UNIVERSITI PUTRA MALAYSIA

INTEGRATED BI-OBJECTIVE MODEL FOR CELLULAR MANUFACTURING SYSTEM

AFSANEH NOURI HOUSHYAR

INTEGRATED BI-OBJECTIVE MODEL FOR CELLULAR MANUFACTURING SYSTEM

By

AFSANEH NOURI HOUSHYAR

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

December 2014

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

INTEGRATED BI-OBJECTIVE MODEL FOR CELLULAR MANUFACTURING SYSTEM

By

AFSANEH NOURI HOUSHYAR

December 2014

Chair : Zulkiflle bin Leman, PhD
Faculty : Engineering

Today's globalized business environment has brought about new and greater challenges to manufacturers: product life cycles are shortened; consumer demands and expectations change rapidly, and manufacturing technologies have seen significant advances. Many attempts have been made to overcome these challenges and adopting the Cellular Manufacturing System (CMS) is one of the most successful. CMS is an efficient application of group technology, with the capability to overcome these problems. CMS and dynamic environment over recent years have gained a lot of attention. This study proposed a comprehensive intelligent nonlinear mathematical model, the nonlinear terms of which were linearized through linearization steps to identify machine cells, choose optimum machine layout for each cell and also assign part operations to the machines in each period to minimize total cost and completion time, with maintenance planning considered as one of the key advantages. This model can intelligently provide the most proper maintenance plan for each duplicate of machine type in each production period. This model is able to consider operation sequences, processing time, production volumes of parts, machine rotation, define distance between machines, duplicate machines, unequal-area facilities and machine relocations under the dynamic situation in CMS. This study offers five contributions namely, a relation to the comprehensive mixed-integer mathematical model formulated to define cell formation, design layout for unequal-area machines and also assign parts operations to the machines in DCMS as a first contribution. It is also capable of locating machines horizontally or vertically in each cell in each period to achieve the most efficient layout as a second contribution. A third contribution is its capability to consider the defined distance between machines for movement of parts and labor to achieve an applicable solution in DCMS. A fourth contribution is related to the model's intelligent capability to decide smartly which of two available maintenance plans should be used for each machine type. The study's fifth contribution is related to the model's bi-objectives, concentrating simultaneously on minimization of total cost and completion time in contrast to previous studies which concentrated on only one objective function. The proposed model was coded and simulated in GAMS during five different steps and in each step one contribution was added for validation by applying the existing data in the literature. Besides the extracted data from the literature, a case study was considered to prove the model's validity. The results showed that, by implementing the proposed model in the manufacturing system, the overhead cost of the system is reduced by 7.37% and also the operation cost was reduced from US$25473 to US$23180, which is equal to nine percent reduction and consequently the total cost is reduced by 2.6% (from US$191308 to US$186185). In addition, results

clarified the cells, machines layout, parts operations assignment and also proper maintenance plan for each machine which were model objectives, plus, the obtained results indicated that cost and completion time were changed in line with demand changes. The proposed model is therefore able to help managers make decisions in designing and planning for an optimized DCMS in terms of total cost and completion time.

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

MODEL BERSEPADU DWI OBJEKTIF BAGI SISTEM PEMBUATAN BERSEL

Oleh

AFSANEH NOURI HOUSHYAR

Disember 2014

Pengerusi: Zulkiflle bin Leman, PhD
Fakulti: Kejuruteraan

Persekitaran perniagaan global hari ini telah membawa cabaran baru dan lebih besar kepada pengilang : kitaran hayat produk yang dipendekkan ; permintaan dan harapan pengguna yang berbeza dengan cepat , dan teknologi pembuatan telah melihat kemajuan yang signifikan . Banyak percubaan telah dibuat untuk mengatasi cabaran-cabaran ini dan menerima pakai Sistem Pembuatan Bersel (CMS) adalah salah satu yang paling berjaya daripada percubaan tersebut . CMS adalah aplikasi yang cekap teknologi kumpulan , dengan keupayaan untuk mengatasi masalah-masalah ini . CMS dan persekitaran dinamik dalam tahun baru-baru ini telah mendapat banyak perhatian . Kajian ini mencadangkan satu model matematik tak linear pintar komprehensif , terma tak lelurus yang dileluruskan melalui langkah-langkah yang linear untuk mengenalpasti sel mesin , memilih susun atur mesin yang optimum untuk setiap sel dan juga menetapkan operasi bahagian untuk mesin-mesin dalam setiap tempoh untuk meminimumkan jumlah kos dan masa siap dengan perancangan penyelenggaraan dianggap sebagai salah satu kelebihan utama . Model ini secara bijak boleh menyediakan pelan penyelenggaraan yang paling sesuai untuk setiap salinan jenis mesin dalam tempoh setiap pengeluaran . Model ini dapat mempertimbangkan urutan operasi , masa pemprosesan , jumlah pengeluaran alat ganti , putaran mesin , menentukan jarak antara mesin , mesin pendua , kemudahan yang tidak sama rata - kawasan penempatan-penempatan semula dan mesin bawah keadaan dinamik dalam CMS . Kajian ini menawarkan lima sumbangan iaitu , yang berhubung dengan bercampur - integer model yang komprehensif matematik digubal bagi menentukan pembentukan sel , susun atur reka bentuk yang tidak sama rata untuk mesin - kawasan dan juga menetapkan operasi bahagian untuk mesin-mesin dalam DCMS sebagai sumbangan pertama . Ia juga mampu mencari mesin mendatar atau menegak dalam setiap sel dalam setiap tempoh untuk mencapai susun atur yang paling berkesan sebagai sumbangan kedua .Sumbangan ketiga ialah keupayaan untuk mempertimbangkan jarak antara mesin ditakrifkan untuk pergerakan bahagian-bahagian dan buruh untuk mencapai satu penyelesaian yang diguna pakai dalam DCMS itu . Sumbangan keempat berkaitan dengan keupayaan pintar model untuk membuat keputusan bijak yang dua pelan penyelenggaraan disediakan perlu digunakan untuk setiap jenis mesin . Sumbangan kelima kajian ini berkaitan dengan dua objektif model , menumpukan perhatian pada masa yang sama meminimumkan jumlah kos dan masa penyelesaian berbeza dengan kajian sebelum ini yang menumpukan kepada hanya satu fungsi objektif. Model yang dicadangkan telah dikodkan dan disimulasikan dalam Gams dalam lima langkah yang berbeza dan dalam setiap langkah satu sumbangan dimasukkan untuk pengesahan melalui menggunakan data yang sedia ada dalam

sorotan kajian . Selain daripada data yang diekstrak daripada literatur, kajian kes telah dipertimbangkan untuk membuktikan kesahihan model . Hasil kajian menunjukkan bahawa , dengan melaksanakan model yang dicadangkan dalam sistem pembuatan , kos overhead sistem dikurangkan sebanyak 7.37 % dan juga capaian kos operasi 25473-23180 $ yang sama dengan pengurangan 9 % dan seterusnya jumlah kos dikurangkan sebanyak 2.6 % (191308-186185 $). Di samping itu, keputusan menjelaskan sel-sel , susun atur mesin , operasi bahagian tugasan dan juga pelan penyelenggaraan yang betul bagi setiap mesin yang tidak objektif model , tambahan, mendapat keputusan menunjukkan bahawa kos dan masa siap diubah selaras dengan perubahan permintaan . Model yang dicadangkan adalah dengan itu dapat membantu pengurus membuat keputusan dalam mereka bentuk dan perancangan untuk DCMS dioptimumkan dari segi jumlah kos dan masa siap .

