UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF CONCENTRIC SEMI-AUTOMATED MANIPULATOR FOR ASSEMBLY PROCESS

TAN KAI JIN

DEVELOPMENT OF CONCENTRIC SEMI-AUTOMATED MANIPULATOR FOR ASSEMBLY PROCESS

By

TAN KAI JIN

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

August 2018

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

DEVELOPMENT OF CONCENTRIC SEMI-AUTOMATED MANIPULATOR FOR ASSEMBLY PROCESS

By

TAN KAI JIN

August 2018

Chair : Tang Sai Hong, PhD
Faculty : Engineering

This thesis is about the design, modelling and comparison studies on the concentric loading design used in a pneumatic manipulator. Pneumatic manipulator is one of the material handling system widely used in industries. Applications of pneumatic manipulator enable flexible facilities reconfiguration and tool sharing among various products. Existing design requires many components due to the mechanism design concept, which makes the size of the mechanism bulky and heavy. Several designs of powered assisted manipulator were studied. The working principle of the pneumatic manipulator complies with the equilibrium of the moment. Force to balance the lifted weight must be maintained constantly. Piston rod of the cylinder to apply force must be guided precisely in vertical and the relevant parts of the guide connected must be flexible. Concentric loading was designed with different mechanism concept required less components and fabrication parts but enabled the force from the cylinder to balance the working load and was applied vertically and constantly on a specified spot. Two nos. of ball rollers replaced 8 nos. of existing ball bearing side roller mechanism to reduce the cost and maintain the same functionalities. The integration of different parts into one part was studied and applied. Side plates were used as the guide for the side roller mechanism and as a support to the mechanism body. Reduction of purchasing components and fabrication parts aim to reduce the maintenance cost and components inventory cost in a long run. Since some of the concepts of the mechanism were changed, some ball bearing rollers and fabrication parts to cover existing mechanism were not further required. An actual model of a pneumatic manipulator in industry which has a combination of a few manipulator design characteristics and available in the market was used as a case study. Comparison studies between this selected model of the pneumatic manipulator and a concentric loading design pneumatic manipulator were carried out. Simulation on the concentric loading mechanism was done to avoid potential problem before the prototype was built.

Overall, the results showed a 28% reduction in weight of the manipulator mechanism body, 8.9% to 32% reduction of size in width, length and height of the manipulator mechanism body and a 39% reduction in cost of the manipulator mechanism body. Fabrication parts of manipulator mechanism body were reduced from 48 pieces to 20 pieces. A prototype was built to test on the functionality of the concentric loading mechanism. Detail drawings of the prototype were then created and send for fabrication. Standard components were purchased. A pneumatic controlled circuit was developed to operate the prototype. Several observations on the concentric loading mechanism were done during the prototype mechanism testing. The working condition of the concentric loading mechanism was recorded and discussed. It showed that the mechanism of the prototype working well and proved that concentric loading mechanism meet the requirement of moment concept and able to lift and balance the lifted load. The transition of the balancing mechanism was smooth. Other observations were discussed for future studies.

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

PEMBANGUNAN DAYA PEMUSATAN SEMI-AUTOMASI MANIPULATOR UNTUK PROSES PEMASANGAN

Oleh

TAN KAI JIN

Ogos 2018

Pengerusi : Tang Sai Hong, PhD
Fakulti : Kejuruteraan

Tesis ini adalah mengenai reka bentuk, pemodelan dan kajian perbandingan mengenai reka bentuk daya pemusatan yang digunakan dalam manipulator pneumatik. Manipulator pneumatik adalah salah satu sistem pengurusan bahan yang digunakan secara meluas dalam industri. Aplikasi manipulator pneumatik membolehkan konfigurasi kemudahan dan perkongsian alat yang fleksibel di antara produk berbeza. Reka bentuk manipulator yang sedia ada memerlukan banyak komponen kerana konsep reka bentuk mekanisma menjadikan saiz mekanisma manipulator besar dan berat. Beberapa jenis reka bentuk manipulator berkuasa telah dikaji. Prinsip kerja manipulator pneumatik mesti mematuhi konsep keseimbangan momen. Daya untuk mengimbangi berat bahan yang diangkat mesti dikekalkan secara berterusan. Omboh piston silinder untuk memindah daya mesti dibimbing dengan tepat secara menegak dan bahagian panduan yang berkaitan mestilah fleksibel. Daya pemusatan adalah konsep mekanisma yang berbeza dimana ianya memerlukan kurang komponen dan bahagian fabrikasi tetapi membolehkan daya dari silinder kekal secara menegak dan sentiasa menuju di pusat titik tertentu untuk mengimbangi beban kerja. Dua biji bola penggelek digunakan untuk menggantikan lapan biji bebola mekanisma yang sedia ada untuk mengurangkan kos dan mengekalkan fungsi yang sama. Integrasi bahagian-bahagian yang berlainan ke dalam satu bahagian dikaji dan diterapkan, plat sisi digunakan sebagai panduan untuk mekanisma penggelek sisi dan sebagai sokongan kepada badan mekanisma. Pengurangan pembelian komponen dan bahagian fabrikasi bertujuan untuk mengurangkan kos penyelenggaraan dan kos inventori komponen dalam jangka panjang. Memandangkan beberapa konsep mekanisma telah berubah, beberapa penggelek galas bebola dan bahagian fabrikasi untuk menampung mekanisma sedia ada tidak diperlukan lagi. Model sebenar manipulator pneumatik dalam industri yang mempunyai kombinasi beberapa ciri reka bentuk manipulator dan sedia ada di pasaran digunakan sebagai kajian kes. Kajian perbandingan antara model manipulator pneumatik ini dan manipulator pneumatik reka bentuk daya pemusatan telah dijalankan. Simulasi pada

mekanisma daya pemusatan telah dilakukan untuk mengelakkan masalah yang mungkin berlaku sebelum prototaip dibina.

Secara keseluruhannya, hasil kajian menunjukkan pengurangan sebanyak 29% keatas berat badan mekanisma manipulator, 8.9% hingga 32% pengurangan saiz untuk lebar, panjang dan ketinggian badan mekanisma manipulator dan 39% pengurangan kos untuk badan mekanisma manipulator. Bahagian fabrikasi mekanisma manipulator dikurangkan dari 48 keping hingga 20 keping. Sebuah prototaip telah dibina untuk menguji fungsi mekanisma daya pemusatan. Lukisan terperinci prototaip pembuatan telah dibuat dan dihantar untuk fabrikasi. Komponen standard manipulator yang diperlukan telah dibeli untuk pemasangan. Litar kawalan pneumatik telah dibangunkan untuk mengendalikan prototaip. Beberapa pemerhatian mengenai mekanisma daya pemusatan telah dilakukan semasa ujian ke atas mekanisma prototaip. Keadaan mekanisma daya pemusatan semasa ujian dijalankan telah direkodkan dan dibincangkan. Ia menunjukkan bahawa mekanisma prototaip berfungsi dengan baik dan membuktikan bahawa mekanisma daya pemusatan memenuhi keperluan konsep keseimbangan momen dan dapat mengangkat dan mengimbangi beban yang diangkat. Peralihan mekanisma pengimbangan adalah lancar. Kajian masa depan untuk lain-lain pemerhatian telah dibincangkan.

