Global Journals LaTeX JournalKaleidoscope™

Artificial Intelligence formulated this projection for compatibility purposes from the original article published at Global Journals. However, this technology is currently in beta. *Therefore, kindly ignore odd layouts, missed formulae, text, tables, or figures.*

A Review of Modelling Techniques for Loading Problems in Flexible Manufacturing System

Ranbir Singh[1]

[1] DCRUST Murthal

Received: 7 December 2014 Accepted: 31 December 2014 Published: 15 January 2015

Abstract

Though flexible manufacturing systems have promised wide range of benefits but the implementation of FMS has fraught with difficulty as a result of which the implementation rate of FMS is much lower than has been expected. To bridge the gap efforts at global level are carried out widely in today?s global and informative world. In the progress, modelling plays a vital role in the design, planning, implementation and operation of FMSs. Models are used widely to provide insight into how the FMS system and its components interact. With time new optimization problems arises in FMS, thus new modelling methods and techniques and updation of the existing needs to be developed time to time. Since the publication of the first articles on the planning problems of FMS?s (Stecke Kathryn E. and Solberg James J., 1981)(Stecke, 1983b), much research has been devoted to the solution of these types of problems. The aim of this paper is to review the approaches to model FMS and the solution approaches. A review paper provides basis and direction for future research directions.

Index terms— flexible manufacturing system (fms), loading in fms, modelling of fms, mathematical modelling of fms, artificial intelligence in FMS.

1 Introduction

o satisfy rapidly changing global market and requirements of customer demand, systems needs to be designed to increase flexibility. Flexible manufacturing is the answer to the problem. FMS are as flexible as job shop and as efficient as production lines. Thus FMS are complex and combinational problem, where arises a wide range of problems with its exploration. Prior to start of manufacturing, production planning problems is one among them. FMS planning problems is to decide which cutting tools are to be placed in which tool magazine, to decide when and which part to be produced and in what quantity, how pooling of the machines and tools has to be done, number and types of fixtures and pallets required and available, number and type of cutting tools available and required, type of operations that can be performed etc. These decisions are to be made before the start of manufacturing. The scheduling problem needs next to be addressed. The five production planning problems mentioned by Kathryn E. Stecke (Stecke, 1983a(Stecke, , 1983b)) needs to be solved before solving scheduling problem. Solution of production planning problem is the prerequisite to solve the scheduling problem. Scheduling is the time table for the machines set up for prescribed production target. Production planning problem needs to be solved to reach the shop floor and scheduling need to be done for actual production to begun.

Depending on the type of the manufacturing problem objectives are defined for problem formulation and optimal solution. The type and number of objective function depends on the type and nature of a particular manufacturing system. One or more objective may be desirable at one or more stage of FMS life cycle, i.e. from FMS conception, design, to scheduling. For handling large number of objectives the weightage factor for each objective needs to be defined to solve the problem. Various modelling techniques for different objectives have been identified and different solution techniques were targeted in the literature.

2 II. Literature Review of Modelling for fms Loading Problem

A model is a representation of the construction and working of some system of interest. A model is similar to but simpler than the system it represents. A model enables the analyst to predict the effect of changes to the system. A model should be a close approximation to the real system and should incorporate most of its salient features and, it should not be so complex to understand and experiment with. A good model is a judicious trade-off between realism and simplicity. Simulation practitioners recommends for increasing the complexity of a model iteratively. An important issue in modelling is model validity. According to Maria model validation techniques include simulating the model under known input conditions and comparing model output with system output (Maria, 1997). Mathematical programming models, Heuristic approaches, Queuing network models, Simulation models etc. have been utilized for modelling various types of complex problems of FMS's. Different modelling methods and approaches used for modelling FMS's, particularly the loading problem of FMS's have been identified and classified pearly reviewed as under.

a) Artificial Intelligence (AI) AI covers techniques like fuzzy logic, neural networks, and immune algorithms. AI is potentially suitable for complex and ill-defined problem (Kempf, 1985) (Lu, 1986). Loading problems in FMS has been modelled with fuzzy logic by Vidyarthi and Tiwari in 2001 (Vidyarthi & Tiwari, 2001)

3 b) Branch and Backtrack Approach

Branch and backtrack and Heuristic procedure for modelling the loading problem has been used by Shankar and Srinivasulu in 1989 (Shankar & Srinivasulu, 1989).

4 c) Branch and Bound Approach

The method was first described by Land and Doig in 1960 (Land & Doig, 1960). Branch and bound algorithm works by enumerating possible combinations of the variables in a branch and bound tree. A few integer variables are fixed to have zero or one value and others are allowed to have any value in the range between zero and one. The root of the tree is the original problem. A leaf node is selected from the tree and the algorithm is solved. In each iteration the descendents of feasible solutions are selected for further branching, and descendents of infeasible solutions are ignored.

Branch and bound approach for formulation of loading problem of FMS has been discussed by

5 d) Heuristic Approaches

Heuristics was the name of a certain branch of study, not very clearly circumscribed, belonging to logic, or to philosophy or to psychology often outlined, seldom presented in detail.

The aim of heuristic is to study the methods and rules of discovery and invention. A few traces of such study may be found in the commentators of Euclid; a passage of Pappus is particularly interesting in this respect. The most famous attempts to build up a system of heuristic are due to Descartes and to Leibnitz, both great mathematicians and philosophers. Bernard Bolzano presented a notable detailed account of heuristic. The present booklet is an attempt to revive heuristic in a modern and modest form. Heuristic reasoning is reasoning not regarded as final and strict but as provisional and plausible only, whose purpose is to discover the solution of the present problem. We shall attain complete certainty when we shall have obtained the complete solution, but before obtaining certainty we must often be satisfied with a more or less plausible guess. We may need the provisional before we attain the final. We need heuristic reasoning when we construct a strict proof as we need scaffolding when we erect a building.

Heuristic reasoning is often based on induction, or on analogy. Provisional, merely plausible heuristic reasoning is important in discovering the solution, but you should not take it for a proof; you must guess, but also examine your guess (Polya, 1945).

