley & Sons.

Gen, M., Cheng, R., & Wang, Q. (1997). Genetic algorithms for solving shortest path problems. In , *IEEE International Conference on Evolutionary Computation, 1997* (pp. 401–406).. doi:10.1109/ICEC.1997.592343

Gen, M., & Lin, L. (2005). Multi-objective hybrid genetic algorithm for bicriteria network design problem. *Complexity International*, *11*(11), 73–83.

Gen, M., Lin, L., & Zhang, H. (2009). Evolutionary techniques for optimization problems in integrated manufacturing system: State-of-the-art-survey. *Computers & Industrial Engineering*, *56*(3), 779–808. doi:10.1016/j.cie.2008.09.034

Gil, M. A., Corral, N., & Gil, P. (1985). The fuzzy decision problem: An approach to the point estimation problem with fuzzy information. *European Journal of Operational Research*, *22*(1), 26–34. doi:10.1016/0377-2217(85)90112-2

Gnanavel Babu, A., Jerald, J., Noorul Haq, A., Muthu Luxmi, V., & Vigneswaralu, T. P. (2010). Scheduling of machines and automated guided vehicles in FMS using differential evolution. *International Journal of Production Research*, *48*(16), 4683–4699. doi:10.1080/00207540903049407

Gonçalves, J. F., & Almeida, J. R. de. (2002). A Hybrid Genetic Algorithm for Assembly Line Balancing. *Journal of Heuristics*, *8*(6), 629–642. doi:10.1023/A:1020377910258

Gonçalves, J. F., & Resende, M. G. C. (2011). Biased random-key genetic algorithms for combinatorial optimization. *Journal of Heuristics*, *17*(5), 487–525. doi:10.1007/s10732-010-9143-1

Groover, M. P. (2014). *Automation, Production Systems, and Computer-Integrated Manufacturing*. Pearson Education, Limited.

Gunasekaran, A. (1997). Implementation of computer-integrated manufacturing: A survey of integration and adaptability issues. *International Journal of Computer Integrated Manufacturing*, *10*(1-4), 266–280. doi:10.1080/095119297131363

Heragu, S. S., & Kusiak, A. (1988). Machine Layout Problem in Flexible Manufacturing Systems. *Operations Research*, *36*(2), 258–268. doi:10.1287/opre.36.2.258

Herrera, F., & Lozano, M. (1996). Adaptation of genetic algorithm parameters based on fuzzy logic controllers. *Genetic Algorithms and Soft Computing*, *8*, 95–125.

Holland, J. H. (1975). *Adaptation in natural and artificial systems: An introductory analysis with applications to biology, control, and artificial intelligence* (Vol. viii). Oxford, England: U Michigan Press.

Holsapple, C. W., Jacob, V. S., Pakath, R., & Zaveri, J. S. (1993). A genetics-based hybrid scheduler for generating static schedules in flexible manufacturing contexts. *IEEE Transactions on Systems, Man and Cybernetics*, *23*(4), 953–972. doi:10.1109/21.247881

Horn, J., Nafpliotis, N., & Goldberg, D. E. (1994). A niched Pareto genetic algorithm for multiobjective optimization. In , *Proceedings of the First IEEE Conference on Evolutionary Computation, 1994. IEEE World Congress on Computational Intelligence* (pp. 82–87 vol.1).. doi:10.1109/ICEC.1994.350037

Hoshino, S., Ota, J., Shinozaki, A. ., & Hashimoto, H. . (2007). Hybrid Design Methodology and Cost-Effectiveness Evaluation of AGV Transportation Systems. *IEEE Transactions on Automation Science and Engineering*, *4*(3), 360–372. doi:10.1109/TASE.2006.887162

Ilić, O. R. (1994). Analysis of the number of automated guided vehicles required in flexible manufacturing systems. *The International Journal of Advanced Manufacturing Technology*, *9*(6), 382–389. doi:10.1007/BF01748483

Ishibuchi, H., & Murata, T. (1998). A multi-objective genetic local search algorithm and its application to flowshop scheduling. *IEEE Transactions on Systems, Man, and Cybernetics, Part C: Applications and Reviews*, *28*(3), 392–403. doi:10.1109/5326.704576