ACKNOWLEDGEMENTS

In the name of Allah, the Compassionate, the Merciful who gave me the ability, strength and patience to complete this study.

The accomplishment of this research has been made possible by the firm support from my supervisor, Associate Professor Dr. Zulkiflle Bin Leman. His invaluable advice and help were always there especially in difficult times to give me the courage and motivation to persevere with the journey toward success.

Many thanks are also due to my committee members, Professor Datin Dr. Napsiah Ismail, Associate Professor Ir Dr. Mohd Khairol Anuar bin Mohd Ariffin, and Professor Dr. Hossein Iranmanesh, for their valuable comments and suggestions that have helped me to improve the quality of this research.

Finally, I would like to express my sincere gratitude to my parents and family; without their support, I would never have accomplished anything.

I certify that a Thesis Examination Committee has met on 17/12/2014 to conduct the final examination of Afsaneh Nouri Houshyar on her thesis entitled "Integrated Bi-Objective Model for Cellular Manufacturing System" in accordance with the Universities and University Colleges Act 1971 and the Constitution of 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:

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

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

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

Turkay Dereli, PhD
Professor
Faculty of Engineering
University of Gaziantep
(External Examiner)

ZULKARNAIN ZAINAL PhD,
Professor & Deputy Dean
School of Graduate Studies,
Universiti Putra Malaysia

Date: 19 March 2015

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:

Zulkiflle bin Leman, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohd Khairol Anuar bin Mohd Ariffin, PhD, P.Eng
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

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

Hossein Iranmanesh, PhD
Professor
Faculty of Engineering
University of Tehran
(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 supervisor and the office of 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 the 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: ______________________
Name of Chairman of Supervisory Committee: ______________________

Signature: ______________________
Name of Member of Supervisory Committee: ______________________

Signature: ______________________
Name of Member of Supervisory Committee: ______________________

Signature: ______________________
Name of Member of Supervisory Committee: ______________________

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

B&B	Branch and bound
B&C	Branch and cut
BC	Backorder cost
BL	Backorder level
CF	Cell formation
CMS	Cellular manufacturing system
CI	Capital investment
CLV	Cell load variation
CSC	Cell set up cost
CM	Completion time
CCM	Machine constant cost
CS	Cell size
DBH	Decomposition base heuristic
DCMS	Dynamic cellular manufacturing system
DP	Dynamic programming
DS	Dissimilarity between parts
ECR	Extra capacity requirement
EE	Exceptional elements
FIC	Firing cost
FRM	Failure rate of machine
GA	Genetic algorithm
GL	Group layout
GT	Group technology
HC	Holding cost
HGA	Hierarchical genetic algorithm
HHGA	Hybrid Hierarchical genetic algorithm
HIA	Hierarchical approach
IC	Inventory cost
ICAL	Intra-cell layout
ICL	Inter-cell layout
IL	Inventory level
INTER	Inter-cell material handling cost
INTRA	Intra-cell material handling cost
INTRAT	Intra-cell move time
IP	Integer program
ISR	Inverse of system reliability
IT	Inventory transportation
MAC	Machine amortization cost
MBC	Machine breakdown cost
MC	Maintenance cost
MD	Machine duplication
MFA-SA	Mean field annealing and simulated annealing
MINLP	Mixed integer non-linear program
MIP	Mixed integer program
MM	Material moves
MO	Multi-objective
MOSS	Multi-objective scatter search

MPP	Multi period planning
MSE	Machine sequence
NA	Neural approach
NLP	Non-linear program
NUC	Non utilization cost
OPC	Operation cost
OVC	Overhead cost
PC	Production cost
PL	Production level
PM	Preventive maintenance cost
PP	Production plan
PR	Process route
PRP	Processing part requirement
PS	Production scheduling
PSO	Particle swarm optimization
PUC	Purchase cost
QAP	Quadratic assignment problem
RC	Reconfiguration cost
RCP	Reconfiguration plan
SAC	Salary cost
SBQ	Subcontracted quantity
SC	System cost
SO	Single objective
SS	Scatter search
STP	Stochastic problem
TDT	Total distance traveled
TMHC	Total material handling cost
2SP	Two stage scheduling problem
TS	Tabu search
VCM	Machine variable cost
VO	Total number of voids
WA	Worker assignment
WIP	Work in process

CHAPTER 1

INTRODUCTION

1.1 Background

In previous decades, manufacturers faced a lot of challenges because of globalization and high competition in markets. These problems arise from the shortening of product life cycle, rapid variations in product demand, and also rapid changes in manufacturing technologies. Nowadays, most manufacturing companies pay considerable attention to improving flexibility and responsiveness in order to overcome these kinds of problems and also meet customers' needs. One of the major techniques being applied for improving manufacturing competitiveness is Cellular Manufacturing System (Ahi et al., 2009). Cellular Manufacturing System is an efficient application of Group Technology (Logendran & Talkington, 1997) which is able to take advantage of the superiority of both flow lines and job shops (traditional manufacturing system) and is capable of overcoming traditional weaknesses. In other words, CMS is a hybrid system linking the advantages of both job shops (flexibility in producing a wide variety of products) and flow lines (efficient flow and high production rate).

CMS can be considered as a successful manufacturing system which is able to meet today's market requirements (Rafiee et al., 2011). Ariafar (2012) explains some of the main benefits of CMS implementation in comparison with traditional manufacturing system as follows:

1. Reduction in inventory
2. Reducing the work in process
3. Decreasing the set up time and throughput time
4. Reduction in material handling cost
5. Simplification of production planning and scheduling
6. Improvement of product quality

In CMS, parts are grouped based on their similarities like shape, tolerance and process plan. These groups of parts will be named part families. There are many machine cells in CMS and in each machine cell, there are dissimilar machines which are dedicated to manufacture one or more part families. CMS has two main elements which are shown in Figure 1-1.

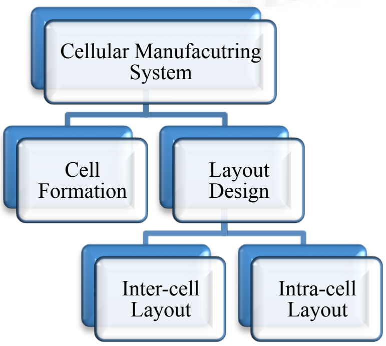

Figure 1-1: Elements of CMS

The first step in designing CMS is called cell formation (CF), which is a process of grouping parts into the part families and also dedicating part families to machine cells in order to be produced. This step in CMS is a crucial stage and has gained a lot of attention and become a well-studied problem in the past few decades (Papaioannou & Wilson, 2010; Sarker, 1998; Yin, 2005, 2006).