Heuristic is a program, rule, piece of knowledge, etc., which one is not entirely confident to be useful in providing a practical solution, but has reason to believe to be useful, and which is added to a problem-solving system in expectation that an average the performance will improve (Romanycia & Pelletier, 1985).

Heuristics are defined as the set of rules that provides optimal or non-optimal solution to the problem with less computational work (Greene & Sadowski, 1986). For different manufacturing enterprises a wide range of heuristics procedures have been developed. Heuristics for FMS in 1987 ((Werra, 1987), and Petri net modelling combined with heuristic for FMS in 1994 (D. Y. Lee & DiCesare, 1994) has been developed. Heuristic model for the FMS capacity planning problem was presented in 1989 (Mazzola, 1989).

The loading problems of FMS has been modelled with simple heuristics by Stecke and Talbot in 1983 (Stecke & Talbot, 1983)

6 e) Hierarchical Model

Hierarchy modelling method is amongst the oldest modelling methods, dating from 1960's. This method processes data efficiently at faster rate but it is less flexible for optimization. The system is classified according to its hierarchy and its network tree is formulated. All links from one to many networks, from parent to child are specified. The system at higher level is parent to its lower level hierarchy.

Modelling (Mazzola, 1989).

7 f) Markov Chains

A Markov chain is a model consisting of a group of states and specified transitions between the states. A Markov chain can have a finite or infinite number of states. In a discrete time Markov chain (DTMC) each state change takes place at a fixed decision point and the time between changes is constant. In a continuous time Markov chain (CTMC), changes can happen at any instant. Transitions in a Markov chain depend on only the current state, and not on any history of previous states.

Markov chains have been used to model FMS by Vishwanadham et al. in 1992 (Vishwanadham, Narahari, & Johnson, 1992) and loading problems of FMS by Aldaihani and Savsar in 2005 (Aldaihani & Savsar, 2005).

8 g) Mathematical Modelling

Mathematics has been the language of science. Mathematics is used to solve many real-world problems of industry, physical sciences, economics, social and human sciences, engineering and technology (Stecke, 2005a). A mathematical model can be deterministic (input and output variables are fixed values) or stochastic (at least one of the input or output variables is probabilistic); static (time is not taken into account) or dynamic (time-varying interactions among variables are taken into account). In a mathematical model usually, some of the decision variables are restricted to integer values and some are continuous. Usually the optimization problems are formulated with zero-ones to encode choices from a small set of available options to a decision, usually in binary form of zero and one. Use of mathematics and simple mathematical models to solve problems in industry were discussed in detail by Stecke in 2005 (Stecke, 2005b). Mathematical programming models have been applied widely to solve the production planning problems. Mathematical programming requires high degree of accuracy and the solution approach requires efficient computational help. Integer programming (IP), mixed integer programming (MIP) and linear integer programming (LIP) has been widely utilized for mathematical modelling.

Stecke applied 0-1 nonlinear MIP for formulation of mathematical model of grouping and loading problems during 1981-83 (Stecke, 1981) (Stecke, 1982) (Stecke, 1983b) and mathematical program for FMS in 1983 (Stecke, 1983b **??**Hwang, 1986). Equivalent IP formulation for the process planning problem of FMS was carried out by Kusiak and Finke in 1988 (Kusiak & Finke, 1988).

Kimemia in 1982 (Kimemia, 1982) and Kimemia and Gershwin in 1983 (Kimemia & Gershwin, 1983) used dynamic programming; Kimemia in 1982 (Kimemia, 1982), Kusiak in 1983(Kusiak, 1983)

9 h) Multi-Criterion Programming

The loading problem of FMS has been formulated with multi-criterion programming model by Kumar et al. in 1987 (Kumar P. et al., 1987).

10 i) Network Modelling

Network modelling has a wide range of applications. The manufacturing processes have also been be modelled as queueing networks, both as open or close networks. QN models are built in an aggregate way thus the models work well at the higher and more aggregate levels of a hierarchy of planning (Buzacott & **??**hanthikumar, 1980). Because of dynamic operations at lower levels, QN models are quite impractical at lower level of hierarchy. Also the specific distributions may not accurately reflect the true operating characteristics of the particular FMS. The queueing network modelling can be closed (CQN) and open (OQN) type. The difference between CQN and OQN is that CQN contains fixed number of parts with no external arrivals or departures. For analysis of the queueing network model Buzen's algorithm and mean value analysis were widely used.

FMS has been modelled with CQN by Solberg in 1977 (Solberg, 1977), 1979 (Solberg, 1979) and 1980 (Solberg, 1980)

11 k) Petri Nets

A Petri net has its origin from the dissertation of Carl Adam Petri, submitted in 1962 (Petri, 1962), to the faculty of Mathematics and Physics at the Technical University of Darmastadt, West Germany. The English translation of the report is also available in 1966 (Petri, 1966)

12 l) Sequential Approach

The loading problem of FMS has been modelled with two-stage sequential approach by Liang in 1994 (Liang, 1993) and Ming in 1994 (Ming, 1994), and sequential approach by Liang and Dutta in 2009 (Liang & Dutta, 2009).

The sequential modelled FMS problems have been solved with application of Lagrangian relaxation approach by Liang and Dutta in 2009 (Liang & Dutta, 2009).

13 m) Simulation Models

Simulation is a descriptive modelling technique through computer based programmes for analysis of the problems and solutions. FMS problems are very complex in nature, so simulation models are widely used to solve FMS problems because of its descriptive nature. Cost and computational time increases with increase in complexity of the problems.

A virtual manufacturing system mode has been developed for flexible manufacturing cells using objectoriented paradigm, and implemented with QUEST/IGRIP software by Kim and Choi in 2000 (S. ??im & Choi, 2000). Computer simulation package Simfactory II.5 has been used for modelling loading problem of FMS by Gupta in 1999 ??Gupta, 1999).

14 n) Unit Operation Approach

Unit operation has been used to model Block Angular Structures of loading problems by Kouvelis and Lee in 1991 (Kouvelis & Lee, 1991). Accuracy, results acceptability and adaptability, computational time and cost are the major factors for selection of the type of particularly loading problems of FMS.

III.