Jain, A., Jain, P. K., Chan, F. T. S., & Singh, S. (2013). A review on manufacturing flexibility. *International Journal of Production Research*, *51*(19), 5946–5970. doi:10.1080/00207543.2013.824627

Jaszkiewicz, A. (2002). Genetic local search for multi-objective combinatorial optimization. *European Journal of Operational Research*, *137*(1), 50–71. doi:10.1016/S0377-2217(01)00104-7

Jawahar, N., Aravindan, P., & Ponnambalam, D. S. G. (1998). A genetic algorithm for scheduling flexible manufacturing systems. *The International Journal of Advanced Manufacturing Technology*, *14*(8), 588–607. doi:10.1007/BF01301703

Jeon, S. M., Kim, K. H., & Kopfer, H. (2011). Routing automated guided vehicles in container terminals through the Q-learning technique. *Logistics Research*, *3*(1), 19–27. doi:10.1007/s12159-010-0042-5

Jerald, J., Asokan, P., Prabaharan, G., & Saravanan, R. (2005). Scheduling optimisation of flexible manufacturing systems using particle swarm optimisation algorithm. *The International Journal of Advanced Manufacturing Technology*, *25*(9-10), 964–971. doi:10.1007/s00170-003-1933-2

Jerald, J., Asokan, P., Saravanan, R., & Rani, A. D. C. (2006). Simultaneous scheduling of parts and automated guided vehicles in an FMS environment using adaptive genetic algorithm. *The International Journal of Advanced Manufacturing Technology*, *29*(5-6), 584–589. doi:10.1007/BF02729112

Jones, D. F., Mirrazavi, S. K., & Tamiz, M. (2002). Multi-objective meta-heuristics: An overview of the current state-of-the-art. *European Journal of Operational Research*, *137*(1), 1–9. doi:10.1016/S0377-2217(01)00123-0

Kim, C. W., & Tanchoco, J. M. A. (1991). Conflict-free shortest-time bidirectional AGV routeing. *International Journal of Production Research*, *29*(12), 2377–2391. doi:10.1080/00207549108948090

Kim, C. W., Tanchoco, J. M. A., & Koo, P.-H. (1997). Deadlock Prevention in Manufacturing Systems With AGV Systems: Banker's Algorithm Approach. *Journal of Manufacturing Science and Engineering*, *119*(4B), 849–854. doi:10.1115/1.2836834

Kim, D. B., & Hwang, H. (2001). A Dispatching Algorithm for Multiple-Load Agvs Using a Fuzzy Decision-Making Method in a Job Shop Environment. *Engineering Optimization*, *33*(5), 523–547. doi:10.1080/03052150108940932

Kim, H. S., & Hwang, H. (1999). An adaptive dispatching algorithm for automated guided vehicles based on an evolutionary process. *International Journal of Production Economics*, *60–61*, 465–472. doi:10.1016/S0925-5273(98)00132-7

Kim, I. Y., & Weck, O. L. de. (2005). Adaptive weighted-sum method for bi-objective optimization: Pareto front generation. *Structural and Multidisciplinary Optimization*, *29*(2), 149–158. doi:10.1007/s00158-004-0465-1

Kim, K., Yamazaki, G., Lin, L., & Gen, M. (2004). Network-based hybrid genetic algorithm for scheduling in FMS environments. *Artificial Life and Robotics*, *8*(1), 67–76. doi:10.1007/s10015-004-0291-y

Kim, M. H., & Kim, Y.-D. (1994). Simulation-based real-time scheduling in a flexible manufacturing system. *Journal of Manufacturing Systems*, *13*(2), 85–93. doi:10.1016/0278-6125(94)90024-8

Krasnogor, N., & Smith, J. (2005). A tutorial for competent memetic algorithms: model, taxonomy, and design issues. *IEEE Transactions on Evolutionary Computation*, *9*(5), 474–488. doi:10.1109/TEVC.2005.850260

Krishnamurthy, N. N., Batta, R., & Karwan, M. H. (1993). Developing Conflict-Free Routes for Automated Guided Vehicles. *Operations Research*, *41*(6), 1077–1090. doi:10.1287/opre.41.6.1077

Kumar, R., Tiwari, M. K., & Shankar, R. (2003). Scheduling of flexible manufacturing systems: An ant colony optimization approach. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, *217*(10), 1443–1453. doi:10.1243/095440503322617216