ACKNOWLEDGEMENTS

Firstly, I would like to express my sincere gratitude to my supervisor Assoc. Prof. Dr. Tan Sai Hong for the continuous support of my Ph.D study and related research, for his patience, motivation, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I appreciate all his contribution of time, ideas and guidance to make my Ph.D. experience productive and stimulating.

Besides my supervisor, I would like to thank the rest of my thesis committee: Assoc. Prof. Dr. Azmah Hanim bt. Mohamed Ariff, and Assoc. Prof. Dr Ir. B.T Hang Tuah b. Baharudin for their insightful comments and encouragement, which incented me to widen my research from various perspectives.

Last but not the least, I would like to thank my family: my parents and to my wife for supporting me spiritually, cheering me up and stood by me.

I certify that a Thesis Examination Committee has met on 26 February 2018 to conduct the final examination of Tan Kai Jin on his thesis entitled " Development of concentric semi-automated manipulator for assembly process" 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:

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

Mohd Khairol Anuar bin Mohd Ariffin, PhD
Professor Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Nuraini Abdul Aziz, PhD
Associate Professor Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

M. S. J. Hashmi, PhD
Professor
School of Mechanical & Manufacturing
Dublin City University
Ireland
(External Examiner)

____
RUSLI HAJI ABDULLAH, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 31 October 2018

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

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

Azmah Hanim bt. Mohamed Ariff, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

B.T Hang Tuah b. Baharudin, PhD
Associate Professor Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Member)

____
ROBIAH BINTI YUNUS, 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: 2018.12.08

Name and Matric No.: TAN KAI JIN (GS 32213)

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: ______________________________
Name of Chairman of Supervisory Committee: Tang Sai Hong

Signature: ______________________________
Name of Member of Supervisory Committee: Azmah Hanim bt. Mohamed Ariff

Signature: ______________________________
Name of Member of Supervisory Committee: B.T Hang Tuah b. Baharudin

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

SCARA	selective compliance assembly robot arm
CAD	computer-aided design
FEA	finite element analysis

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

In the next 10 or 20 years, there are five challenges that most industry will face especially those with low volume but high variety of product which are globalization, product differentiation, product development, supply chain restructuring and marketing & distribution (Booz and Hamilton, 1999).

The changes of global, skilled labour, technologies (Sachin and Chaudhari, 2010), individualization etc. challenge the manufacturers to meet the market expectations (Andreas et al., 2004). Higher demands of customer preference, implement of new act on the safety standard, environmental awareness (Stefan et al., 2008), competitiveness among competitors etc. are as a result of the existing automation facilities which may not flexible, cost effective or to be fully relied on (Nagabhushana, 2008).

According to the study by Spencer Stuart's consulting firm, maintaining a flexible production system could position an organization to respond quickly to shifts in global demand (Simonei et al., 2006). Flexible automation with minimal life cycle cost of manufacturing (Martin et al., 1999) increases variant of product and reduce time to market (Gudrun, 2010). Flexible assembly line becomes a key success factor for OEM to react quickly to customized customer demands (Andreas et al., 2004).

Robots arms is one of the flexible solution but classification is only valid for large companies as reprogrammed and reconfigured robots are often relied on and performed by specialized technicians and automation experts (Germano, et al., 2012). The use of industrial robotics in the manufacturing industry enhance process efficiency (Behzad et al., 2016). More and more robots arm applications are implemented in manufacturing plant. However, investing in industrial robots always involved a huge amount of cost and skilled worker training (Martin et al., 2005). The percentages of adopters and the automation intensity ratios are much higher in the group of high technology manufacturing industries (Angel, 1995). The lifecycle of a product is getting shorter, rapid changes of model in order to compete in the market cause the changes of customer preferences (Neil, 2011). Thus, investing in industrial robot system may not be a cost effective solution.

Machines possess high accuracy, consistency in job repeatability but limited intelligence mental capability. Human consistencies are low but human possess high degree of intelligence and are capable to solve sudden problem (Craig, 1993). Besides, human can be affected by hazardous environment and subjected to fatigue (Dianne et al., 2006).

The reasons for high degree of manual assembly operations which can be found in industries are high demands on the availability, flexibility of assembly systems and complex assembly operations (Feldmann et al., 1999). There are still many jobs which involves visual inspection and repetitive jobs where manual assembly is more preferred. The advantages are hand tools required is simple, less costly, and has higher toleration on the variation of part dimensions (Hugo et al., 2010).

Automation becomes a more expensive proposition as the volume of the products produced decreases and increase in the product variety (Vijay et al., 2006). A balanced combination of manual and automated processes as shown in Figure 1.1 is more practical to increase flexibility, reduces manufacturing costs, provides high quality and throughout (Igor and Oliver, 2008). One of the design processes in successful flexible manufacturing system implementation is material handling system design (Michael et al., 1993). Material handling system plays an important role in enhancing the flexibility of manufacturing system (Behzad et al., 2016). Powered assisted manipulator combines concept of amplifying operator’s capacity of lifting load and prevent operator suffering from accidents and injuries (Pablo Gonzalez et al., 2010) due to repetitive job while maintaining the flexibility of various product handling.