The next prominent step in designing CMS is layout design. The aim of this step is, to arrange departments, aisles, machines, tools and instruments on the shop floor in the most efficient way. Layout design in CMS includes arranging cells on the shop floor (inter-cell layout) and also arranging facilities in the cells (intra-cell layout). Layout design is an important decision in CMS, which has tremendous impacts on manufacturing performance; hence, evaluating the performance of layout is a crucial issue in the manufacturing system. In order to evaluate the layout performance, different criteria can be defined for this mean such as: material handling cost, throughput time, lead time and so on. Based on the literature, material handling cost is the most important criteria applied for evaluating the layout performance. In other words, 20-50 % of the operating expenses are allocated to material handling cost, and by implementing an efficient layout design, the operating expenses can be reduced by 10-30% (Tompkins, 2010). Therefore, a well-designed layout leads to a reduction in material handling cost, lead time and throughput time. In contrast, inefficient layout causes system inefficiency, increased cost and also an increase in accumulated work in process. Although layout design is important in the manufacturing system, especially in CMS, this issue has attracted less attention to itself in comparison to cell formation (Ahi et al., 2009; Ariafar, 2012; Sangwan & Kodali, 2009; Sarker, 1998; Wang et al., 2001).

Besides the importance of cell formation and layout design in CMS, as explained earlier, another crucial issue in CMS is related to the concept of a static or dynamic environment for the system. There are two types of manner for cellular manufacturing system which are named static and dynamic condition. A static environment is related to the traditional CMS where no changes in demand are taken into account, whereas in dynamic environment, part demand and part mix will change in successive periods (Papaioannou & Wilson, 2010). In other words, these concepts mean that the cell formation and facility layout are either constant during the whole period of production or will change period by period in the production process.

Most previous researchers considered CMS under the static condition and merely formed cells in a single-time period in order to prevent complexity in their study but Rafiee et al. (2011) expressed clearly that optimum cell configuration in one period may not be suitable for another period, since nowadays short product life cycle leads to change in the demand and product mix over a period. Therefore, concentrating on dynamic situation in CMS has taken on greater importance. Recently, most researchers have focused on dynamic CMS, since it is more practical and also more close to reality.

CMS and dynamic environment have been emerging topics in recent years, having gained a lot of interest from researchers (Ariafar, 2012). According to the research scope, a review has been done in the literature of the Cellular Manufacturing System (CMS), and Dynamic Cellular Manufacturing System (DCMS) to determine the existing gaps and identify the problem statement for this study.

1.2 Problem statement

As explained in the previous section, the main focused areas of this research are CMS and DCMS and as such the author has made attempts to review the literature related to these topics, besides also focusing more on the most recently published papers in this research area (Kia et al., 2012b). A review of the literature has revealed some gaps in previous studies which are summarized as follows:

1. There have been several studies done on cell formation and layout design in CMS, but there is a need to have more investigation on these two issues simultaneously in the dynamic environment of the CMS. In other words, the first gap indicated in the literature is related to a lack of a comprehensive mathematical model for DCMS, which simultaneously concentrates on cell formation and layout design (Mohammadi & Foroghi, 2014; Mahdavi et al., 2013).
2. Moreover, as stated in the previous section, layout design is one of the main elements of CMS, which must be considered in designing the manufacturing system. In the designing step of the intra-cell layout, it is crucial to consider the machine dimensions as such data will help in designing a practical and efficient layout which is more close to the real situation of the manufacturing system. Although some previous studies considered dimensions of machine in facility layout design, none of them combined this issue with CMS and specifically with the DCMS. This means to say that many researchers considered facilities as equal or unequal-area machines in their study but this issue has not been considered in DCMS. A recent research by Kia et al., (2012b) paid attention to this issue and proposed a mathematical model for DCMS by focusing on unequal-area machine; therefore, there is a big need to investigate the dimensions of machine in designing a DCMS. In other words, the second gap, revealed in the literature is related to the lack of a DCMS model which takes into account the dimensions of machines for designing more applicable layout (Kia et al., 2012b; Mohammadi & Foroghi, 2014).
3. In addition, as the literature review has shown, none of the previous studies considered a specific distance between machines for movement of parts and labor in DCMS. In other words, defining the distance between machines in order to allow movement of parts and labor across them is crucial in layout design of DCMS. Indeed, this essential spatial factor must be taken into account in the designing step in order to make the model more practical and close to reality; hence, the third gap seen in literature is related to considering the defined distance between the machines for movement of parts and labor.
4. Moreover, as the literature review illustrates, there are many models which have been proposed for designing a CMS by defining different objective functions such as: inter and intra-cell material handling, operation cost, procurement cost and so on. Although, the importance of reliability and maintenance planning in a manufacturing system is obvious and has been illustrated in the literature, there are just a few researchers who have considered this issue in their work. Therefore, there is a need to investigate more on the reliability and maintenance planning with the incorporation of other elements simultaneously in CMS and especially in DCMS to make it more close to reality (Aljuneidi, 2013). To put it differently, the fourth gap, which is revealed in literature is related to taking into account maintenance planning and machine reliability in the DCMS model. Preventive maintenance

practices will be promptly activated thus increasing equipment reliability, decreasing the frequency of unexpected random failures and ultimately decreasing corrective maintenance interventions; therefore, maintenance planning which means, letting the system decides about the most proper maintenance plan for its machines should be considered in the manufacturing system (Colledani et al., 2014; Negahban & Smith, 2014).

5. In addition, as can be seen in the literature, the majority of proposed models are single-objective models. That is to say, most of the models define one type of objective function which has the same nature; then, makes an attempt to minimize or maximize them. These types of models are named single-objective models. Most of the researchers have focused on minimization or maximization of one objective function in order to avoid model complexity. However, although some researchers have made attempts to consider more than one objective in their model, there is still a lack of multi-objective models as has been revealed in the literature for DCMS. In other words, the fifth gap, revealed in the literature is related to objectives of the model. Most previous DCMS models were single-objective; therefore, there is an urgent need to propose multi-objective models in DCMS.

The above stated issues are some of the main gaps that have been revealed in DCMS literature. This study makes an attempt to fill these identified gaps and the research attempts are as follows:

1. Since the first revealed gap is related to lack of a comprehensive DCMS model for solving cell formation and layout design problems simultaneously, therefore, this research proposes a comprehensive mathematical model which integrates cell formation and intra-cell layout design concurrently. It considers operation sequences, processing time, production volumes of parts, duplicate machines, machine capacity, intra-cell layout design, and machine relocations under the dynamic situation in CMS. In other words, in order to fill the first gap, this research proposes a comprehensive CMS model which considers different manufacturing features under the dynamic situation for making cell formation and designing intra-cell layout concurrently. Since all previous proposed models have been non-linear mathematical models, this study proposes a comprehensive non-linear mathematical model at first, then the non-linear terms are linearized through the linearization steps and finally the comprehensive mixed-integer mathematical model is applied in order to identify the machine cell, part families and assign them to the cell and concurrently choose the optimum machine layout in each cell and also the assignment of part operation to the machines with regard to the model objective function.