Lacomme, P., Larabi, M., & Tchernev, N. (2013). Job-shop based framework for simultaneous scheduling of machines and automated guided vehicles. *International Journal of Production Economics*, *143*(1), 24–34. doi:10.1016/j.ijpe.2010.07.012

Langevin, A., Lauzon, D., & Riopel, D. (1996). Dispatching, routing, and scheduling of two automated guided vehicles in a flexible manufacturing system. *International Journal of Flexible Manufacturing Systems*, *8*(3), 247–262. doi:10.1007/BF00403127

Le-Anh, T., & De Koster, M. B. M. (2006). A review of design and control of automated guided vehicle systems. *European Journal of Operational Research*, *171*(1), 1–23. doi:10.1016/j.ejor.2005.01.036

Lee, C.-C., & Lin, J. T. (1995). Deadlock prediction and avoidance based on Petri nets for zone-control automated guided vehicle systems. *International Journal of Production Research*, *33*(12), 3249–3265. doi:10.1080/00207549508904872

Lin, L., & Gen, M. (2007). A bicriteria shortest path routing problems by hybrid genetic algorithm in communication networks. In *IEEE Congress on Evolutionary Computation, 2007. CEC 2007* (pp. 4577–4582).. doi:10.1109/CEC.2007.4425071

Lin, L., & Gen, M. (2009). Priority-Based Genetic Algorithm for Shortest Path Routing Problem in OSPF. In M. Gen, D. Green, O. Katai, B. McKay, A. Namatame, R. A. Sarker, & B.-T. Zhang (Eds.), *Intelligent and Evolutionary Systems* (pp. 91–103). Springer Berlin Heidelberg.

Lin, L., Shinn, S. W., Gen, M., & Hwang, H. (2006). Network model and effective evolutionary approach for AGV dispatching in manufacturing system. *Journal of Intelligent Manufacturing*, *17*(4), 465–477. doi:10.1007/s10845-005-0019-4

Lozano, M., & García-Martínez, C. (2010). Hybrid metaheuristics with evolutionary algorithms specializing in intensification and diversification: Overview and progress report. *Computers & Operations Research*, *37*(3), 481–497.

Maffei, A. (2012). *Characterisation of the Business Models for Innovative, Non-Mature Production Automation Technology*. The Royal Institute of Technology, Stockholm. Retrieved from http://www.diva-portal.org/smash/get/diva2:570401/FULLTEXT02.pdf

Mahadevan, B., & Naeendran, T. T. (1993). Estimation of number of AGVs for an FMS: an analytical model. *International Journal of Production Research*, *31*(7), 1655–1670. doi:10.1080/00207549308956815

Mamdani, E. H., & Assilian, S. (1975). An experiment in linguistic synthesis with a fuzzy logic controller. *International Journal of Man-Machine Studies*, *7*(1), 1–13. doi:10.1016/S0020-7373(75)80002-2

Marler, R. T., & Arora, J. S. (2004). Survey of multi-objective optimization methods for engineering. *Structural and Multidisciplinary Optimization*, *26*(6), 369–395. doi:10.1007/s00158-003-0368-6

Marler, R. T., & Arora, J. S. (2010). The weighted sum method for multi-objective optimization: new insights. *Structural and Multidisciplinary Optimization*, *41*(6), 853–862. doi:10.1007/s00158-009-0460-7

Mendes, J. J. M., Gonçalves, J. F., & Resende, M. G. C. (2009). A Random Key Based Genetic Algorithm for the Resource Constrained Project Scheduling Problem. *Comput. Oper. Res.*, *36*(1), 92–109. doi:10.1016/j.cor.2007.07.001

Moscato, P. (1989). *On Evolution, Search, Optimization, Genetic Algorithms and Martial Arts-Towards Memetic Algorithms* (C3P Technical Report No. 826). Calfonia, USA: California Institute of Technology.