15 Conclusion

Hierarchical modelling, mathematical modelling, heuristic approaches, network modelling, simulation techniques, artificial intelligence (fuzzy logic, artificial immune algorithms and artificial neural network), Petri nets, Markov chains, branch and bound approach, multi-criterion programming model, branch and backtrack approach, sequential approach, unit operation approach and perturbation approach have been discussed in the literature for modelling loading problems of FMS's. Mathematical, heuristics, hierarchical approaches and network modelling are the widely used and accepted ones. Moreover the global optimization techniques have been widely used for solving the formulated problems.

Solution of the mathematical models have been approached by branch and backtrack method, branch and bound algorithm, ant colony optimization (ACO), genetic algorithm (GA), harmony search algorithm (HS), simulated annealing (SA), particle swarm optimization (PSO), approximation technique, artificial immune algorithm, artificial neural network (ANN), box complex method, computer simulation package simfactory II.5, fuzzy-based solution methodology, GA-HS hybrid algorithm, GA-PSO hybrid heuristic technique, GA-SA hybrid algorithm, heuristic algorithms, meta hybrid PSO, min-max approach, sequential and simultaneous approaches, simulation, surrogate and lagrangian approaches, TS-SA hybrid algorithm and -constraint method.

Heuristics solutions do not assure optimal solution (Manoj Kumar Tiwari, Kumar, Kumar, Prakash, & , GA-based heuristics for the loading problem lead to constraint violations and large number of generations (A. Kumar et al., 2006) and PSO avoids premature convergence (Biswas & Mahapatra, 2007). Because of less computational requirements, easy and fast convergence, better ease of apply, less time requirements are some of the factors attracting the researchers to use global optimization techniques for solving the mathematical or other model of the loading problems and other problems and FMS's. The authors after spending a lot of time on analysing and studying the research papers, books, Ph.D. thesis and other relevant materials suggests integer programming for modelling the loading problems and PSO for solution of the model.

To analyse the system performance and to provide insight of how the system behaves, and how system component behaves, and to identify the key factors and parameters affecting the system, modelling and simulation of the physical system is the only best solution. Various types of results, graphs, plots etc can be generated for useful analysis of the system. The key to be remembered is that the validity and accuracy of the result will depend on the model developed, and the information induced in the model (value of parameters and key variables). It is the human who developed the model and it is him only to validate and validate the results. The software or model will give the results in the type the user wants. Validation, accuracy and acceptance of the results depend on the user. The modelling simulation and analysis can be expensive and time consuming to develop and run for desired accurate and acceptable results and outputs. An ideal model should be least expensive which should require least computational time. A research work is required to compare the various modelling techniques on basis of certain parameters, which will help the industry and academicians in selection of the type of modelling techniques under certain parameters and constraints. The authors are working on this research. [1]

Figure 1:

Figure 2:

Figure 3:

Figure 4:

Abazari et al. in 2012 (Aba
Sattari, 2012)discussed mathemat
programming for the loading problems.

MIP is utilized by Greene a
(Greene & Sadowski, 1986), Liang and Dutt in 199
(Liang & Dutt, 1990), Henery et al. in 1990 (Hener
Co, Biermann, & Chen, 1990), Guerrero in 1999
(Guerrero, 1999), Lee and Kim in 2000 (D.-H. Lee
2000) Kumar and Shanker in 2000 (N. Kumar &
Shanker, 2000), Kumar and Shanker in 2001 (N. Ku
& Shanker, 2001), Yang and Wu in 2002 (Yang & W
2002), Tadeusz in 2004 (Tadeusz, 2004), Bilgin and
Azizoglu in 2006 (Bilgin & Azizoglu, 2006), Murat
Erol in 2012 (Murat & Erol, 2012) and Yusof et al.
(Yusof et al., 2012) for loading problems of FMS.
0-1 Linear MIP is utilized by Chakravarty and Scht

Sawik in 2000 (Sawik, 2000) and Dobson and Nambimadom in 2001 (Dobson & Nambimadom, 2001) adopted IP
formulation; Taboun & Ulger in 1992 (Taboun & Ulger, 1992), Swarnkar & Tiwari in 2004 (Swarnkar & Tiwari, 2004) and Sujono & Lashkari in 2007 (Sujono & Lashkari, 2007) utilized 0-1 IP formulation; and Jahromi
& Tavakkoli-Moghaddam in 2012 (Jahromi & Tavakkoli-
Moghaddam, 2012) discussed 0-1 LIP formulation for modelling the loading problems of FMS.
Sarin and Chen in 1987 (Sarin & Chen, 1987), Rajamani and Adil in 1996 (Rajamani & Adil, 1996), Ozdamarl and Barbarosoglu in 1999 (Ozdamarl & Barbarosoglu, 1999), Chen and Ho in 2005 (Chen & Ho,
2005), Nagarjuna et al. in 2006 (Nagarjuna, Mahesh, &
Rajagopal, 2006), Goswami and Tiwari in 2006 (Goswami & Tiwari, 2006), Kumar et al. in 2006 (A. Kumar, Prakash, Tiwari, Shankar, & Baveja, 2006), Biswas and Mahapatra in 2007 (Biswas & Mahapatra, 2007) and 2008(Biswas & Mahapatra, 2008), Ponnambalam and Kiat in 2008 (Ponnambalam & Kiat, 2008), Yogeswaran et al. in 2009(Yogeswaran, Ponnambalam, & Tiwari, 2009), Yusof et al. in 2011 (Yusof, Budiarto, & Deris, 2011), Mgwatu in 2011 (Mgwatu, 2011), Yusof et al. in 2011 (Yusof, Budiarto, &
Venkat, 2011), Kumar et al. 2012 (V. M. Kumar, Murthy,
& Chandrashekara, 2012), Yaqoub and Abdulghafour in
2012 (Yaqoub & Abdulghafour, 2012), Yusof et al. in 2012 (Yusof, Budiarto, & Deris, 2012) and Mahmudy et
al. in 2012 (Mahmudy, Marian, & Luong, 2012) utilized mathematical modelling for loading problems of FMS.
Mathematical programming for loading
problems of FMS is discussed by Kiran and Tansel in