2. According to second revealed gap, which is related to considering the dimensions of the machine and its effective impacts on the layout design for DCMS, this study attempts to focus on both equal and unequal-area machines for designing a DCMS. In addition, the proposed model of this research is able to rotate the machines in order to utilize the shop floor space in the most efficient way. In other words, in response to the second gap, this study attempts to take into account the dimensions of machines in the proposed mathematical model and also consider machines as unequal-sized facilities; also, the proposed model is able to locate machines horizontally or vertically in

the cells in such a way that no overlapping occurs. Indeed, this model will decide whether the machine must be located horizontally or vertically in the cells in order to achieve the most efficient layout during each production period.

3. Based on the third existing gap, in this research the author considers the defined distance between machines for movement of parts and labor. In fact, defining this distance between machines in the proposed model is crucial for a logical layout; otherwise, the model will decide to locate the machines so close to each other in order to utilize the cell's area in the most spatially economical way which is not applicable since there is no space between them for movement. Therefore, in order to address the third gap, this research considers the specific distance between all machines to let the model design the layout in such a way that there is no overlap between machines and there is a distance between them for movement of parts and labor.

4. Based on the fourth revealed gap, maintenance planning and reliability of machine are important issues in manufacturing planning which must be considered. Although, some of the previous research made attempts to propose comprehensive model (Kia et al., 2012b), none of them took into account the issue of maintenance planning. In order to fill the fourth gap, this study considers maintenance planning in its proposed mathematical model. Indeed, the author considers maintenance planning in the model and proposes the model in such a way that it works smartly and intelligently. In fact, in this model, the author defines two types of maintenance plan for the system, which are Plan 1 and Plan 2. Plan 1 merely considers the corrective maintenance, which means when any breakdown or problem occurs; the machines are repaired in order to return back to the normal situation and production. In contrast, Plan 2 considers both preventive and corrective maintenance for the machine. In other words, in this plan, plus the corrective maintenance which must be done when encountering the machine breakdown, the preventive maintenance also must be carried out before the start of next production run in order to improve the machine reliability or to return the machine to the 'as good as new' condition. In fact, the proposed model is defined intelligently to enable it to decide on the selection of either Plan 1 or 2 for its machines by considering the minimization of cost as the objective of the system (the objective function includes different costs which are: inter-cell material handling cost, intra-cell material handling cost, operation cost, overhead cost, reconfiguration cost, and maintenance cost). Put differently, although Plan 2 has extra cost for preventive maintenance, it is able to decrease the possibility of breakdown happening in the system, in other words, it is able to increase the average time between the machine's failures; therefore, it is crucial for the model to work smartly to define the proper maintenance plan for each machine in each period. In fact, the proposed model is defined intelligently to decide the selection of either Plan 1 or 2 for its machines.

5. Since the fifth revealed gap relates to a lack of multi-objective DCMS models; therefore, this research attempts to consider another objective for the proposed DCMS model. In order to fill the fifth gap, this study proposes a comprehensive bi-objective model for DCMS, which is able to help the decision-makers to consider two conflicting objectives simultaneously in their

deciding process. Since the importance of minimizing the cost in any manufacturing system is obvious and also based on the intention of all manufacturers to reduce system costs, the cost function is considered as a first objective function for this study, which must be minimized. In addition, according to the research of Wu et al., (2007b) and Tavakkoli-Moghaddam et al., (2010), completion time also is considered as an important objective for a Cellular Manufacturing System, which has effective influence on the system; hence, minimization of completion time is defined as a second objective function for the proposed model in this research. Since the first objective is minimization of cost and the second objective is minimization of completion time; therefore, a trade-off must be made between these two objective functions in order to reach the optimal situation.

To sum it up, due to the importance of existing gaps in the literature, this research proposes a comprehensive intelligent non-linear mathematical model, the non-linear terms are linearized through linearization steps in order to identify the machine cell and part families and assign them to the cell and also concurrently, choose the optimum machine layout in each cell and also assign the part operation to each machine with regards to minimization of total cost (material handling cost, operation cost, overhead cost, reconfiguration cost and maintenance cost) and also completion time. In other words, this research proposes a comprehensive mathematical model, which integrates cell formation and intra-cell layout design. Moreover, it considers operation sequences, processing time, production volumes of parts, duplicate machines, machine capacity, intra-cell layout design, unequal-area facilities, continuous area cells, machines rotation, defined distance for movement of parts and labor, and machine relocations under the dynamic situation in CMS. The research's novelties are related to: multi-objective nature of the proposed model, defining the maintenance plan for the model (makes it as an intelligent model) and also the linearization of non-linear terms of mathematical model in contrast to previous researches.

1.3 Importance of the study

Batch manufacturing has a significant share of the total manufacturing activities. Due to the present competitive market, it needs to produce a large variety of products in small manufacturing lot sizes at a competitive price in response to customer needs. Conventional manufacturing systems (job shops and flow shops) have found it difficult to comply with these requirements and have resorted to Group technology (Niaki et al., 2011). Manufacturer applied Group technology is one of the best manufacturing systems used in order to survive in the competitive international market (Aljuneidi, 2013). One of the most important applications of GT in the manufacturing context is CMS. Reduction in product life cycle and variations in product mix and demands create dynamic conditions in the manufacturing system which lead to DCMS. It is important for companies that use DCMS to invest sufficient time in the design and planning phase of any DCMS implementation. The benefits of DCMS can only occur to the company if strategic decisions are based upon results obtained from mathematical models (Aljuneidi, 2013). The applicable DCMS model is the one which covers manufacturing attributes such as operation sequence, processing time, production volumes of parts, inter cell and intra cell movements, machine duplications, cell reconfiguration, machine procurements, machine size, machine layout, machine capacity, alternate routing, breakdown and maintenance planning, and lot split (Saxena & Jane 2011; Aljuneidi, 2013; Mohammadi & Foroghi, 2014). Some of these issues have been considered in previous researches but based on the literature review of this study and also the problem statement, there is need to propose a comprehensive integrated model for DCMS design with their simultaneous consideration since the absence of these factors in the problem, limits its application in most real-life cases (Mohammadi & Foroghi, 2014). The author simultaneously included the various cost terms in objective function of the model from the various cost term combinations considered by earlier researchers. In addition, since time is a crucial factor in any manufacturing system; therefore, the author consider it as a second objective function for the model in order to help managers to decide more accurately in the designing step. The proposed DCMS model integrates concurrently the important manufacturing attributes in existing models in a single model such as machines layout by considering their sizes and defined distance between them, machine breakdown effect in terms of maintenance cost and its planning. In fact, the importance of good layout planning is shown by the fact that annually over US$250 billion are spent in the United States alone, layouts that require planning and replanning (Tompkins et al., 2003). Further, between 20% and 50% costs in manufacturing are related to material handling. Effective and innovative facility planning can reduce material handling costs by 10–30% (Tompkins et al., 2003); therefore, it is essential to concentrate on optimum machine layout in the DCMS model. In addition, to attain the benefits of DCMS, its layout should be designed efficiently. Nevertheless, very limited research has been done on this area and also, there are still several shortcomings in those researches for instance: the CF and the intra-cell layout problems are solved sequentially. As a result, the final design may not be efficient so simultaneous consideration is required (Mohammadi & Foroghi, 2014). Besides the machine layout, which must be considered, it is also necessary to focus on machine breakdown. Machines are key elements of manufacturing systems. Traditionally, cell formation and work allocation are done with the assumption of 100% reliability of machines but in practice, machines fail during operations and are not free from vulnerability to disruption so the practical DCMS model should take it into account (Aljuneidi, 2013).