Moscato, P., Cotta, C., & Mendes, A. (2004). Memetic Algorithms. In *New Optimization Techniques in Engineering* (pp. 53–85). Springer Berlin Heidelberg. Retrieved from http://link.springer.com/chapter/10.1007/978-3- 540-39930-8_3

Munir, S. A., Bin, Y. W., Biao, R., & Jian, M. (2007). Fuzzy Logic Based Congestion Estimation for QoS in Wireless Sensor Network. In *IEEE Wireless Communications and Networking Conference, 2007.WCNC 2007* (pp. 4336–4341).. doi:10.1109/WCNC.2007.791

Narasimhan, R. (1999). Routing automated guided vehicles in the presence of interruptions. *International Journal of Production Research*, *37*(3), 653–681. doi:10.1080/002075499191724

Naso, D., & Turchiano, B. (2005). Multicriteria meta-heuristics for AGV dispatching control based on computational intelligence. *Systems, Man, and Cybernetics, Part B: Cybernetics, IEEE Transactions on*, *35*(2), 208–226

.

Nejad, H. T. N., Sugimura, N., & Iwamura, K. (2011). Agent-based dynamic integrated process planning and scheduling in flexible manufacturing systems. *International Journal of Production Research*, *49*(5), 1373–1389. doi:10.1080/00207543.2010.518741

Nishi, T., Ando, M., & Konishi, M. (2005). Distributed route planning for multiple mobile robots using an augmented Lagrangian decomposition and coordination technique. *IEEE Transactions on Robotics*, *21*(6), 1191–1200. doi:10.1109/TRO.2005.853489

Nishi, T., Hiranaka, Y., & Grossmann, Ii. E. (2011). A Bilevel Decomposition Algorithm for Simultaneous Production Scheduling and Conflict-free Routing for Automated Guided Vehicles. *Comput. Oper. Res.*, *38*(5), 876–888. doi:10.1016/j.cor.2010.08.012

Nishi, T., Morinaka, S., & Konishi, M. (2007). A distributed routing method for AGVs under motion delay disturbance. *Robotics and Computer-Integrated Manufacturing*, *23*(5), 517–532. doi:10.1016/j.rcim.2006.10.007

Novas, J. M., & Henning, G. P. (2014). Integrated scheduling of resource-constrained flexible manufacturing systems using constraint programming. *Expert Systems with Applications*, *41*(5), 2286–2299. doi:10.1016/j.eswa.2013.09.026

Oboth, C., Batta, R., & Karwan, M. (1999). Dynamic conflict-free routing of automated guided vehicles. *International Journal of Production Research*, *37*(9), 2003–2030. doi:10.1080/002075499190888

Ouelhadj, D., & Petrovic, S. (2009). A survey of dynamic scheduling in manufacturing systems. *Journal of Scheduling*, *12*(4), 417–431. doi:10.1007/s10951-008-0090-8

Palacharla, P. v., & Nelson, P. c. (1999). Application of fuzzy logic and neural networks for dynamic travel time estimation. *International Transactions in Operational Research*, *6*(1), 145–160. doi:10.1111/j.1475-3995.1999.tb00148.x

Prakash, A., Tiwari, M. K., & Shankar, R. (2008). Optimal job sequence determination and operation machine allocation in flexible manufacturing systems: an approach using adaptive hierarchical ant colony algorithm. *Journal of Intelligent Manufacturing*, *19*(2), 161–173. doi:10.1007/s10845-008-0071-y

Precup, R.-E., & Hellendoorn, H. (2011). A survey on industrial applications of fuzzy control. *Computers in Industry*, *62*(3), 213–226. doi:10.1016/j.compind.2010.10.001

Qiu, L., & Hsu, W.-J. (2001). A bi-directional path layout for conflict-free routing of AGVs. *International Journal of Production Research*, *39*(10), 2177–2195. doi:10.1080/00207540110038531

Qiu, L., Hsu, W.-J., Huang, S.-Y., & Wang, H. (2002). Scheduling and routing algorithms for AGVs: A survey. *International Journal of Production Research*, *40*(3), 745–760. doi:10.1080/00207540110091712

Rajotia, S., Shanker, K., & Batra, J. L. (1998a). A semi-dynamic time window constrained routeing strategy in an AGV system. *International Journal of Production Research*, *36*(1), 35–50. doi:10.1080/002075498193921

Rajotia, S., Shanker, K., & Batra, J. L. (1998b). Determination of optimal AGV fleet size for an FMS. *International Journal of Production Research*, *36*(5), 1177–1198. doi:10.1080/002075498193273