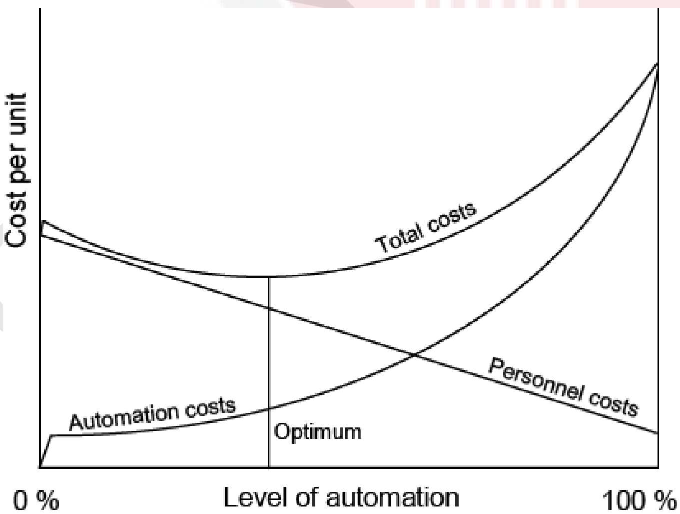

Figure 1.1: Graph of Cost Versus Level of Automation
(Source: Igor and Oliver, 2008)

1.2 Problem Statements

Pneumatic manipulators have been widely used in industry nowadays to assist human in handling and transferring products. It helps reduce manpower for moving products and material; handling of heavy products without requiring strong physical and working in an ergonomic way for repeated task.

Due to the mechanism design concept of pneumatic manipulator, the existing designs of the pneumatic manipulator mechanism require components for the mechanism to be working which may be unnecessary. An integral construction of one part is preferable (Wolf gang and Karl-H., 1994). By consolidating few parts of an existing assembly into one part eliminates the assembly time and reduce the inventory costs (Thompson et al., 2016). The design of load engaging mechanism coupling applied in electronic air regulation controlled pantographic linkage manipulator by Cary and Stephen (1995) was complex whilst Bronislav Vatel (1993) had a relatively simple design. However, more than double in space is required in vertical for the cylinder for a specified stroke and higher stiffness beam was required for the structure for the cylinder's weight to sit on the end of the manipulator arm.

The design should be made to be mechanism parts integrated with support to itself to reduce support structure build up (Hällgrena et al., 2016). An integrated product design aims for potential lightweight design in realized product (Ross et al., 2016). These additional components lead to the design of the manipulator body large space occupied and heavy. A reduction of 54% in parts count shows a reduction of 22% in weight in general (Robert, 2012).

These indirectly increase the cost and time of manufacturing and difficulties of assembly. When parts count increase, more operations, fabrication and assembly steps are involved (Selvaraj et al., 2009).

Maintenance plays an important role in keeping product availability, reliability and quality at appropriate level (Mahmood and Stefanka, 2013). Design and manufacturing decisions must be made by considering the costs of operation and support for the system (Amit and Ming, 1998). Unnecessary moving parts and expensive spare parts should be avoided (Vaneker and Diapen, 2016). Pablo Gonzalez de Santos (2010) used AC motors controlled joint actuator, PID controlling boards; PCI bus based I/O boards and controllers in manipulator controlled instead of pneumatic which resulted in higher development cost. In long term, the cost of maintenance will increase as well due to high number of parts and components to be maintained and availability of spare parts inventory (Helio Fiori and Katia, 2006).

In conclusion, the mechanisms of most of the existing manipulator are too complex and consist of many parts and components. There is potential to reduce approximately up to 54% of this parts count that will further lead to optimize the layout space of the manipulator mechanism body. Reduction of standard purchased components further reduce the manufacturing cost of the manipulator and the inventory cost to keep these spare parts. The aims of the end study are to reduce 22% of the mechanism body weight, average of 20% to 30% reduce in size of the mechanism body and 54% reduce of the components and parts of the manipulator mechanism body.

1.3 Objectives

The aim of this project is to improve market available manipulator by developing a concentric loading semi-automated manipulator system for assembly process, simulate the model, build and test a scaled down prototype of the pneumatic manipulator system. The aim can be achieved by fulfilling few objectives below to reduce the cost, size and weight of the pneumatic manipulator:

(1.) To design a force transmission mechanism applied in pneumatic manipulator,
(2.) To analyse the force transmission mechanism of manipulator,
(3.) To fabricate and build a scaled down prototype, and
(4.) To verify the lifting mechanism using the prototype.

1.4 Scopes

Design and develop semi-automated pneumatic manipulator for tools handling, lifting and transferring in manufacturing industry. The manipulator should be operated at the limit of maximum 60kg lifting force under minimum 0.5MPa to maximum of 1.0MPa of pneumatic air pressure supply. The horizontal reach from the centre of the manipulator column to end effector should be approximately 2600mm and the maximum lifting stroke is at 1200mm (Karmegam et al., 2011).

The design of the manipulator mechanism focuses on the alternative mechanism design with fewer components to replace the existing mechanism. Feasibility study was carried out on the layout of the new mechanism design in order to minimize the mechanism body. Functional parts integration study was carried out in order to achieve reduction in manufacturing cost, assembly time and procedure by reducing the number of parts in the existing mechanism. Identified and reduce purchased of components in existing mechanism to reduce the maintenance cost and components inventory in future.

Develop a scaled down prototype of pneumatic manipulator for physical lifting and operation testing. The prototype structure was designed to carry a maximum of 6kg lifting. Most of the parts were formed by standard sizes of plate, sheet metal, round bar and structural steel. Air pressure of a maximum 0.45 MPa was considered so that pneumatic system should not be able to perform lifting of more than 6kg work piece loading before manipulator structure come to a failure. A simple pneumatic circuit was designed in order to run the prototype for testing.

1.5 Thesis Organization

The first part of this chapter is the study of the background, history and applications of powered assisted manipulator. Chapter 2 introduces the types of manufacturing flexibility and various design of the powered assisted manipulator. Chapter 3 describes the steps of methodology. Chapter 4 explains the design of the concentric loading, development of the prototype and lifting test on the prototype. Chapter 5 discusses the results and summary.

REFERENCES

Abdi, M. R., and A. W. Labib. (2004). Grouping and selecting products: the design key of Reconfigurable Manufacturing Systems (RMSs). *International Journal of Production Research* 42(3): 521-546.

Adil, Baykasogˇlu. (2009). Quantifying machine flexibility. *International Journal of Production Research* 47(15): 4109-4123.

Agnetis, A., Pacifici, A., Rossi, F., Lucertini, M., Nicoletti, S., Nicolb, F., Oriolo, G., Pacciarelli, D., Pesaro, E. (1997). Scheduling of flexible flow lines in an automobile assembly plant. *European Journal of Operational Research* 97(2): 348-362.

Ahmed, M. Deif, and ElMaraghy Waguih. (2006). Effect of reconfiguration costs on planning for capacity scalability in reconfigurable manufacturing systems. *International Journal of Flexible Manufacturing System* 18: 225-238.

Akhmedov, M. A., Sh. B. Akhmedov, Sh. R. Ragimov, and L. I. Volchkevich. (1995). System for structural modeling of flexible production system. *Chemical and Petroleum Engineering* 31: 9-10.