FMS has also been modelled with advanced CQN by Seidmann et al. in 1987 (Seidmann, Schweitzer, & Shalev-oren, 1987), with discrete generalized network by Ram et al. in 1990 (Ram, Sarin, & Chen, 1990) and with queueing networks by Narahari et al. in 1990 (Narahari, Viswanadham, Meenakshisundaram, & Rao, 1990) and Vishwanadham et al. in 1992 (Vishwanadham et al., 1992). Queueing model has been developed for the performance prediction of FMS's by Jain et al. in 2008 (Jain, Maheshwari, & Baghel, 2008). Modelling of the loading problems of FMS with single server CQN model by Stecke and Morin in 1984 (Stecke & Morin, 1984), CQN model by Stecke and Kim in 1987 (Stecke & Kim, 1987) and constrained network model by Bretthauer and Venkataramanan in 1990 (Bretthauer & Venkataramanan, 1990) were developed. Solution of the network modelled FMS problems has been achieved by surrogate and Lagrangian relaxation by Bretthauer and Venkataramanan in 1990 (Bretthauer & Venkataramanan, 1990). Mean value analysis (MVA) has a wide suitability for solving the network models. MVA is an iterative technique that avoids numerical instabilities, developed by Reiser and Lavenberg in 1978-80 as an efficient solution technique numerical problems raised with the convolution algorithms (Reiser & Lavenberg, 1978)(Reiser & Lavenberg, 1980). MVA is based on applications of Little's theorem (Little, 1961). The application of Mean-value analysis of queues (MVAQ) for FMS modelling has for queueing network models, to overcome the

Year 2015 27 XV Issue I Version I Global Journal of Researches in Engineering ( ) Volume A

been discussed by Suri and Hildebrant in 1984 (Suri & Hildebrant, 1984).

j) Perturbation Approach

Perturbation for modelling the loading problems of FMS has been used by Mukhopadhyay et al. in 1998 (Mukhopadhyay, Singh, & Srivastava, 1998).

[Note: © 2015 Global Journals Inc. (US) Perturbation modelled FMS loading problem has been solved with application of SA in by Mukhopadhyay et al. 1998 (Mukhopadhyay et al., 1998).]

Figure 6:

.

Petri nets are graphical and mathematical
modelling tool used to model physical systems.
Because of its graphic nature Petri nets are used as
visual communication tool similar to flow charts,
networks and block diagrams. It is possible to set up
state equations, algebraic equations and other
governing equations because of its mathematical
nature.
FMS has been modelled with timed Petri nets by

Figure 7:

1

Year 2015
28
I Version I
e XV Issue
( ) Volum A
Global Journal of Researches in Engineering
13

[Note: A Review of Modelling Techniques for Loading Problems in Flexible Manufacturing System]

Figure 8: Table 1 :

4. Al Titinchi, A. A., & Al Aubidy, K. M. (2004). Density of literature Modeling and analysis of an on-line FMS scheduler collected (over 1977-2013) International Journal of & Information Sciences, 2(2), 74-83. 5. Ammons, J. C., Lofgren, C. B., & McGinnis, L. F. 12 (1985). A large scale machine loading problem in 10 flexible assembly. Annals of Operations Research, 3, 319 -332. 8 6. Atmaca, E., & Erol, S. (2000). Goal programming model for loading and routing problems in flexible 6 manufacturing systems. ICMIT 2000 (IEEE), 843-2 847. 4 7. Bell, R., & Bilalis, N. (1982). Loading and control strategies for an FMS for rotational parts. In 1st International Conference on Flexible

1986), Kim and (Shankar & Tzen, 1985).

.1 Global Journals Inc. (US) Guidelines Handbook 2015

www.GlobalJournals.org

[Econometrika] , Econometrika . 28 p. .

[Michigan] , Michigan .

[Narahari et al. ()] , Y Narahari , N Viswanadham , C R Meenakshisundaram , P H Rao . 1990.

[Vishwanadham et al. ()] , N Vishwanadham , Y Narahari , T L Johnson . 1992.

[A A Review of Modelling Techniques for Loading Problems in Flexible Manufacturing System flexible manufacturing system Inte ‘A A Review of Modelling Techniques for Loading Problems in Flexible Manufacturing System flexible manufacturing system’. *International Journal of Production Research* 27 (6) p. .

[Yeong and Candace ()] *A branch and bound approach for the loading problem in flexible manufacturing systems: an unbalancing case*, Kim Yeong , -Dae , Yano Candace , A . 87-18. 1987. (Technical Report)

[Kumar et al. ()] ‘A fuzzy based algorithm to solve the machine-loading problems of a FMS and its neuro fuzzy petri net model’. R R Kumar , A K Singh , M K Tiwari . 10.1007/s00170-002-1499-4. *International Journal of Advanced Manufacturing Technology* 2004. (23) p. .

[Petrovic and Akoz ()] ‘A fuzzy goal programming approach to integrated loading and scheduling of a batch processing machine’. D Petrovic , O Akoz . 10.1057/palgrave.jors.2602467. *Journal of the Operational Research Society* 2008. 59 (9) p. .

[Kumar and Shanker ()] ‘A genetic algorithm for FMS part type selection and machine loading’. N Kumar , K Shanker . *International Journal of Production Research* 2000. 38 (16) p. .

[Kumar et al. ()] ‘A goal programming model for multistage, multiobjective problems grouping and loding problems in a flexible manufacturing system’. P Kumar , N Singh , N K Tewari . *European Journal of Operational Research* 1991. 53 p. .

[Mukhopadhyay et al. ()] ‘A heuristic procedure for loading problem in flexible manufacturing systems’. S K Mukhopadhyay , S Midha , V Murlikrishna . 10.1080/00207549208948146. *International Journal of Production Research* 1992. 30 (9) p. .

[Tiwari et al. ()] ‘A heuristic solution approach to the machine loading problem of an FMS and its Petri net model’. M K Tiwari , B Hazarika , N K Vidyarthi , JP , MS K . *International Journal of Production Research* 1997. 35 (8) p. .

[Stecke ()] ‘A hierarchical approach to solving machine grouping and loading problems of flexible manufacturing systems’. K E Stecke . *European Journal of Operational Research* 1986. 24 p. .