The proposed model of this study, to the best of the author's knowledge, is the most comprehensive model to date with a more integrated approach to the DCMSs, which is able to cover the mentioned gaps in the previous sections.

1.4 Objectives

Based on the problems statements which have been explained in the previous section, the specific objectives of this study are summarized as follows:

1. To propose a comprehensive intelligent nonlinear mathematical DCMS model by considering the unequal-area machines for solving the cell formation and intra-cell layout problem.
2. To linearize the comprehensive intelligent non-linear mathematical DCMS model to achieve the comprehensive intelligent mixed-integer mathematical DCMS model.
3. To solve and validate the proposed comprehensive mixed-integer mathematical DCMS model by previous and physical data via the GAMS.

1.5 Contribution of the study

In previous sections, the main objectives of this research have been explained. The aim of this section is to clarify the main contributions of this study.

a) The first contribution of this study is related to the comprehensive mixed-integer mathematical model, which has been formulated for defining the cell formation, designing the layout for unequal-area machines and also assigning the part operation to each machine under dynamic environment in Cellular Manufacturing System. The model arranges the machines in the cell in the most efficient manner. In fact, the first proposed model is a non-linear model, and then non-linear terms are identified and linearized through linearization step to reach the comprehensive mixed-integer mathematical model.
b) The second contribution of this study is related to the capability of the model in machine rotation. Put differently, the model is able to locate the machines horizontally or vertically in each cell in each period in order to reach the most efficient layout in DCMS.
c) The third contribution of this research is related to considering the defined distance between machines for movement of parts and labor. This contribution is for achieve a more applicable and practical solution in DCMS.
d) The fourth contribution of this study is related to its intelligence capability. Indeed, the proposed model of this research performs smartly and intelligently. In other words, two types of maintenance plans (Plan1 and Plan 2) are defined for the system and the proposed smart model is able to decide which maintenance plan is more suitable for each machine in each period in DCMS.
e) The fifth contribution of this model relates to the model's objective, which is bi-objectives. Indeed, this model concentrates simultaneously on minimization of two objectives, which are named cost function and completion time in contrast to previous researches which had been concentrated on only one objective function for DCMS.

1.6 Scope of study

In previous sections, the existing gaps in the literature and the main aspects of this study were explained. In the following figure and section the main scope of the proposed model is summarized:

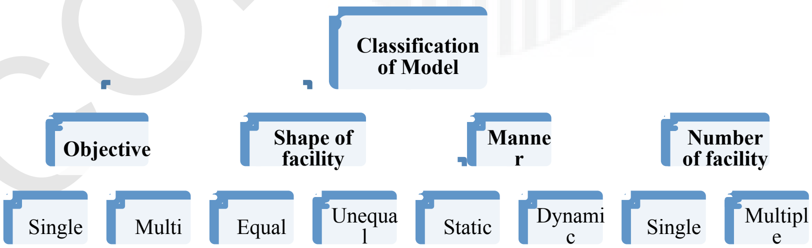

Figure 1-2: Classification of model

Based on figure 1-2, for the first classification, it can be mentioned that this research proposes a multi-objectives model. The proposed model includes two minimization objective functions, which are cost function and also completion time. The cost function includes different costs in the systems which are: inter-cell material handling cost, intra-cell material handling cost, operation cost, overhead cost, reconfiguration cost and maintenance cost.

For the next category which is related to the shape of facilities, this research focuses on unequal-area machines. The proposed model is able to design the most efficient layout for unequal–area machines in each cell. The proposed model considers the size and rotation of each machine in each cell in each period.
By surveying the literature, it becomes obvious that, in the current competitive market, the static manufacturing system cannot perform productively; hence, most manufacturing systems go toward the dynamic status to survive in the volatile market; therefore, this study concentrates on the dynamic CMS not static CMS.

The last category is related to the number of facilities, which can be single or multiple. In the present research, the main focus is on multiple machines with multi-products under multi-periods. The issue is that, most of previous researches assumed that all their machines are multi-process machines to prevent complications in their model, but this research tries to be close to the reality; therefore, has omitted this assumption and assumes that each machine is able to process only some operation of each part in the system, which are defined in advance and the model is able to assign part operation to the machines by considering the objective functions. Although this assumption makes the model more complicated, it becomes more practical.

At the end, it can be concluded that, the proposed model can be applicable for the manufacturing system, since it is so comprehensive and intelligent. It helps managers to make decision in the designing and planning step for their system and also helps them to reach the optimized DCMS according to the total cost and completion time.

1.7 Outline of thesis

This thesis is organized into five chapters. Chapter 2 reviews the relevant literature with regard to CMS, DCMS, machine reliability and breakdown in CMS. In Chapter 3, the research method which has been applied in this study is explained; in addition, the mathematical model is formulated in this chapter. Chapter 4 is dedicated to validation of the proposed mathematical model. Moreover, the results are discussed and analyzed in the same chapter. Finally, chapter 5 provides the summary, conclusion and future direction of this study.

REFERENCES

Abounacer, R., Rekik, Mo., & Renaud, J., (2012). An Exact Solution Approach for Multi-Objective Location- Transportation Problem for Disaster Response. *Inter-university Research Center on Enterprise Network, Logistics and Transportation.*

Afentakis, P., Millen, R., & Solomon, M. (1990). Dynamic layout strategies for flexible manufacturing systems. *International Journal of Production Resaerch, 28*(3), 11-23.

Afrazeh, A., Keivani, A., & Najafabadi Farahani, L. (2010). A new model for dynamic multi floor facility layout problem *Journal of Advanced Modeling and Optimization, 12*(2), 249-256.

Ahi, A., Aryanezhad, M.B., Ashtiani, B. and Makui, A. (2009). A novel approaach to determine cell formation, intracellular machine layout and cell layout in CMS problem based on TOPSIS method. *Computers and Operations Research., 36*(5), 1478-1496.

Ahkioon, S., Bulgak, A.A. , & Bektas, T. . (2009). Cellular manufacturing systems design with routing flexibility, machine procurement, production planning and dynamic system reconfiguration. *International Journal of Production Research, 47*(6), 1573-1600.

Akturk, M. , & Turkcan, A. (2000). Cellular manufacturing system design using a holonistic approach. *International Journal of Production Research, 38*(10), 2327-2347.

Aljuneidi, T. (2013). *A mathematical approach to the design of cellular manufacturing system considering dynamic production planning and worker assignments.*(PHD), Concordia University.

Ameli, M.S., & Arkat, J. (2008). Cell formation with alternative process routing and machine relaibility consideration. *The International Journal of Advanced Manufacturing Technology, 35*(7-8), 761-768.

Ariafar, S, & Ismail, N. (2009). An improved algorithm for layout design in cellular manufacturing systems. *Journal of Manufacturing Systems, 28*(4), 132-139.