Reddy, B. S. P., & Rao, C. S. P. (2006). A hybrid multi-objective GA for simultaneous scheduling of machines and AGVs in FMS. *The International Journal of Advanced Manufacturing Technology*, *31*(5-6), 602–613. doi:10.1007/s00170-005-0223-6

Rossi, A., & Dini, G. (2000). Dynamic scheduling of FMS using a real-time genetic algorithm. *International Journal of Production Research*, *38*(1), 1–20. doi:10.1080/002075400189545

Sankar, S. S., Ponnambalam, S. G., & Gurumarimuthu, M. (2006). Scheduling flexible manufacturing systems using parallelization of multi-objective evolutionary algorithms. *The International Journal of Advanced Manufacturing Technology*, *30*(3-4), 279–285. doi:10.1007/s00170-005-0045-6

Sarker, B. R., & Gurav, S. S. (2005). Route planning for automated guided vehicles in a manufacturing facility. *International Journal of Production Research*, *43*(21), 4659–4683. doi:10.1080/00207540500140807

Schaffer, J. D. (1985). Multiple Objective Optimization with Vector Evaluated Genetic Algorithms. *Proceedings of the First Int. Conference on Genetic Algortihms, Ed. G.J.E Grefensette, J.J. Lawrence Erlbraum*, 93–100.

Sethi, A. K., & Sethi, S. P. (1990). Flexibility in manufacturing: a survey. *International journal of flexible manufacturing systems*, *2*(4), 289–328.

Shalaby, M. A., Elmekkawy, T. Y., & Fahmy, S. A. (2006). A cost based evaluation of a zones formation algorithm in tandem AGV systems. *The International Journal of Advanced Manufacturing Technology*, *31*(1-2), 175–187. doi:10.1007/s00170-005-0163-1

Shnits, B., & Sinreich, D. (2006). Controlling flexible manufacturing systems based on a dynamic selection of the appropriate operational criteria and scheduling policy. *International Journal of Flexible Manufacturing Systems*, *18*(1), 1–27. doi:10.1007/s10696-006-9001-5

Smolic-Rocak, N., Bogdan, S., Kovacic, Z., & Petrovic, T. (2010). Time Windows Based Dynamic Routing in Multi-AGV Systems. *IEEE Transactions on Automation Science and Engineering*, *7*(1), 151–155. doi:10.1109/TASE.2009.2016350

Solimanpur, M., Vrat, P., & Shankar, R. (2005). An ant algorithm for the single row layout problem in flexible manufacturing systems. *Computers & Operations Research*, *32*(3), 583–598. doi:10.1016/j.cor.2003.08.005

Song, Y. H., Wang, G. S., Wang, P. Y., & Johns, A. T. (1997). Environmental/economic dispatch using fuzzy logic controlled genetic algorithms. *Generation, Transmission and Distribution, IEE Proceedings-*, *144*(4), 377–382. doi:10.1049/ip-gtd:19971100

Soukhal, A., Oulamara, A., & Martineau, P. (2005). Complexity of flow shop scheduling problems with transportation constraints. *European Journal of Operational Research*, *161*(1), 32–41. doi:10.1016/j.ejor.2003.03.002

Spears, V. M., & Jong, K. A. D. (1991). On the virtues of parameterized uniform crossover. In *Proceedings of the Fourth International Conference on Genetic Algorithms* (pp. 230–236). San Francisco, USA: Morgan Kaufmann Publishers Inc.

Srinivasan, M. M., Bozer, Y. A., & Cho, M. (1994). Trip-Based Material Handling Systems: Throughput Capacity Analysis. *IIE Transactions*, *26*(1), 70–89. doi:10.1080/07408179408966586

Srinivas, N., & Deb, K. (1994). Muiltiobjective Optimization Using Nondominated Sorting in Genetic Algorithms. *Evolutionary Computation*, *2*(3), 221–248. doi:10.1162/evco.1994.2.3.221

Subramanian, A., Battarra, M., & Potts, C. N. (2014). An Iterated Local Search heuristic for the single machine total weighted tardiness scheduling problem with sequence-dependent setup times. *International Journal of Production Research*, *52*(9), 2729–2742. doi:10.1080/00207543.2014.883472

Sugeno, M. (1985). *Industrial applications of fuzzy control*. North-Holland.