Alessandro, Levizzari, Di Pardo Massimo, and Luchetti Tommaso. (2010). New generation of industrial manipulators based on ergonomic and haptic technologies. *Human Factors and Ergonomics in Manufacturing & Service Industries* 20(4): 335-338.

Alexopoulos, K., D. Mourtzis, N. Papakostas, and G. Chryssolouris. (2007). DESYMA: assessing flexibility for the lifecycle of manufacturing systems. *International Journal of Production Research* 45(7): 1683-1694.

Alexopoulos, K., N. Papakostas, D. Mourtzis, P. Gogos, and G. Chryssolouris. (2007). Quantifying the flexibility of a manufacturing system by applying the transfer function. *International Journal of Computer Integrated Manufacturing* 20(6): 538-547.

Amer, S. Al-Yahmadi, Abdo Jamil, and T.C. Hsia. (2007). Modeling and control of two manipulators handling a flexible object. Journal of the Franklin Institute 344: 349-361.

Amit, Monga, and J. Zuo Ming. (1998). Optimal system design considering maintenance and warranty. *Computers Operations Research* 25(9): 691-705.

Amitabh, S. Raturi, and P. Jack Eric. (2006). Creating a volume-flexible firm. *Business Horizons* 47(6): 69-78.

Andreas, Gallasch, Grafe Jörg, Hans René, and Neil Salter Brian. (2004). Challenges for the automotive industry in an on demand environment." IBM

Business Consulting Services. http://www-935.ibm.com/services/us/imc/pdf/g510-3956-challenges-automotive-on-demand.pdf. (Accessed on 21/03/2012)

Andrew, Lee-Mortimer. (2006). Improved product design as an alternative to outsourcing manufacture and assembly. *Assembly Automation* 26(2): 121-126.

Angel, Martinez Sanchez. (1995). Innovation cycles and flexible automation in manufacturing industries. *Technovation* 15(6): 351-362.

Antonio, K.W. Lau, C.M. Yam Richard, and Tang Esther. (2009). The complementarity of internal integration and product modularity: An empirical study of their interaction effect on competitive capabilities. *Journal of Engineering and Technology Management* 26: 305-326.

Anumba, C. J. (1996). Functional integration in CAD systems. *Advances in Engineering Software* 25: 103-109.

Arun, Mathew, and C.S.P. Rao. (2010). A CAD system for extraction of mating features in an assembly. *Assembly Automation* 30(2): 142-146.

Arzanpour, S., J. Fung, J.K. Mills, and W.L. Cleghorn. (2006). Flexible fixture design with applications to assembly of sheet metal automotive body parts. *Assembly Automation* 26(2): 143-153.

Atushi, Masuyama. (1995). Idea and Practice of Flexibile Manufacturing System of Toyota. *Manufacturing Research and Technology* 23:305-316.

Baines, T. S., D. E. Whitney, and C. Fine. (1999). Manufacturing technology sourcing practices in the USA. *International of Production Research* 37(4): 939-956.

Bardasz, T., and I. Zeid. (1991). Applying analogical problem solving to mechanical design. *Computer-Aided Design* 23(3): 202-212.

Beach, R., A. P. Muhlemann, D.H.R. Price, A. Paterson, and J.A. Sharp. (2000). A review of manufacturing flexibility. *European Journal of Operation Research* 122: 41-57.

Behzad Esmaeilian, Sara Behdadb, Ben Wang. (2016). The evolution and future of manufacturing: *A review. Journal of Manufacturing Systems* 39: 79-100.

Bi, Z. M., and W. J. Zhang. (2001). Flexible fixture design and automation: Review, issues and future directions. *International Journal of Production Research* 39(13): 2867-2894.

Bimal, Nepal, Monplaisir Leslie, and Famuyiwa Oluwafemi. (2012). Matching product architecture with supply chain design. *European Journal of Operational Research* 216: 312-325.

Birgitta, Mathisson-Oè Jmertz, and Matsm I. Johansson. (2000). Influences of process location on materials handling: Cases from the automotive industry. *International Journal of Logistics Research and Applications: A Leading Journal of Supply Chain Management* 3(1): 25-39.

Booz, Allen, and Hamilton. (1999). Challenges facing the global automotive industry. *Consumer and Engineered Products* 1(1): 1-8.

Bronislav, Vatel. (1993). Load balancing manipulator. United Stated of America Patent 5,296,644.

Cary, M. Pierson, and Stephen. L. Heston (1995). Load balancing arm. United States of America Patent 5,456,130.

Cemalettin, Kubat. (2004). The database management system for Sakarya. *Production Planning & Control* 15(7): 719-730.

Chang, An Yuan. (2012). Prioritising the types of manufacturing flexibility in an uncertain environment. International *Journal of Production Research* 50(8): 2133-2149.

Chang, Kuang-Hua, and Sung-Hwan Joo. (2006). Design parameterization and tool integration for CAD-based mechanism optimization. *Advances in Engineering Software* 37: 779-796.

Chang, Minho, Minsuk Ko, and Sang C. Park. (2011). Fixture modelling for an automotive assembly line. *International Journal of Production Research* 49(15): 4593-4604.

Chelpanov, I. B., and S. N. Kolpashnikov. (1983). Problems with the mechanics of industrial robot grippers. *Mechanism and Machine Theory* 18(4): 295-299.

Chen, Heping, George Zhang, Hui Zhang, and A. Fuhlbrigge Thomas. (2007). Integrated robotic system for high precision assembly in a semi-structured environment. *Assembly Automation* 27(3): 247-252.

Chen, Xiang, Shuming Gao, Youdong Yang, and Shuting Zhang. (2012). Multi-level assembly model for top-down design of mechanical products. *Computer-Aided Design* 44: 1033-1048.

Chi-Haur Wu, Yujun Xie, and Swee Mean Mok. (2007). Linking product design in CAD with assembly operations in CAM for virtual product assembly. *Assembly Automation* 27(4): 309-323.

Choi, Ho, and Koc Muammer. (2006). Design and feasibility tests of a flexible gripper based on inflatable rubber pockets. *International Journal of Machine Tools & Manufacture* 46: 1350-1361.

Choi, Wonjoon, and Yongil Lee. (2002). A dynamic part- feeding system for an automotive assembly line. *Computer and Industrial Engineering* 43: 123-134.

Christer, Johansson, Martensson Nils, and Sohlenius Gunnar. (1985). Grippers, tools and fixtures for flexible automated assembling. *Manufacturing Technology* 34(1): 21-24.

Christine, Connolly. (2009). Pneumatic modules for automatic applications. *Assembly Automation* 29(4): 321-325.