Ariafar, S. (2012). *Inter-cell and intra-cell facility layout models under different demand environments in cellular manufacturing systems.* (PHD), universiti Putra Malaysia.

Bajestani, AM., Rahimi-Vahed, AR., & Khoshkhou, BG. (2009). A multi-objective scatter search for a dynamic cell formation problem. *Computer Operation Resaerch, 36*(3), 777-794.

Bagheri, M., Bashiri., M. (2014). A new mathematical model towards the integration of cell formation with operator assignment and inter-cell layout problems in a dynamic environment. *Applied Mathematical Modelling*. 38, 1237-1254

Balakrishnan, J., & Cheng, C.H. (2005). Dynamic cellular manufacturing under multiperiod planning horizons. *Journal of Manufacturing Technology Management, 16*(5), 516-530.

Baykasoglu, A., Gindy, NNZ. , & Cobb, RC . (2001). Capability based formulation and solution of multiple objective cell formation problems using simulated annealing. *Integr Manuf Syst 12*(4), 258-274.

Bazargan-Lari, M., Kaebernick, H., & Harraf, A. (2000). Cell formation and layout designs in a cellular manufacturing environment a case study. *International Journal of Production Research, 38*(7), 1689-1709.

Bazargan-Lari, Massoud. (1999). Layout designs in cellular manufacturing. *European Journal of Operational Research, 112*(2), 258-272.

Bussieck, MichaelR, & Meeraus, Alex. (2004). General Algebraic Modeling System (GAMS). In J. Kallrath (Ed.), *Modeling Languages in Mathematical Optimization* . 88, pp. 137-157): Springer US.

Chan, Felix T. S., Lau, K. W., Chan, P. L. Y., & Choy, K. L. (2006). Two-stage approach for machine-part grouping and cell layout problems. *Robotics and Computer-Integrated Manufacturing, 22*(3), 217-238.

Chang, C., Wu, T., & Wu, C. (2013). An efficient approach to determine cell formation, cell layout and intracellular machine sequence in cellular manufacturing systems. *Computers & Industrial Engineering, 66*(2), 438-450.

Chang, J., Zhong, Y., & Han, Z. (2004). Small cell layouts based on accounting product demand and operating sequences. *Tsinghua Science and Technology, 9*(5), 589-595.

Chung, S., Wu, T., & Chang, C. (2011). An efficient tabu search algorithm to the cell formation problem with alternative routings and machine reliability considerations. *Computers & Industrial Engineering, 60*(1), 7-15.

Colledani, M., Tolio, T., Fischer, A., Lung, B., Lanza, G., Schmitt, R., & Vancza, J. (2014), Design and management of manufacturing systems for production quality. *CIRP Annals- Mnufacturing Technology, 63 (2),773-796.*

Das, K. (2008). A comparative study of exponential distribution vs Weibull distribution in machine reliability analysis in a CMS design. *Computers & Industrial Engineering, 54*(1), 12-33.

Das, K. , Lashkari, RS., & Sengupta, S. . (2006). Reliability considerations in the design of cellular manufacturing systems: a simulated annealing based approach. *International Journal of Quality Reliability Manage 23*(7), 880-904.

Das, K., Lashkari, R. S., & Sengupta, S. (2007a). Machine reliability and preventive maintenance planning for cellular manufacturing systems. *European Journal of Operational Research, 183*(1), 162-180.

Das, K., Lashkari, R. S., & Sengupta, S. (2007b). Reliability consideration in the design and analysis of cellular manufacturing systems. *International Journal of Production Economics, 105*(1), 243-262.

Deep, K., Singh, P. (2015). Design of robust cellular manufactruing system for dynamic part population considering multiple processing routes using genetic algorithm. *Journal of Manufacturing Systems*. 35, 155-163.

Defersha, F, & Chen, M. (2006). A comprehensive mathematical model for the design of cellular manufacturing systems. *International Journal of Production Economics, 103*, 767-783.

Defersha, F.M., & Chen, M. (2008). A linear programming embedded genetic algorithm for an integrated cell formation and lot sizing considering product quality. *European Journal of Operation Research 187*, 46–69.

Deljoo, V., Mirzapour Al-e-hashem, S. M. J., Deljoo, F., & Aryanezhad, M. B. (2010). Using genetic algorithm to solve dynamic cell formation problem. *Applied Mathematical Modelling, 34*(4), 1078-1092.

Diallo, M., Pierreval, H, & Quilliot, A. (2001). Manufacturing cells design with flexible routing capability in presence of unreliable machines. *International Journal of Production Economics, 74*(1–3), 175-182.

Dixit, A.R., & Mishra, P.K. (2010). Ex-CLASS: Extended cell formation and layout selection considering production parameters with sequence data. *International Journal of Production Development, 10*(1-3), 180-200.

Drira, A, Pierreval, H, & Hajri-Gabouj, S. (2007). Facility layout problems: A survey. *Annual Reviews in Control, 31*(2), 255-267.

Dunker, T., Radons, G., & Westkämper, E. (2005). Combining evolutionary computation and dynamic programming for solving a dynamic facility layout problem. *European Journal of Operational Research, 165*(1), 55-69.

Fardis, F., Zandi, A., & Ghezavati, V. (2013). Stochastic extension of cellular manufacturing systems: a queuing-based analysis. *International Journal of Industrial Engineering* 9-20.

Florios, K., Mavrotas, G., & Diakoulaki, D. (2010). Solving multiobjective, multiconstraint knapsack problems using mathematical programming and evolutionary algorithms. *European Journal of Operational Research*, 23(1), 14-21.

Geletu, Abebe. (2008). GAMS - Modeling and Solving Optimization Problems. Institute of Mathematics, Department of Operations Research & Stochastic: Ilmenau University of Technology.

Ghotboddini, M. M., Rabbani, M., & Rahimian, H. (2011). A comprehensive dynamic cell formation design: Benders' decomposition approach. *Expert Systems with Applications, 38*(3), 2478-2488.

Hakobyan, A. (2008). *Heuristics for the dynamic facility layout problem with unequal area departments.* (Doctor of Philosophy), West Virginia University.

Hawang, C.L., Masud, A. Multiple Objective Decision Making. Methods and Applications: A State of the Art Survey, Lecture Notes in Economics and Mathematical Systems, vol. 164, Springer-Verlag, Berlin, 1979.

Herague, S.S. (1989). Knowlede based approach to machine cell layout. *Computer and Industrial Engineering, 17*(1-4), 37-42.

Hernandez Gress, ES., Mora-Vargas, J., Herrera del Canto, LE., & Diaz-Santillan, E. A. (2011). Genetic algorithm for optimal unequal-area block layout design. *International Journal of Production Research, 49*(8), 1-13.

Hsu, C. T., & Su, C. M. (1998). Multi-objective machine-part cell formation through parallel simulated annealing. *International Journal of Production Research, 36*(8), 2185-2207.

Iranshahi, M.B., Shahandeh, A., & Husseini, S.M.M. (2005). A Simulated annealing solving for facility layout problems under variable demand in cellular manufacturing system. *Amirkabir Journal of Science & Technology, 16*(61B), 1-11.