Susman, G. I., & Dean Jr, J. W. (1989). Strategic use of computer-integrated manufacturing in the emerging competitive environment. *Computer Integrated Manufacturing Systems*, *2*(3), 133–138. doi:10.1016/0951-5240(89)90003-7

Taghaboni-Dutta, F., & Tanchoco, J. M. A. (1995). Comparison of dynamic routeing techniques for automated guided vehicle system. *International Journal of Production Research*, *33*(10), 2653–2669. doi:10.1080/00207549508945352

Talbi, E.-G., Basseur, M., Nebro, A. J., & Alba, E. (2012). Multi-objective optimization using metaheuristics: non-standard algorithms. *International Transactions in Operational Research*, *19*(1-2), 283–305. doi:10.1111/j.1475-3995.2011.00808.x

Tanaka, Y., Nishi, T., & Inuiguchi, M. (2010). Dynamic Optimization of Simultaneous Dispatching and Conflict-free Routing for Automated Guided Vehicles. *Journal of Advanced Mechanical Design, Systems, and Manufacturing*, *4*(3), 701–715. doi:10.1299/jamdsm.4.701

Tan, K. K., Lee, T. H., & Tang, K. Z. (1999). Flexible Dispatching Rules for Automated Guided Vehicles Based on a Self-Adapting Fuzzy Prioritizing System. *Intelligent Automation & Soft Computing*, *5*(4), 327–336. doi:10.1080/10798587.1999.10750612

Tan, K. K., Tan, K. C., & Tang, K. Z. (2000). Evolutionary tuning of a fuzzy dispatching system for automated guided vehicles. *Systems, Man, and Cybernetics, Part B: Cybernetics, IEEE Transactions on*, *30*(4), 632–636.

Thierens, D., & Goldberg, D. (1994). Convergence models of genetic algorithm selection schemes. In *Parallel problem solving from nature—PPSN III* (pp. 119–129).

Tompkins, J. A., White, J. A., Bozer, Y. A., & Tanchoco, J. M. A. (2010). *Facilities Planning*. John Wiley & Sons.

Tyworth, J. E., & Zeng, A. Z. (1998). Estimating the effects of carrier transit-time performance on logistics cost and service. *Transportation Research Part A: Policy and Practice*, *32*(2), 89–97. doi:10.1016/S0965-8564(97)00020-7

Udhayakumar, P., & Kumanan, S. (2010). Sequencing and scheduling of job and tool in a flexible manufacturing system using ant colony optimization algorithm. *The International Journal of Advanced Manufacturing Technology*, *50*(9-12), 1075–1084. doi:10.1007/s00170-010-2583-9

Udhayakumar, P., & Kumanan, S. (2012). Integrated scheduling of flexible manufacturing system using evolutionary algorithms. *The International Journal of Advanced Manufacturing Technology*, *61*(5-8), 621–635. doi:10.1007/s00170-011-3727-2

Ullrich, G. (2015). The History of Automated Guided Vehicle Systems. In *Automated Guided Vehicle Systems* (pp. 1–14). Springer Berlin Heidelberg. Retrieved from http://link.springer.com/chapter/10.1007/978-3-662-44814-4_1

Ulusoy, G., Sivrikaya-Şerifoglu, F., & Bilge, Ü. (1997). A genetic algorithm approach to the simultaneous scheduling of machines and automated guided vehicles. *Computers & Operations Research*, *24*(4), 335–351. doi:10.1016/S0305-0548(96)00061-5

Vallada, E., Ruiz, R., & Framinan, J. M. (2015). New hard benchmark for flowshop scheduling problems minimising makespan. *European Journal of Operational Research*, *240*(3), 666–677. doi:10.1016/j.ejor.2014.07.033

Vesterstrom, J., & Thomsen, R. (2004). A comparative study of differential evolution, particle swarm optimization, and evolutionary algorithms on numerical benchmark problems. In *Congress on Evolutionary Computation, 2004. CEC2004* (Vol. 2, pp. 1980–1987 Vol.2).:10.1109/CEC.2004.1331139