[Stecke ()] *A hierarchical approach to solving machine grouping and loading problems of FMS. The University of Michigan*, K E Stecke . 1983a. p. 331. (Working Paper)

[Kumar et al. ()] ‘A hybrid algorithm optimization approach for machine loading problem in flexible manufacturing system’. V M Kumar , A N N Murthy , K Chandrashekara . *Journal of Industrial Engineering International* 2012. 8 (3) p. .

[Murat and Erol ()] ‘A hybrid simulated annealing-tabu search algorithm for the part selection and machine loading problems in flexible manufacturing systems’. A Murat , S Erol . 10.1007/s00170-011-3506-0. *International Journal of Advanced Manufacturing Technology* 2012. 59 p. .

[Ozpeynirci and Azizoglu ()] ‘A Lagrangean relaxation based approach for the in flexible allocation capacity problem manufacturing systems’. S Ozpeynirci , M Azizoglu . 10.1057/jors.2009.19. *Journal of the Operational Research Society* 2010. (20) p. .

[Shankar and Tzen ()] ‘A loading and dispatching problem in a random flexible manufacturing system’. K Shankar , Y Tzen . 10.1080/00207548508904730. *International Journal of Production Research* 1985. 23 (3) p. .

[Afentakis ()] ‘A loop layout design problem for flexible manufacturing systems’. P Afentakis . *International Journal of Flexible Manufacturing Systems* 1989. 1 p. .

[Kiran and Tansel ()] *A mathematical model for flexible manufacturing systems*, A S Kiran , B C Tansel . 1985. (Working Paper)

[Solberg (1977)] ‘A mathematical model of computerised manufacturing systems’. J J Solberg . *Proceedings of the 4th International Conference on Production Research*, (the 4th International Conference on Production ResearchTokyo, Japan) 1977. August.

[Liang and Dutt ()] ‘A mixed-integer programming approach to the machine loading and process planning problem in a process payout pnvironment’. M Liang , S P Dutt . 10.1080/00207549008942806. *International Journal of Production Research* 1990. 28 (8) p. .

[Ram et al. ()] 'A model and a solution approach for the machine loading and tool allocation problem in a flexible manufacturing system'. B Ram , S Sarin , C S Chen . 10.1080/00207549008942745. *International Journal of Production Research* 1990. 28 p. .

[Sujono and Lashkari ()] 'A multiobjective model of operation allocation and material handling system selection in FMS design'. S Sujono , R S Lashkari . 10.1016/j.ijpe.2005.07.007. *International Journal Production Economics* 2007. 105 p. .

[Kim and Yano ()] *A new branch and bond algo for loading problems in flexible manufacting system*, Y.-D Kim , C A Yano . 1989.

[Narahari and Viswanadham ()] 'A Petri net approach to the modelling and analysis of flexible manufacturing systems'. Y Narahari , N Viswanadham . *Annals of Operations Research* 1985. 3 p. .

[Little ()] 'A proof of the queueing formula L=?W'. J D C Little . *Operational Research* 1961. 9 (3) p. .

[A Review of Modelling Techniques for Loading Problems in Flexible Manufacturing System ()] *A Review of Modelling Techniques for Loading Problems in Flexible Manufacturing System*, 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012.

[Aldaihani and Savsar ()] 'A stochastic model for the analysis of a two-machine flexible manufacturing cell'. M M Aldaihani , M Savsar . *Computers & Industrial* 2005.

[Stecke and Kim ()] 'A study of unbalancing and balancing for systems of pooled machines of unequal sizes'. K E Stecke , I Kim . *proceeding of IEEE International Conference on: Robotics and Automation*, (eeding of IEEE International Conference on: Robotics and AutomationAnn Arbor, Michigan) 1987. 4. The University of Michigan

[Stecke ()] 'Addressing industrial problems using various mathematical models'. K E Stecke . 10.1287/ited.5.3.8. *INFORMS Transactions on Education* 2005a. 5 (3) p. .

[Kimemia and Gershwin ()] 'An algorithm for the computer control production in FMS'. J G Kimemia , S B Gershwin . *IIE Transactions* 1983. 15 (4) p. .

[Land and Doig ()] *An automatic method of solving discrete programming problems*, A Land , A Doig . 1960.

[Yogeswaran et al. ()] 'An efficient hybrid evolutionary heuristic using genetic algorithm and simulated annealing algorithm to solve machine loading problem in FMS'. M Yogeswaran , S G Ponnambalam , M K Tiwari , U K Yusof , R Budiarto , S Deris . *3rd IEEE Conference on Data Mining and Optimization (DMO)*, (Selangor, Malaysia) 2009. 2011. June 2011. 149 p. . (Harmony search algorithm for flexible manufacturing system (FMS) machine loading problem)

[Sawik ()] 'An LP-based approach for loading and routing in a flexible assembly line'. T Sawik . *International Journal Production Economics* 2000. 64 p. .

[Solberg (1979)] 'Analytical performance of FMS'. J J Solberg . *Proceedings of the 18th IEEE conference on Decision and control*, (the 18th IEEE conference on Decision and controlSan Diego CA) 1979. December. p. .

[Wilson ()] 'Approaches to machine load balancing in flexible manufacturing systems'. J M Wilson . `http://www.jstor.org/stable/2583561` *The Journal of the Operational Research Society* 1992. 43 (5) p. .

[Nagarjuna et al. ()] *based on multi-stage programming approach for machine-loading problem in a flexible and Computer-Integrated Manufacturing*, N Nagarjuna , O Mahesh , K Rajagopal . 10.1016/j.rcim.2005.07.006. 2006. 22 p. .

[Kouvelis and Lee ()] 'Block angular structures and the loading problem in flexible manufacturing systems'. P Kouvelis , H L Lee . *Institute for Operations Research and the Management Sciences (INFORMS)* 1991. 39 (4) p. .

[Solberg ()] 'CAN-Q User's Guide'. J J Solberg . *NSF GRANT No. APR74 15256. West Lafayetee IN*, 1980. (Report)

[Petri ()] *Communication with Automata*, C A Petri . RADC-TR-65-377. 1966. (Technical Report) (Suppl-1)

[Kumar and Shanker ()] 'Comparing the effectiveness of workload balancing objectives in FMS loading'. N Kumar , K Shanker . *International Journal of Production Research* 2001. 39 (5) p. .