Jajodia, S., Minis, I., Harhalakis, G., & Proth, J. (1992). CLASS: Computerized LAyout Solutions using Simulated annealing. *International Journal of Production Research, 30*(1), 95-108.

Jeon, G, Leep, H. R, & Parsei, H. R. (1998). Cellular manufacturing system based on new similarity coefficient which considers alternative routes during machine failure. *Computers and Industrial Engineering, 34*(1), 21-36.

Jolai, F., Taghipour, M., & Javadi, B. (2011). A Variable neighborhood binary particle swarm algorithm for cell layout problem. *International Journal of Advanced Manufacturing Technology, 55*(1-4), 327-339.

Khaksar-Haghani, F., Kia, R., Mahdavi, I., Javadian, N., & Kazemi, M. (2011). Multi-floor layout design of cellular manufacturing systems. *International Journal of Management Science and Engineering Management, 6*(5), 356-365.

Kia, R., Baboli, A., Javadian, N., Tavakkoli-Moghaddam, R., Kazemi, M., & Khorrami, J. (2012a). Solving a group layout design model of a dynamic cellular manufacturing system with alternative process routings, lot splitting and flexible reconfiguration by simulated annealing. *Computers & Operations Research, 39*(11), 2642-2658.

Kia, R., khorrami, J., Mahdavi, I., Javadian, N., & Kazemi, M. (2012b). Designing an intra-cell layout model in dynamic cellular manufacturing systems with unequal-area facilities. *International Journal of Management Science and Engineering Management, 7*(1), 10-19.

Kia, R., Khaksar-Haghani, F., Javadian, N., & Tavakkoli-Moghadam, R., (2014). Solving a multi-floor layout design model of a dynamic cellular manufacturing system by an efficient genetic algorithm. *Journal of Manufacturing Systems,* 33, 218-232.

Kia, R., Paydar, M.M., Jondabeh, M.A, Javadian, N., & Nejatbakhsh, Y. (2011). A fuzzy linear programming approach to layout design of dynamic cellular manufacturing systems with route selection and cell reconfiguration. *International Journal of Management Science and Engineering Management, 6*(3), 219-230.

Kioon, S.A., Bulgak, A.A., & Bektas, T. (2009). Integrated cellular manufacturing system design with production planning and dynamic system reconfiguration. *European Journal of Operation Research, 192*, 414-428.

Kuroda, M., & Tomita, T. (2005). Robust design of a cellular-line production system with unreliable facilities. *Computers & Industrial Engineering, 48*(3), 537-551.

Lee, M., Kazerooni, M., Luong, H. S., & Abhary, Kazem. (1997). A genetic algorithm based cell design considering alternative routing. *Computer Integrated Manufacturing Systems, 10*(2), 93-108.

Li, H. , & Love, P.E.D. (2000). Genetic search for solving construction site-level unequal-area facility layout problems. . *Automation in Construction, 9*(2), 217-226.

Logendran, R, & Talkington, D. (1997). Analysis of cellular and functional manufacturing system in the presence of machine breakdown. *International Journal of Production Economics, 53*(3), 239-256.

Lokesh, K., & Jain, P.K. (2010). Dynamic cellular manufacturing systems design -A comprehensive model & HHGA. *Advances in Production Engineeing & Management, 5*(3), 151-162.

Lopez, R., Ritto, T.G., Sampaio, R.,Eduardo, J., & Cursi, S. (2013). A new multiobjective optimization algorithm for nonconvex pareto fronts and objective functions. Asociación Argentina de Mecánica Computacional.669-679.

Mahdavi, I., Alaei, A., Paydar, MM., & Solimanpour, M. (2010). Designing a mathematical model for dynamic cellular manufacturing systems considering production planning and worker assignment. *Computer Math Application, 60*(4), 1014-1025.

Mahdavi, I., Shirazi, B., & Paydar, M. (2008). A flow matrix-based heuristic algorithm for cell formation and layout design in cellular manufacturing system. *The International Journal of Advanced Manufacturing Technology, 39*(9-10), 943-953.

Mahdavi, I., Teymourian, E., Tahami Baher, N., & Kayvanfar, V. (2013). An integrated model for solving cell formation and cell layout prblem simultaneously considering new situations. *Journal of Manufacturing Systems*.

Mahdavi, I., Aalaei, A., Paydar, M.i, & Solimanpur, M. (2012). A new mathematical model for integrating all incidence matrices in multi-dimensional cellular manufacturing system. *Journal of Manufacturing Systems, 31*(2), 214-223.

Mahdavi, I., & Mahadevan, B. (2008). CLASS: An algorithm for cellular manufacturing system and layout design using sequence data. *Robotics and Computer-Integrated Manufacturing, 24*(3), 488-497.

Majazi Dalfard, V. (2013). New mathematical model for problem of dynamic cell formation based on number and average length of intra and intercellular movements. *Applied Mathematical Modelling, 37*(4), 1884-1896.

Mak, KL., & Wang, XX. (2002). Production scheduling and cell formation for virtual cellular manufacturing system. *International Journal of Advance Manufturing Technology, 20*(2), 144-152.

McKendall Jr, R., & Hakobyan, A. (2010). Heuristics for the dynamic facility layout problem with unequal-area departments. *European Journal of Operational Research, 201*(1), 171-182.

McKinney, D.C., & Savitsky, A. (2006). Basic Optimization Models for Water and energy management. Center for Research in Water Resources: University of Texas at Austin.

Mohammadi, M., & Foroghi, K. (2014). A novel approach for considering layout problem in cellular manufacturing systems with alternative processing routings and subcontracting approach. *Applied Mathematical Modelling,* 38, 3624-3640.

Mungwattana, A. (2000). *Design of cellular manufacturing system for dynamic and uncertain production requirements with presence of routing flexibility.* (PhD thesis).

Nair, G. Jayakrishnan, & Narendran, T. T. (1998). CASE: A clustering algorithm for cell formation with sequence data. *International Journal of Production Research, 36*(1), 157-180.

Negahban,A, & Smith, J. (2014). Simulation for manufacturing sysytem design and operation: Litertaure review and analysis. *Journal of Mnaufacturing Systems,* 33, 241-261.

Niaki, V., Mehdizadeh,E., Tavakkoli-Moghadam, R. (2011).A mathematical model for dynamic cellular manufacturing systems production planning and labor assignment, POMS 23rd Annual Conference, Chicago, Illinois, USA.

Nouri, H., Hong, T., Development of bactria foraging otimization algorithm for cell formation in cellular manufacturing system considering cell load variations.

Nsakanda, A., Diaby, M., & Price, W. . (2006). Hybrid genetic approach for solving large-scale capacitated cell formation problems with multiple routings. *European Journal of Operational Research, 171*, 1051-1070.

Papaioannou, G., & Wilson, J.M. (2010). The evoultion of cell formation problem methodologies based on recent studies (1997-2008): Review and directions for future resaerch. *European Journal of Operational Research, 206*(3), 509-521.

Paydar, M., Mahdavi, I., Sharafuddin, I., & Solimanpur, M. (2010). Applying simulated annealing for designing cellular manufacturing system using MDmTSP. *Computer and Industrial Engineering, 59*(4), 929-936.