Corinne, M. Karuppan, and C. Ganster Daniel. (2004). The labor–machine dyad and its influence on mix flexibility. *Journal of Operations Management* 22: 533-556.

Craig, A. Will. (1993). Comparing human and machine performance for natural language information extraction: Results from the tipster text evaluation. http://acl.ldc.upenn.edu/X/X93/X93-1018.pdf. (Accessed on 26/03/2012)

Daniel, E. Whitney. (2006)/ The role of key characteristics in the design of mechanical assemblies. *Assembly Automation* 26(4): 315-322.

Darja Zunic Lojen. (1998). Simulation of sewing machine mechanism using program package ADAMS. *International of Clothing Science and Technology* 10(3/4): 219-225.

David, Francas, Lohndorf Nils, and StefanMinner. (2011). Machine and labor flexibility in manufacturing networks. *International Journal of Production Economics* 131: 165-174.

David, G. Ullman. (2010). Using The 6-3-5 Method as a Source of Ideas. In The Mechanical Design Process, pp. 190-191. International Edition: McGraw-Hill.

David, G. Ullman, Wood Stephen, and Craig David. (1990). The importance of drawing in the mechanical design process. *Computers & Graphics* 14(2): 263-274.

David, Sanders, Yong Chai Tan, Rogers Ian, and E. Tewkesbury Giles. (2009). An expert system for automatic design-for-assembly. *Assembly Automation* 29(4): 378-388.

Dean, M. England, Rahimifard Shahin, and T. Newman Stephen. (2005). Bridging the gap between volume and variety oriented production systems for the automotive industry. *International Journal of Computer Integrated Manufacturing* 18(5): 408-417.

Delbressine, F.L.M., and A.C.H. Van der Wolf. (1990). Integrating design and manufacturing. *Manufacturing Technology* 39(1): 149-152.

Dianne, A.C.M. Commissaris, Schoenmaker Noortje, A.Th. Beune Erik, and M. Eikhout Sandra. (2006). Applying principles of change management in ergonomic projects: A case study. *Human Factors and Ergonomics in Manufacturing & Service Industries* 16(2): 195-223.

Domenico, Aprile, A. Claudio Garavelli, and Giannoccaro Ilaria. (2005). Operations planning and flexibility in a supply chain. *Production Planning & Control: The Management of Operations* 16(1): 21-31.

Dragan, Milutinovi, and Potkonjak Veljko. (1990). A new concept of the SCARA robot. *Robotics & Computer-lntegrated Manufacturing* 7(3/4): 337-343.

Ehud Kroll. (2013). Design theory and conceptual design: contrasting functional decomposition and morphology with parameter analysis. *Research in Engineering Design* 24(2): 165-183.

Eric, P. Jack, and S. Raturi Amitabh. (2002). Sources of volume flexibility and their impact on performance. *Journal of Operations Management* 20: 519-548.

Eversheim, W., and P. Herrmann. (1982). Recent trends in flexible automated manufacturing. *Journal of Manufacturing Systems* 1(2): 139-148.

Feldmann, K., B. Muller, and T. Haselrnann. (1999). Automated assembly of lightweight automotive components. *Manufacturing Technology* 48(1): 9-12.

Fok, S.C., and E.K. Ong. (1999). Position control and repeatability of a pneumatic rodless cylinder system for continuous positioning. *Robotics and Computer Integrated Manufacturing* 15: 365-371.

Gaalman, G.J., W.M. Nawijn, and L.W. Platzer. (1987). Tool sharing in an fms - A feasibility study. *Engineering Costs and Production Economics* 12: 107-115.

Germano, Veiga, Malaca Pedro, Pires J. Norberto, and Nilsson Klas. (2012). Separation of concerns on the orchestration of operations in flexible manufacturing. *Assembly Automation* 32(1): 38-50.

Ghosh, S.K., J.C. Beitialarrangoitia, and S.S. Douglas. (1993). An automatic process-planning strategy applied to a flexible two-dimensional cutting facility. *Journal of Materials Processing Technology* 37: 61-81.

Gudrun, Litzenberger. (2010). The robotics industry is getting back on track! Sales slump in 2009 - Strong recovery in 2010 – Further growth expected in 2011 and 2012. IFR Statistic Department. 2010. http://www.ifr.org/fileadmin/user_upload /downloads/Press/2010-06-09_PI_IFR_Automatica_english.pdf. (Accessed on 21/03/2012)

Guneri, A.F., A. Kuzu, and A. Taskin Gumus. (2009). Flexible kanbans to enhance volume flexibility in a JIT environment: a simulation based comparison via ANNs. *International Journal of Production Research* 47(24): 6807-6819.

Hällgrena, Sebastian, Lars Pejrydb, and Jens Ekengrenb. (2016) Design for Additive Manufacturing. *Procedia CIRP* 50: 246-25.

Helio Fiori, de Castro, and Lucchesi Cavalca Katia. (2006). Maintenance resources optimization applied to a manufacturing system. *Reliability Engineering & System Safety* 91: 413-420.

Henry, Aigbedo, and Tanniru Mohan. (2004). Electronic markets in support of procurement processes along the automotive supply chain. *Production Planning & Control: The Management of Operations* 15(7): 688-695.

Hideo, Fujimoto, Ahmed Alauddin, Ahmed Alauddin, and Hanai Mineo. (2003). Assembly process design for managing manufacturing complexities because of product varieties. *The International Journal of Flexible Manufacturing Systems* 15(4): 283-307.

Hiroshi, Makino, and Arai Tamio. (1994). New Developments in Assembly Systems. *Manufacturing Technology* 43(2): 501-512.

Hoda, A. ElMaraghy. (2006). Flexible and reconfigurable manufacturing systems paradigms. *International Journal of Flexible Manufacturing System* 17: 261-276.

Hu, S.J., Ko, J., Weyand, L., ElMaraghy, H.A., Lien, T.K., Koren, Y., Bley, H., Chryssolouris, G., Nasr, N., Shpitalni, M. (2011). Assembly system design and operations for product variety. *Manufacturing Technology* 60(2): 715-733.

Hugo, Medellin, Corney Jonathan, Ritchie James, and Lim Theodore. (2010). Automatic generation of robot and manual assembly plans using octrees. Assembly Automation 30(2): 173-183.

Igor, Gorlach, and Wessel Oliver. (2008). Optimal level of automation in the automotive industry. *Engineering Letters* 16(1): 141-149.

Jan, C. Aurich, and P. Barbian. (2004). Production projects – Designing and operating lifecycle-oriented and flexibility-optimized production systems as a project. *International Journal of Production Research* 42(17): 3589-3601.