[Kiran ()] *Complexity of FMS loading and scheduling problems*, S Kiran . 1986. (Working Paper)

[Seidmann et al. ()] 'Computerized closed qeueing network models of flexible manufacturing systems: a comparative vealuation'. A Seidmann , P J Schweitzer , S Shalev-Oren . *Large Scale Systems* 1987. 12 p. .

[Yusof et al. ()] 'Constraint-chromosome genetic algorithm for flexible manufacturing system machine-loading problem'. U K Yusof , R Budiarto , S Deris . *International Journal of Innovative Computing, Information and Control* 2012. 8 (3) p. .

[O'grady ()] *Controlling Automated Manufacturing Systems*, P J O'grady . 1987. London: Chapman & Hall/ Kogam.

[Werra and De ()] 'Design and operation of flexible manufacturing systems : the kingdom of heuristic methods'. D Werra , De . *Operations Research* 1987. 21 (4) p. .

[Yaqoub and Abdulghafour ()] 'Development of Job Scheduling and Machine Loading System in FMS'. D Z H Yaqoub , D A B Abdulghafour . *Engineering & Technology Journal* 2012. 30 (7) p. .

[Turkcan et al. ()] 'Due date and cost-based FMS loading , scheduling and tool management'. A Turkcan , M S Akturk , R H Storer . 10.1080/00207540600559955. *International Journal of Production Research* 2007. 45 (5) p. .

[Roh and Kim Yeon ()] 'Due-date based loading and scheduling methods for a flexible manufacturing system with an automatic tool transporter'. H.-K Roh , -D Kim Yeon . *International Journal of Production Research* 1997. 35 (11) p. .

[Kinemia and Gershwin ()] 'Flow optimization in flexible manufacturing systems'. J G Kinemia , S B Gershwin . *International Journal of Production Research* 1985. 23 p. .

[Mukhopadhyay et al. ()] 'FMS machine loading: A simulated annealing approach'. S K Mukhopadhyay , M K Singh , R Srivastava . *International Journal of Production Research* 1998. 36 (6) p. .

[Rajagopalan ()] 'Formulation and heuristic solutions for parts grouping and tool loading in flexible manufacturing systems'. S Rajagopalan . *Proceedings of the Second ORSA/TIMS Conference on Flexible Manufacturing Systems*, (the Second ORSA/TIMS Conference on Flexible Manufacturing SystemsAnn Arbor) 1986.

[Stecke ()] 'Formulation and solution of nonlinear integer production planning problems for flexible manufacturing systems'. K E Stecke . 10.1287/mnsc.29.3.273. *Management Science* 1983b. 29 (3) p. .

[Yeung et al. ()] 'Fuzzy coloured Petri nets in modelling flexible manufacturing systems'. D S Yeung , J N K Liu , S C K Shiu , G S K Fung . *ISAI/ IFIS'96*, 1996. p. . (ITESM)

[Yang and Wu ()] 'GA-based integrated approach to FMS part type selection and machineloading problem'. H Yang , Z Wu . *International Journal of Production Research* 2002. 40 (16) p. .

[Kim and Yano ()] *Heuristic approaches for loading problems in flexible manufacturing systems*, Y.-D Kim , C A Yano . 87- 21. 1987. (Technical report)

[Stecke and Talbot ()] *Heuristic loading algorithms for Flexible Manufacturing System*, K E Stecke , F B Talbot . 1983. The University of Michigan (Working Paper No 348)

[Tiwari et al. ()] 'Heuristic solution approaches for combinedjob sequencing and machine loading problem in flexible manufacturing systems'. M K Tiwari , J Saha , S K Mukhopadhyay . 10.1007/s00170-005-0259-7. *International Journal of Advanced Manufacturing Technology* 2007. 31 p. .

[Stecke and Brian ()] 'Heuristics for loading flexible manufacturing systems'. K E Stecke , T F Brian . *Flexible manufacturing systems: recent developments*, A Raouf, M Ben-Daya (ed.) 1995. p. .

[Stecke and Talbot ()] 'Heuristics for loading flexible manufacturing systems, in Flexible Manufacturing: Recent Developments in FMS'. K E Stecke , B F Talbot . *Robotics, CAD-CAM, CIM*, A I Raouf & S, Ahmad (ed.) (Amsterdam) 1985. Elsevier Science Publishers. p. .

[Mazzola ()] 'Heuristics for the FMS/MRP rough-cut capacity planning problem'. J B Mazzola . *Proceedings of the Third ORSA/TIMS Conference on Flexible Manufacturing Systems: Operations Research Models and Applications*, (the Third ORSA/TIMS Conference on Flexible Manufacturing Systems: Operations Research Models and Applications) 1989.

[Polya ()] *Heuristics. In How To Solve It*, G Polya . 1945. 132 p. .

[Kimemia ()] *Hierarchical control of production in FMS. MIT Laboratory for Information and Decision System*, J G Kimemia . LIDS-TH-1215. 1982. (Report)

[Ozdamarl and Barbarosoglu ()] 'Hybrid heuristics for the multi-stage capacitated lot sizing and loading problem'. L Ozdamarl , G Barbarosoglu . *Journal of the Operational Research Society* 1999. 50 (8) p. .

[Mandal et al. ()] 'Incorporating dynamism in traditional machine loading problem : an AI-based optimisation approach'. S K Mandal , M K Pandey , M K Tiwari . *International Journal of Production Research* 2010. 48 (12) p. .

[Ming ()] 'Integrating machining speed, part selection and machine loading decisions in flexible manufacturing systems'. L Ming . *Computers & Industrial Engineering* 1994. 26 (3) p. .

[Mgwatu ()] 'Interactive decisions of part selection , machine loading , machining optimisation and part scheduling sub-problems for flexible manufacturing systems'. M I Mgwatu . *International Transaction Journal of Engineering* 2011. 2 (1) p. . (Management, & Applied Sciences & Technologies)

[Maria ()] 'Introduction to modeling and simulation'. A Maria . *Proceedings of the 1997 Winter Simulation Conference*, S Andradottir, K J Healy, D H Withers, B L Nelson (ed.) (the 1997 Winter Simulation Conference) 1997. p. .