Rafiee, K., Rabbani, M., Rafiei, H., & Rahimi-Vahed, A. (2011). A new approach towards integrated cell formation and inventory lot sizing in an unreliable cellular manufacturing system. *Applied Mathematical Modelling, 35*(4), 1810-1819.

Ramkumar, A.S., Ponnambalam, S.G., & Jawahar, N. (2009). A new iterated fast local search heuristic for solving QAP formulation in facility layout design *Robotics and Computer-Integrated Manufacturing, 25*(3), 620-629.

Saeidi, S., Solimanpur, M., Mahdavi, I., & Javadian, N. (2014). A multi-objective genetic algorithm for solving cell formation problem using a fuzzy goal programming approach. *The International Journal of Advanced Manufacturing Technology, 70*(9-12), 1635-1652.

Safaei, N. , & Tavakkoli-Moghaddam, R. (2009). Integrated multi-period cell formation and subcontracting production planning in dynamic cellular manufacturing. *International Journal of Production Economics*, 120 (2), 3-1-314.

Safaei, N., Saidi-Mehrabad, M., & Jabal-Ameli, M. S. (2008). A hybrid simulated annealing for solving an extended model of dynamic cellular manufacturing system. *European Journal of Operational Research, 185*(2), 563-592.

Saidi-Mehrabad, M. , & Safaei, N. A. (2007). New model of dynamic cell formation by a neural approach. *International Journal of Advanced Manufacturing Technology, 33*(9-10), 1001-1009.

Samarghandi, H., Taabayan, P., & Behroozi, M. (2013). Metaheuristic for fuzzy dynamic facility layout problem with unequal area constraints and closness ratings. *International Journal of Advanced Manufacturing Technology, 67*, 2701-2715.

Sangwan, K. S., & Kodali, R. (2009). FUGEN: A tool for the design of layouts for cellular manufacturing systems. *International Journal of Services and Operations Mangement, 5*(5), 595-616.

Sangwan, K.S., & Kodali, R. (2011). An integrated hybrid model for the integrated design of cellular manufacturing systems. *International Journal of Services and Operations Management, 9*(2), 202-226.

Sarker, B.R. & Xu, Y. (1998). Operation sequences-based cell formation methods: A critical survey. *Production Planning and Control., 9*(8), 771-783.

Sarker, B.R. & Xu, Y.I. (2000). Designing multi-product lines:Job routing in cellular manufacturing systems. *IIE Transactions, 32*(3), 219-235.

Savsar, M. (2000). Reliability analysis of a flexible manufacturing cell. *Reliability Engineering & System Safety, 67*(2), 147-152.

Saxena, L., & Jain, P. (2011). Dynamic cellular manufacturing systems design—a comprehensive model. *International Journal of Advanced Manufacturing Technology 53*(1), 11-34.

Schaller, J. (2007). Designing and redesigning cellular manufacturing systems to handle demand changes. *Computers & Industrial Engineering, 53*(3), 478-490.

See, P., & Wong, K. (2008). Application of ant colony optimisation algorithms in solving facility layout problems formulated as quadratic assignment problems: a review. *International Journal of Industrial and Systems Engineering, 3*(6), 644-672.

Seifoddini, S, & Djassemi, M (2001). The effect of reliability consideration on the application of quality index. *Computers and Industrial Engineering, 40*(1-2), 65-77.

Singh, S. P., & Sharma, R. R. K. (2006). A review of different approaches to the facility layout problems. *The International Journal of Advanced Manufacturing Technology, 30*(5-6), 425-433.

Sofianopoulou, S. (1999). Manufacturing cells design with alternative process plans and/or replicate machines. *International Journal of Production Research, 37*(3), 707-720.

Solimanpur, M., Vrat, P, & Shankar, R. (2004). Ant colony optimization algorithm to the inter-cell layout problem in cellular manufacturing. *European Journal of Operational Research, 157*(3), 592-606.

Tavakkoli-Moghaddam, R, Javadian, N, Javadi, B, & Safaei, N. (2007). Design of a facility layout problem in cellular manufacturing systems with stochastic demands. *Applied Mathematics and Computation, 184*(2), 721-728.

Tavakkoli-Moghaddam, R., Aryanezhad, M. B., Safaei, N., & Azaron, A. (2005). Solving a dynamic cell formation problem using metaheuristics. *Applied Mathematics and Computation, 170*(2), 761-780.

Tavakkoli-Moghaddam, R., Javadian, N., Khorrami, A. , & Gholipor-Kanani, Y. (2010). Design of a scatter search method for a novel multi-criteria group scheduling problem in a cellular manufacturing system. *Expert Syst Appl, 37*(3), 2661-2669.

Tavakkoli-Moghaddam, R., Safaei, N., & Sassani, F. (2008). A new solution for a dynamic cell formation problem with alternative routing and machine costs using simulated annealing. *Journal of Operational Research Society, 59*(4), 443-454.

Tompkins, J., White, J. and Bozer, Y. (2010). *Facilities Planning*.

Vakharia, AJ., & Chang, YL. (1997). Cell formation in group technology: a combinatorial search approach. *International Journal of Production resaerch 35*(2), 185-207.

Wang, T., Lin, H., & Wu, K. (1998). An improved simulated annealing for facility layout problems in cellular manufacturing system. *Computers & Industrial Engineering, 34*(2), 309-319.

Wang, T. Y., Wu, K. B., & Liu, Y. W. (2001). A simulated annealing algorithm for facility layout problems under variable demand in Cellular Manufacturing Systems. *Computers in Industry, 46*(2), 181-188.

Wicks, EM., & Reasor, RJ. (1999). Designing cellular manufacturing systems with dynamic part populations. *Inst Indust Eng 31*(1), 11-20.

Won, Y.D. (1997). A Linear programming approach to linear machine layout problem. *Industrial Mathematics, 47*(2), 59-68.

Wu, X., Chu, C., Wang, Y., & Yan, W. (2007a). A genetic algorithm for cellular manufacturing design and layout. *European Journal of Operational Research, 181*(1), 156-167.

Wu, X., Chu, C., Wang, Y., & Yue, D. (2007b). Genetic algorithms for integrating cell formation with machine layout and scheduling. *Computers & Industrial Engineering, 53*(2), 277-289.

Yazhau, J., Molin, W., & Zhixin, J. (1995). Probability failures of machining center failures. *Reliability Engineering and System Safety, 50*(1), 121-125.

Yin, Y. & Yasuda, K. (2005). Similarity coefficient methods applied to the cell formation problem: A comparative investigation. *Computeres and Industrail Engineering, 48*(3), 471-489.

Yin, Y. & Yasuda, K. (2006). Similarity coeffiecient methods applied to the cell formation problem: A taxonomy and review. *International Journal of Production Economics, 101*(2), 329-352.

Yin, Y., & Yasuda, K. (2002). Manufacturing cells' design in consideration of various production factors. *International Journal of Production Research, 40*(4), 885-906.

Zhu, H., & Ye, W. (2009). Application of particle swarm algorithm based on simulated annealing in variable cellular facility layout problems. *Zhongguo Jixie Gongcheng/ china Mechanical Engineering, 20*(2), 181.