Vieira, G. E., Herrmann, J. W., & Lin, E. (2003). Rescheduling Manufacturing Systems: A Framework of Strategies, Policies, and Methods. *Journal of Scheduling*, *6*(1), 39–62. doi:10.1023/A:1022235519958

Vis, I. F. A. (2006). Survey of research in the design and control of automated guided vehicle systems. *European Journal of Operational Research*, *170*(3), 677–709. doi:10.1016/j.ejor.2004.09.020

Watanabe, M., Furukawa, M., & Kakazu, Y. (2001). Intelligent AGV driving toward an autonomous decentralized manufacturing system. *Robotics and Computer-Integrated Manufacturing*, *17*(1–2), 57–64. doi:10.1016/S0736-5845(00)00037-5

Wu, H.-C. (2003). The fuzzy estimators of fuzzy parameters based on fuzzy random variables. *European Journal of Operational Research*, *146*(1), 101–114. doi:10.1016/S0377-2217(02)00140-6

Wu, N., & Zeng, W. (2002). Deadlock avoidance in an automated guidance vehicle system using a coloured Petri net model. *International Journal of Production Research*, *40*(1), 223–238. doi:10.1080/00207540110073037

Wu, N., & Zhou, M. (2005). Modeling and deadlock avoidance of automated manufacturing systems with multiple automated guided vehicles. *IEEE Transactions on Systems, Man, and Cybernetics, Part B: Cybernetics*, *35*(6), 1193–1202. doi:10.1109/TSMCB.2005.850141

Wu, N., & Zhou, M. (2007). Shortest Routing of Bidirectional Automated Guided Vehicles Avoiding Deadlock and Blocking. *IEEE/ASME Transactions on Mechatronics*, *12*(1), 63–72. doi:10.1109/TMECH.2006.886255

Yamashita, H. (2001). Analysis of dispatching rules of AGV systems with multiple vehicles. *IIE Transactions*, *33*(10), 889–895. doi:10.1080/07408170108936881

Yang, J.-B. (2001). GA-based discrete dynamic programming approach for scheduling in FMS environments. *Systems, Man, and Cybernetics, Part B: Cybernetics, IEEE Transactions on*, *31*(5), 824–835.

Yeh, M. S., & Yeh, W. C. (1998). Deadlock prediction and avoidance for zone-control AGVS. *International Journal of Production Research*, *36*(10), 2879–2889. doi:10.1080/002075498192526

Yeh, W. C. (2002). Real-Time Deadlock Detection and Recovery for Automated Manufacturing Systems. *The International Journal of Advanced Manufacturing Technology*, *20*(10), 780–786. doi:10.1007/s001700200237

Yoo, J., Sim, E.-S., Cao, C., & Park, J.-W. (2005). An algorithm for deadlock avoidance in an AGV System. *The International Journal of Advanced Manufacturing Technology*, *26*(5-6), 659–668. doi:10.1007/s00170-003-2020-4

Yun, Y., & Gen, M. (2003). Performance Analysis of Adaptive Genetic Algorithms with Fuzzy Logic and Heuristics. *Fuzzy Optimization and Decision Making*, *2*(2), 161–175. doi:10.1023/A:1023499201829

Zadeh, L. A. (1965). Fuzzy sets. *Information and Control*, *8*(3), 338–353. doi:10.1016/S0019-9958(65)90241-X

Zadeh, L. A. (1973). Outline of a New Approach to the Analysis of Complex Systems and Decision Processes. *IEEE Transactions on Systems, Man and Cybernetics*, *SMC-3*(1), 28–44. doi:10.1109/TSMC.1973.5408575

Zeng, J., & Hsu, W.-J. (2008). Conflict-free container routing in mesh yard layouts. *Robotics and Autonomous Systems*, *56*(5), 451–460. doi:10.1016/j.robot.2007.09.007

Zhang, M., Batta, R., & Nagi, R. (2008). Modeling of Workflow Congestion and Optimization of Flow Routing in a Manufacturing/Warehouse Facility. *Management Science*, *55*(2), 267–280. doi:10.1287/mnsc.1080.0916

Zheng, Y., Xiao, Y., & Seo, Y. (2014). A tabu search algorithm for simultaneous machine/AGV scheduling problem. *International Journal of Production Research*, *0*(0), 1–16. doi:10.1080/00207543.2014.910628