[O'grady et al. ()] 'Issues in intelligent cell control for flexible manufacturing systems'. P J O'grady , H Bao , K H Lee . *Computers in Industry* 1987. 9 p. .

[Lee and Kim ()] 'Iterative procedures for multi-period order selection and loading problems in flexible manufacturing systems'. D.-H Lee , Y.-D Kim . *International Journal of Production Research* 1998. 36 (10) p. .

[Lu (1986)] 'Knowledge-based expert systems: A new horizon of manufacturing automation'. S C Lu , .-Y . *Winter Annual Meeting of the American Society of Mechanical Engineers*, (Anaheim, CA) 1986. December. p. . (Knowledge Based Expert Systems for Manufacturing)

[Petri ()] 'Kommunikation mit Automaten'. C A Petri . *Institut fur Instrumrntelle Mathematik, Schriften des IIM Nr. 3*, (Bonn) 1962.

[Kumar ()] Kumar . *2004, and Mandal et al. in 2010 (Mandal et al., 2010); with application of particle swarm optimization (PSO) by Biswas and Mahapatra in 2007 (Biswas & Mahapatra, 2007) and 2008 (Biswas & Mahapatra, 2008) and, Ponnambalam and Kiat*, Kumar (ed.) 1999. 1999. 2000. 2000. 2002. 2002. 2006. 2006. 2010. 2010. 2012. 2012. 2012. 1999. 2004. 2008. 2008. 2011. 1991. 1991. 1992. Yusof, Budiarto, & Deris. (with application of Harmony Search algorithm (HS) by Yusof in 2011. with application of approximation technique by Wilson in 1992. and with application of iterative algorithms by Lee et al. in 1997 (D.-H. Lee et al., 1997) and Lee and Kim in 1998 (D.-H)

[Stecke ()] *Linearized nonlinear MIP formulation for loading a Flexible Manufacturing System*, K E Stecke . 1981. The University of Michigan (Working Paper No 278)

[Lee and Kim ()] 'Loading algorithms for flexible manufacturing systems with partially grouped machines'. D.-H Lee , Y.-D Kim . *IIE Transactions* 2000. 32 p. .

[Stecke Kathryn and James ()] 'Loading and control policies for a flexible manufacturing system'. E Stecke Kathryn , Solberg James , J . 10.1080/00207548108956679. *International Journal of Production Research* 1981. 19 (5) p. .

[Tadeusz ()] 'Loading and scheduling of a flexible assembly system by integer programming'. Tadeusz . 10.1016/S0377-. *European Journal of Operational Research* 2004. 154 p. .

[Kusiak ()] *Loading models in flexible manufacturing systems, recent developments in FMS and allied areas. In The Design and Operation of FMS*, A Kusiak . 1983. New York: North Holland.

[Ventura et al. ()] 'Loading tools to machines in flexible manufacturing systems'. J A Ventura , C F Frank , M S Leonard . *Computers & Industrial Engineering* 1988. 15 (1-4) p. .

[Rahimifard and Newman ()] 'Machine loading algorithms for the elimination of tardy jobs in flexible batch machining applications'. S Rahimifard , S T Newman . *Journal of Materials Processing Technology* 2000. 107 p. .

[Rajamani and Adil ()] 'Machine loading in flexible manufacturing systems considering routeing flexibility'. D Rajamani , G K Adil . *International Journal of Advanced Manufacturing Technology* 1996. 11 p. .

[Vidyarthi and Tiwari ()] 'Machine loading problem of FMS: A fuzzy-based heuristic approach'. N K Vidyarthi , M K Tiwari . *International Journal of Production Research* 2001. 39 (5) p. .

[Rai et al. ()] 'Machine-tool selection and operation allocation in FMS: Solving a fuzzy goal-programming model using a genetic algorithm'. R Rai , S Kameshwaran , M K Tiwari . 10.1080/00207540110081515. *International Journal of Production Research* 2002. 40 (3) p. .

[Kosucuoglu and Bilge ()] 'Material handling considerations in the FMS loading problem with full routing flexibility'. D Kosucuoglu , U Bilge . *International Journal of Production Research* 2012. 50 (22) p. .

[Reiser and Lavenberg ()] 'Mean value analysis of closed multichaia queueing networks'. M Reiser , S S Lavenberg . RC 7023. *IBM Res. Rpt. RC* 1978. 7023. (No. Res. Report)

[Reiser and Lavenberg ()] 'Mean value analysis of closed multichain queueing networks'. M Reiser , S S Lavenberg . *Journal of ACM* 1980. 27 (2) p. .

[Swarnkar and Tiwari ()] 'Modeling machine loading problem of FMSs and its solution methodology using a hybrid tabu search and simulated annealing-based heuristic approach'. R Swarnkar , M K Tiwari . 10.1016/j.rcim.2003.09.001. *Robotics and Computer-Integrated Manufacturing* 2004. 20 p. .

[Suri and Hildebrant ()] 'Modelling flexible manufacturing systems using mean value analysis'. R Suri , R R Hildebrant . *Journal of Manufacturing Systems* 1984. 3 (1) p. .

[Tang and Denardo ()] 'Models arising from a flexible manufacturing machine -Part II: minimization of the number of switching instants'. S Tang , E Denardo . *Operations Research* 1988. 36 (5) p. .

[Prakash et al. ()] 'Modified immune algorithm for job selection and operation allocation problem in flexible manufacturing systems'. A Prakash , N Khilwani , M K Tiwari , Y Cohen . 10.1016/j.advengsoft.2007.01.024. *Advances in Engineering Software* 2008. 39 p. .

[Taboun and Ulger ()] 'Multi-objective modelling of operation-allocation problem in flexible manufacturing systems'. S M Taboun , T Ulger . *Computers and Industrial Engineering* 1992. 23 (1-4) p. .

[Lee et al. ()] 'Multi-period part selection and loading problems in flexible manufacturing systems'. D.-H Lee , S.-K Lira , G.-C Lee , H.-B Jun , Y.-D Kim . *Computers and Industrial Engineering* 1997. 33 (3-4) p. .