Jaroslav Mackerle. (2001). 2D and 3D finite element meshing and remeshing A bibliography (1990-2001). *Engineering Computations*18(8): 1108-1197.

Jens, Bengtsson, and Olhager Jan. (2000). The impact of product- mix on the value of the flexibility. *First World Conference on Production and Operations Management POM Sevilla 2000*. 1-10.

Joachim, Doege, Paschke Hanns- Dieter, and Ke D. Tran. (1987). Low friction cylinder for manipulators, based on the pantograph principle and equipped with a pneumatic balancer control. United States of America Patent 4,666,346.

John, Mortimer. (2006). Jaguar uses castings, extrusions to reduce parts count in new sports car. *Assembly Automation* 26(2): 115-120.

Joseph, H. Saleh, Mark Gregory, and C. Jordan Nicole. (20019). Flexibility: A multidisciplinary literature review and a research agenda for designing flexible engineering systems. *Journal of Engineering Design* 20(3): 20: 3: 307-323.

Jouaneh, M., A. Hammad, and P. Datseris. (1997). A flexible automated foam cutting system. *International Journal of Machine Tools Manufacturing* 37(4): 437-449.

Juan, Carlos Ba´rcena-Ruiz, and Olaizola Norma. (2008). Choice of flexible production technologies under strategic delegation. *Japan and the World Economy* 20: 395-414.

Karl, T. Ulrich, and P. Seering Warren. (1990). Function sharing in mechanical design. *Design Studies* 11(4): 223-234.

Karl, T. Ulrich, and Steven D. Eppinger. (2003). The Activity of Concept Generation. In Product Design and Development, pp. 99-120. New York: McGraw-Hill.

Karmegam, K., Sapuan, S. M., Ismail, M. Y., Shamsul Bahri, M. T., Shuib, S., Mohana, G. K., Seetha, P., TamilMoli, P., Hanapi, M. J. (2011). Anthropometric study among adults of different ethnicity in Malaysia. *International Journal of the Physical Sciences* 6(4): 777-788.

Kasarin, Charnsirisakskul, M. Griffin Paul, and Keskinocak Pinar. (2004). Order selection and scheduling with leadtime flexibility. *IIE Transactions* 36(7): 697-707.

Kevin N. Otto, and Kristin L. Wood. (2001). Basic Methods: Information Gathering and Brainstorming. In Product Design, pp. 416-417. New Jersey: Prentice Hall.

Kinya, Tamaki, and Y. Nof Shimon. (1991). Design method of robot kitting system for flexible assembly. *Robotics and Autonomous Systems* 8: 255-273.

Kosmas, Alexopoulos, Papakostas Nikolaos, Mourtzis Dimitris, and Chryssolouris George. (2011). A method for comparing flexibility performance for the lifecycle of manufacturing systems under capacity planning constraints. *International Journal of Production Research* 49(11): 3307-3317.

Lee, Sang-Ho, and Chong-Won Lee. (2001). Hybrid control scheme for robust tracking of two-link flexible manipulator. *Journal of Intelligent and Robotic Systems* 32 (2001): 389-410.

Leu, Ming C., Hoda, A. ElMaraghy, Nee, Andrew Y.C., Ong, Soh Khim, Michele, Lanzetta, Matthias, Putz, Zhu, Wenjuan, Alain, Bernard. (2013). CAD model based virtual assembly simulation, planning and training. *Manufacturing Technology* 62: 799-822.

Li, Sha, Hui Wang, S. Jack Hu, Yhu-Tin Lin, and A. Abell Jeffrey. (2011). Automatic generation of assembly system configuration with equipment selection for automotive battery manufacturing. *Journal of Manufacturing Systems* 30: 188-195.

Lu, Shui-Shong, Ju-Lih Chu, and Huey-Chin Jang. (1997). Development of a novel coordinate transposing fixture system. *International Journal of Advanced Manufacturing Technology* 13: 350-358.

Luca, Bruzzone, and Bozzini Giorgio. (2010). A flexible joints microassembly robot with metamorphic gripper. *Assembly Automation* 30(3): 240-247.

Maarten, van Riemsdijk, and de Leede Jan. (2001). Flexible labour strategy in the dutch. *Creativity and Innovation Management* 10(4): 243-250.

Mahmood, Shafiee, and Chukova Stefanka. (2013). Maintenance models in warranty: A literature review. *European Journal of Operational Research* 229: 561-572.

Manfred Hiller. (2002). Modelling, simulation, and control design for large and heavy manipulators. *Robotics and Autonomous Systems* 19: 167-177.

Marie, Jonsson, and Ossbahr Gilbert. (2010). Aspects of reconfigurable and flexible fixtures. *Production Engineering Research & Development* 4: 333-339.

Mark, L. Nagurka, and J. Englert Paul. (1989). Toward An Intelligent Machine Tool for Flexible Manufacturing. *Robotics & Computer-Integrated Manufacturing* 6(3): 229-236.

Martin, Haegele, Skordas Thomas, Sagert Stefan, Bischoff Rainer, Brogardh Torgny, and Dresselhaus Manfred. (2005). Industrial robot automation. http://www.euron.org/miscdocs/docs/euron2/year2/dr-14-1-industry.pdf. (Accessed on 23/03/2012)

Martin, Mellado, Eduardo Vendrell, Alfons Crespo, Pedro López, Juan Garbajosa, Carmen Lomba, Klaus Schilling, Hubert Stützle, Rudolf Mayerhofer. (1999). Application of a real time expert system platform for flexible autonomous transport in industrial production. *Computer in Industry* 38: 187-200.

Mathias, J¨onsson, Andersson Carin, and ahl Jan-EricSt˚. (2011). Relations between volume Manufacturing flexibility and part cost in assembly lines. *Robotics and Computer-Integrated* 27: 669-673.

Mauro, Onori, and Barata Oliveira Jose. (2010). Outlook report on the future of European assembly automation. *Assembly Automation* 30(1): 7-31.

Mehrabi, M. G., A. G. Ulsoy, Y. Koren, and P. Heytler. (2002). Trends and perspectives in flexible and reconfigurable manufacturing systems. *Journal of Intelligent Manufacturing* 13: 135-146.

Mervi, Ranta, Mantyla Mar-Hi, Umeda Yasushi, and Tomiyama Tetsuo. (1996). Integration of functional and feature-based product modelling- the IMS/GNOSIS experience. *Computer-Aided Design* 28(5): 371-381.

Michael, R. Spano, O'Grady Sr. Peter, and E. Young Robert. (1993). The design of flexible manufacturing system. *Computers in Industry* 21: 185-198.