[Kumar et al. ()] 'Multicriterion analysis of the loading problem in flexible manufacturing systems using min-max approach'. P Kumar , N Singh , N K Tewari . *The International Journal of Advanced Manufacturing Technology* 1987. 2 (2) p. .

[Stecke ()] *Nonlinear MIP formulation of production planing problems in flexible manufacturing systems*, K E Stecke . 1982. (Working Paper no)

[Yusof et al. ()] 'of bio-inspired and musical-composition approach'. U K Yusof , R Budiarto , I Venkat . 10.1109/BIC-TA.2011.10. doi:10.1080. *Sixth International Conference on Bio-Inspired Computing: Theories and Applications*, 2011. 19. IEEE. 47 p. .

[Vinod and Sabbagh ()] 'Optimal performance analysis of manufacturing systems subject to tool availability'. B Vinod , M Sabbagh . *European Journal of Operational Research* 1986. 24 p. .

[Stecke and Morin ()] 'Optimality of balanced workloads in Flexible Manufacturing Systems'. K E Stecke , T L Morin . *European Journal of Operational Research* 1984. (working Paper No. 289-C)

[Stecke and Morin ()] 'Optimality of balancing workloads in certain types of flexible manufacturing systems'. K E Stecke , T L Morin . *European Journal of Operational Research* 1985. 20 p. .

[Abazari et al. ()] 'Optimum loading of machines in a flexible manufacturing system using a mixed-integer linear mathematical programming model and genetic algorithm'. A M Abazari , M Solimanpur , H Sattari . 10.1016/j.cie.2011.10.013. *Computers & Industrial Engineering* 2012. 62 (2) p. .

[Liang ()] 'Part selection, machine loading, and machine speed selection in flexible manufacturing systems'. M Liang . *Computers and Industrial Engineering* 1993. 25 (1-4) p. .

[Nayak and Acharya ()] 'Part type selection, machine loading and part type volume determination problems in FMS planning'. G K Nayak , D Acharya . *International Journal of Production Research* 1998. 36 (7) p. .

[Shanthikumar and Stecke ()] *Reducing work in process inventory in certain class of FMS*, J G Shanthikumar , K E Stecke . 1984. Ann Arbor MI.

[References Références Referencias] *References Références Referencias*,

[Lee and Dicesare ()] 'Scheduling flexible manufacturing systems using Petri nets and heuristic search'. D Y Lee , F Dicesare . *IEEE Transactions on Robotics and Automation* 1994. 10 (2) p. .

[Kusiak and Finke ()] 'Selection of process plans in automated manufacturing systems'. A Kusiak , G Finke . *IEEE Journal of Robotics and Automation* 1988. 4 p. .

[Liang and Dutta ()] *Solving a combined part selection, machine loading, and tool configuration problem in flexible manufacturing systems*, M Liang , S P Dutta . 10.1111/j.1937-5956.1993.tb00093.x. 2009. Production and Operations Management. 2 p. .

[Ponnambalam and Kiat ()] 'Solving machine loading problem in flexible manufacturing systems using particle swarm optimization'. S G Ponnambalam , L S Kiat . *World Academy of Science, Engineering and Technology* 2008. 2 p. .

[Tiwari and Vidyarthi ()] 'Solving machine loading problems in a flexible manufacturing system using a genetic algorithm based heuristic approach'. M K Tiwari , N K Vidyarthi . 10.1080/002075400418298. *International Journal of Production Research* 2000. 38 (14) p. .

[Kumar et al. ()] 'Solving machine-loading problem of a flexible manufacturing system with constraintbased genetic algorithm'. A Kumar , Prakash , M K Tiwari , R Shankar , A Baveja . 10.1016/j.ejor.2005.06.025. *European Journal of Operational Research* 2006. 175 p. .

[Mahmudy et al. ()] 'Solving part type selection and loading problem in flexible manufacturing system using real coded genetic algorithms -Part II : optimization'. W F Mahmudy , R M Marian , L H S Luong . *World Academy of Science, Engineering and Technology* 2012. 69 p. .

[Tiwari et al. ()] 'Solving part-type selection and operation allocation problems in an FMS : an approach using constraints-based fast simulated annealing Algorithm'. M K Tiwari , S Kumar , S Kumar , Prakash , R Shankar . *IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans* 2006. 36 (6) p. .

[Shankar and Srinivasulu ()] *Some selection methodologies for loading problems in a Year*, K Shankar , A Srinivasulu . 1989. 2015.

[Simpson et al. ()] 'The automated manufacturing research facility of the National Bureau of Standards'. J A Simpson , R J Hocken , J S Albus . *Journal of Manufacturing System* 1982. 1 p. .

[Sarin and Chen ()] 'The machine loading and tool allocation problem in a flexible manufacturing system'. S C Sarin , C S Chen . 10.1080/00207548708919897. *International Journal of Production Research* 1987. 25 (7) p. .

[Stecke and Solberg ()] 'The optimality of unbalancing both workloads and machine group sizes in closed queueing networks of multi-server queues'. K E Stecke , J J Solberg . *Operational Research* 1985. 33 p. .

[Lee and Kim ; Yogeswaran ()] 'TS-SA hybrid algorithm by Murat & Erol in 2012 (Murat & Erol, 2012), constraint method by Sujono and Lashkari'. & Lee , Kim ; Yogeswaran . *The loading problem of FMS has also been solved by techniques like TS-SA hybrid algorithm by Swarnkar and Tiwari in 2004 (Swarnkar & Tiwari*, Kumar (ed.) 1998. 2004. 2009. 2009. 2011. 2011. 2012. 2007. 2007. 2010. Sujono & Lashkari. (Sequential and simultaneous approaches by Turkcan et al. in 2007 (Turkcan et al., 2007) and artificial immune system (AIS) by Mandal. et al. in 2010 (Mandal et al.)

[Stecke ()] 'Using mathematics to solve some problems in industry'. K E Stecke . *INFORMS Transactions on Education* 2005b. 5 (2) p. .

[Romanycia and Pelletier ()] 'What is a heuristic ?'. M H J Romanycia , F J Pelletier . *Computer Intelligance* 1985. 1 p. .