Michael, Schneider, Grahl J¨orn, Francas David, and Vigo Daniele. (2013). A problem-adjusted genetic algorithm for flexibility design. *International Journal of Production Economics* 141(1): 56-65.

Miguel Abambres and Mario Rui Arruda. (2016). Finite element analysis of steel structures- a review of useful guidelines. *International Journal of Structural Integrity* 7(40): 490-515.

Mohamed, A. Youssef, and Al-Ahmady Bassam. (2002). The impact of using flexible manufacturing systems on quality management practices. *Total Quality Management* 13(6): 813-825.

Mohammed, Ali, and Wadhwa Subhash. (2010). The effect of routing flexibility on a flexible system of integrated manufacturing. *International Journal of Production Research* 48(19): 5691-5709.

Mohsen, Moradi Dalvand. (2009). Automation of a complex transfer operation using a polar manipulator. *Assembly automation* 29(1): 68-74.

Molina, A., Rodriguez, C. A., Ahuett, H., Corte’ S, J. A., Rami’ Rez, M., Jime’ Nez, G., Martinez, S. (2005). Next-generation manufacturing systems: key research issues in developing and integrating reconfigurable and intelligent machines. *International Journal of Computer Integrated Manufacturing* 18(7): 525-536.

Morioka, M., and S. Sakakibara. (2010). A new cell production assembly system with human–robot cooperation. *Manufacturing Technology* 59: 9-12.

Moses, A.J., F. Al-Naemi, and J. Hall. (2003), Designing and prototyping for production. Practical applications of electromagnetic modelling. *Journal of Magnetism and Magnetic Materials* 254-255: 228-233.

Nagabhushana, Junjappa. (2008). De-Automation to Achieve Lower Manufacturing Costs. http://www.questglobal.com/newsroom/DeAutomation_to_achieve_lower_cost _manufacturing.pdf. (Accessed on 21/02/2012)

Neil, Bristol. (2011). Auto Tax Insights. Price Waterhouse Cooper International Limited. http://www.pwc.se/en_GX/gx/automotive/tax/pdf/auto-tax-insights-jan-2011.pdf. (Accessed on 21/03/2012)

Nils, Boysen, Fliedner Malte, and Scholl Armin. (2008). Assembly line balancing: Which model to use when? *International Journal of Production Economics* 111: 509-528.

Nima, Hamta, S.M.T. Fatemi Ghomi, F. Jolai, and Bahalke Unes. (2011). Bi-criteria assembly line balancing by considering flexible operation times. *Applied Mathematical Modelling* 35: 5592-5608.

Pablo Gonzalez, de Santos, E. Garcia, Sarria Javier, Ponticelli Roberto, and Reviejo Jesus. (2010). A new manipulator structure for power-assist devices. *Industrial Robot: An International Journal* 37(5): 452-458.

Pamela, P. Rogers, Ojha Divesh, and E. White Richard. (2011). Conceptualising complementarities in manufacturing flexibility: A comprehensive view. *International of Production Research* 49(12): 3767-3793.

Paul, K. Wright. (1995). Principles of open-architecture manufacturing. *Journal of Manufacturing Systems* 14(3): 187-202.

Ralf, Becker, Grzesiak Andrzej, and Henning Axel. (2005). Rethink assembly design. *Assembly Automation* 25(4): 262-266.

Ramazan, Yaman. (2008). An assembly line design and construction for a small manufacturing company. *Assembly Automation* 28(2): 163-172.

Reinhart, G., and G. Straßer. (2011). Flexible gripping technology for the automated handling of limp technical textiles in composites industry. *Production Engineering Research & Development* 5: 301-306.

Robert, Bogue. Design for manufacture and assembly: background, capabilities and applications. *Assembly Automation 32*, no. 2 (2012): 112-118.

Robert, R. Inman. (2003). ASRS sizing for recreating automotive assembly sequences. *International Journal of Production Research* 41(5): 847-863.

Rodney, P. Parker, and Wirth Andrew. (1999). Manufacturing flexibility: Measures and relationships. *European Journal of Operational Research* 118: 429-449.

Roongrat, Pisuchpen. (2012). Integration of JIT flexible manufacturing, assembly and disassembly using a simulation approach. *Assembly Automation* 32(1): 51-61.

Ross, Michael, Benjamin Horn, Sebastian Gramlich, Stefan Ulbrich, and Hermann Kloberdanz. (2016). Manufacturing integrated algorithm-based product design- case study of a snap-fit fasterning. *Procedia CIRP* 50: 123-128.

Ruhizan, Liza Ahmad Shauri, and Nonami Kenzo. (2011). Assembly manipulation of small objects by dual-arm manipulator. *Assembly Automation* 31(3): 263-274.

Rui, Fernandes, B. Gouveia Joaquim, and Pinho Carlos. (2012) Product mix strategy and manufacturing flexibility. *Journal of Manufacturing Systems* 31(3): 301-311.

Sachin, Borgave, and Chaudhari, J. S. (2010). Indian auto component industry: Challenges ahead. *International Journal of Economics and Business Modeling* 1(2): 1-11.

Satyandra K. Gupta, Christiaan F. F. Paredis, Rajarishi Sinha, and Peter F. Brown. (2001). Intelligent assembly modeling and simulation. *Assembly Automation* 21(3): 215-235.

Scholz-Reiter, B., and M. Freitag. (2007). Autonomous processes in assembly systems. *Manufacturing Technology* 56(2): 712-729.

Schraft, R.D. (1986). The industrial robot in a flexible manufacturing system: State of the Art and Prospects. *Robotics* 2: 237-247.

Sela, M. N., O. Gaudryt, E. Dombret, and B. Benhabib. (1997). A reconfigurable modular fixturing system for thin-walled flexible objects. *International Journal of Advanced Manufacturing Technology* 13: 611-617.

Selvaraj, P., P. Radhakrishnan, and M. Adithan. (2009). An integrated approach to design for manufacturing and assembly based on reduction of product development time and cost. *International Journal of Advanced Manufacturing Technology* 42: 13-29.

Sethi, Andrea Krasa, and Suresh Pal Sethi. (1990). Flexibility in manufacturing: A survey. *The International Journal of Flexible Manufacturing Systems* 2: 289-328.

Sheldon, H. Jacobson, W. Johnson Alan, A. Sullivan Kelly, A. Fleischer Mark, and Kumar Ashok. (1997). Metaheuristics for a flexible assembly system design problem. *Journal of Heuristics* 3: 139-159.

Simona, Daniela Grigore. (2007). Supply chain flexibility. *Romanian Economic and Business Review* 2(1): 66-70.

Simonei, Maggioni, H. Thiele Reinhold, Rivard Steven, and Turner H. Alvan. (2006). Leadership in the automotive industry. Spencer Stuart. http://content.spencerstuart. /sswebsite/pdf/lib/Automotive_Study_March_06.pdf. (Accessed on 12/08/2013)

Singh, P. J., A. Smith, and A. S. Sohal. (2005). Strategic supply chain management issues in the automotive industry: an Australian perspective. *International Journal of Production Research* 43(16): 3375-3399.

Sorli, Massimo, Laura Gastaldi, Esteban Codina and S. de las Heras. (1999). Dynamic analysis of pneumatic actuators. *Simulation Practice and Theory* 7(5):589-602.

Stefan, Gies, Freialdenhoven Arndt, and Olschewski Ingo. (2008). Challenges and Sustainable Strategies in the Automotive Industry. *International Automotive Congress*, Shenyang.

Stuart C. Burgess. (2012). A Backwards Design Method for Mechanical Conceptual Design. *Juarnal of Mechanical Design* 134(3):031002.

Suh, Eun Suk, de Weck Olivier, Il Yong Kim, and David Chang. (2007). Flexible platform component design under uncertainty. *Journal of Intelligent Manufacturing* 18: 115-126.

Sven, Rogalski. (2012). Factory design and process optimisation with flexibility measurements in industrial production. *International Journal of Production Research* 50(21): 6060-6071.

Tahir, Andrabi, Ghatak Maitreesh, and Ijaz Khwaja Asim. (2006). Subcontractors for tractors: Theory and evidence on flexible specialization, supplier selection, and contracting. *Journal of Development Economics* 79: 273-302.

Takahiro, Tomino, Youngwon Park, Hong Paul, and JungbaeRoh James. (2009). Market flexible customizing system (MFCS) of Japanese vehicle manufacturers: An analysis of Toyota, Nissan and Mitsubishi. *International Journal of Production Economics* 118: 375-386.

Tang, Dunbing, and Xiaoming Qian. (2008). Product lifecycle management for automotive development focusing on supplier integration. *Computers in Industry* 59: 288-295.

Terje, Skarlo. (1999). The flexible landscape: A model for explaining. *Production Planning & Control* 10(8): 735-744.

Thomas, Sillekens, Koberstein Achim, and Suhl Leena. (2011). Aggregate production planning in the automotive industry with special consideration of workforce flexibility. *International Journal of Production Research* 49(17): 5055-5078.

Thompson, Mary Kathryn, Moroni, Giovanni, Vaneker, Tom, Fadel, Georges, Campbell, R. Ian, Gibson, Ian, Bernard, Alain, Schulz, Joachim, Graf, Patricia, Ahuja, Bhrigu, Martina, Filomeno. (2016). Design for additive manufacturing: trends, opportunities, considerations, and constraints. *Manufacturing Technology* 65: 737-760.

Tokhi, Al-Miskiry and Brisland. (2001). Real-time control of air motors using a pneumatic H-bridge. *Control Engineering Practice* 9(4): 449–457

Tritos, Laosirihongthong, Keah-Choon Tan, and Adebanjo Dotun. (2011). Supply chain management in ASEAN automotive manufacturing industry. *International Journal of Logistics: Research and Applications* 14(5): 317-333.

Vaneker, Tom, and Tijmen van Diepen. (2016). Design support for maintenance tasks using TRIZ. *Procedia CIRP* 39: 67-72.

Vijay, Kumar, Bekey George, and Zheng Yuan. (2006). Industrial, personal, and service robots. WTEC Organization. http://www.wtec.org/robotics/report/05-Industrial.pdf. (Accessed on 21/03/2012)

Viswanadham, N, and N R Srinivasa Raghavan. (1997). Flexibility in manufacturing enterprises. *Sadhana* 22(2): 135-163.

Vivek, Hajarnavis, and Young Ken. (2008). An investigation into programmable logic controller software design techniques in the automotive industry. *Assembly Automation* 28(1): 43-54.

Viviana, I. Cesanı´, and J. Steudel Harold. (2005). A study of labor assignment flexibility in cellular manufacturing systems. *Computers & Industrial Engineering* 48: 571-591.

Wadhwa, S., K. S. Rao, and F. T. S. Chan. (2005). Flexibility-enabled lead-time reduction in flexible systems. *International Journal of Production Research* 43(15): 3131-3162.

Wahab, M. I. M. (2005). Measuring machine and product mix flexibilities of a. *International Journal of Production Research* 43(18): 3773-3786.

Wang, Hui, Yiming (Kevin) Rong, Hua Li, and Price Shaun. (2010) Computer aided fixture design: Recent research and trends. *Computer-Aided Design* 42: 1085-1094.

Wang, Yi-Chi. (2008). Evaluating flexibility on order quantity and delivery lead time for a supply chain system. *International Journal of Systems Science* 39(12): 1193-1202.

Wang, Zhongjin, and Yi Li. (2008). Formability of 6k21-T4 car panel sheet for viscoelastic–plastic flexible-die forming. *Journal of Materials Processing Technology* 201: 408-412.

Wiendah, H.-P., et al. (2007). Changeable manufacturing - Classification, design and operation. *Manufacturing Technology* 56(2): 783-809.

Wolfgang, Beitz, and Grote Karl-H. (1994). Design for material saving. *Material & Design* 15(4): 195-202.

Xichun, Luoa, Chenga Kai, Webb Dave, and Wardle Frank. (2005). Design of ultraprecision machine tools with applications to manufacture of miniature and micro components. *Journal of Materials Processing Technology* 167: 515-528.

Xing, Y., G. Chen, X. Lai, S. Jin, and J. Zhou. (2007). Assembly sequence planning of automobile body components based on liaison graph. *Assembly Automation* 27(2): 157-164.

Yahia, Zare Mehrjerdi. (2009). A decision-making model for flexible manufacturing system. *Assembly Automation* 29(1): 32-40.

Yang, D. C. H., and Y. Y. Lin. (1985). Pantograph mechanism as a non-traditional manipulator structure. *Mechanism and Machine Theory* 20(2): 115-122.

Yeon, Je Sung, Jongguk Yim, and Jong Hyeon Park. (2011). Robust control using recursive design method for flexible joint robot manipulators. *Journal of Mechanical Science and Technology* 25(12): 3205-3213.

Zou, Cheng, and Jihong Liu. (2011). An off-line programming system for flexible drilling of aircraft wing structures. *Assembly automation* 31(2): 161-168.