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

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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.

Keywords: flexible manufacturing system (fms), loading in fms, modelling of fms, mathematical modelling of fms, artificial intelligence in FMS.

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AREVIEWOFMODELLINGTECHNIQUESFORLOADINGPROBLEMSINFLEXIBLEMANUFACTURINGSYSTEM

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

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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. The modelling approaches and techniques in the paper are classified into three categories; hierarchical approach, mathematical modelling and artificial approaches. The solution approaches used are discussed with the modelling approaches respectively. A majority of research paper modelled FMS's, production planning problems, loading problem of FMS as mathematical model. This paper provides insight of different modelling approaches proposed in the literature to tackle the FMS problems during the last few decades.

Keywords: flexible manufacturing system (fms), loading in fms, modelling of fms, mathematical modelling of fms, artificial intelligence in FMS.

I. Introduction

To 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, 1983b) needs to be solved before solving scheduling problem. Solution of production planning problem is the pre-requisite 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.

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

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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)*,* Chan and Swarnkar *in 2006* (Chan & Swarnkar, 2006)*,* Petrovic and Akoz *in 2008* (Petrovic & Akoz, 2008) *and Rai et al. in 2012* (Rai, Kameshwaran, & Tiwari, 2002), with *neural and a fuzzy Petri net* by Kumar et al. in 2004 (R. R. Kumar, Singh, & Tiwari, 2004), with *artificial immune algorithm* by Prakash et al. in 2008 (Prakash, Khilwani, Tiwari, & Cohen, 2008) and with *artificial neural network* by Kant and Vaishya in 2013 (Kant & Vaishya, 2013).

The FMS problems modelled with AI techniques have been solved with application of *fuzzy-logic* by Vidyarthi and Tiwari in 2001 (Vidyarthi & Tiwari, 2001), Kumar et al. in 2004 (R. R. Kumar et al., 2004) and Petrovic and Akoz in 2008 (Petrovic & Akoz, 2008), with application of *GA by Rai et al. in 2002* (Rai et al., 2002), with application of *Ant Colony Optimization (ACO*) by Chan and Swarnkar in 2006 (Chan & Swarnkar, 2006), with application of *Artificial Immune Algorithm* by Prakash et al. in 2008 (Prakash et al., 2008) and with application of *Artificial Neural Network (ANN) by* Kant and Vaishya *in 2013* (Kant & Vaishya, 2013).

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).

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 Kim and Yano in 1987 and 1989 (Y.-D. Kim & Yano, 1987)(Y.-D. Kim & Yano, 1989). The loading problem formulated by branch and bond methods has been solved with application of *branch and bound approach* by Kim and Yano in 1987 and 1989 (Y.-D. Kim & Yano, 1987)(Y.-D. Kim & Yano, 1989).

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)*,* Stecke and Talbot (Stecke & Talbot, 1985), Ammons et al. (Ammons, Lofgren, & McGinnis, 1985) and, Shankar and Tzen (Shankar & Tzen, 1985) in *1985,* Rajagopalan in 198*6*(Rajagopalan,

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1986), *Kim and Yano in 1987* (Kim Yeong-Dae and Yano Candace A., 1987), Tang *and* Denardo in *1988* (Tang & Denardo, 1988), Shankar *and* Srinivasulu *in 1989* (Shankar & Srinivasulu, 1989), *Kim and Yano in 1991* (Y. D. Kim & Yano, 1991), Mukhopadhyay et al. in 1992 (Mukhopadhyay, Midha, & Murlikrishna, 1992), Oba and Hashimot in *1993* (Kato, Oba, & Hashimot, 1993), *Roh and Kim* (Roh H.-K. and Kim Yeon-D., 1997) and, Hsu and De-Matta (Hsu & De-Matta, 1997) in 1997, Farkas et al. in *1999* (Farkas, Koltai, & Stecke, 1999), Rahimifard and Newman (Rahimifard & Newman, 2000) *and,* Tiwari and Vidyarthi (M. K. Tiwari & Vidyarthi, 2000) in *2000,* Tiwari *et al. in 2007* (M K Tiwari, Saha, & Mukhopadhyay, 2007) *and,* Biswas *and* Mahapatra *in 2009* (Biswas & Mahapatra, 2009); sequential *heuristic* by Shankar and Tzen in 1985 (Shankar & Tzen, 1985); and branch and backtrack with *heuristics by* Shankar and Srinivasulu in 1989 (Shankar & Srinivasulu, 1989).

The solution to the heuristics modelled loading problems were discussed with application of heuristics by Stecke and Talbot *in 1983*(Stecke & Talbot, 1983), *Kim and Yano in 1987* (Y.-D. Kim & Yano, 1987), Shankar and Srinivasulu in 1989 (Shankar & Srinivasulu, 1989), Mukhopadhyay et al. in 1992 (Mukhopadhyay et al., 1992), Hsu and De-Matta (Hsu & De-Matta, 1997) and, Roh and Kim (Roh H.-K. and Kim Yeon-D., 1997) in 1997, Farkas et al. in 1999 (Farkas et al., 1999) and, Rahimifard and Newman in 2000 (Rahimifard & Newman, 2000); with application of *branch & bound, and branch & backtrack method* by Kato et al. in 1993 (Kato et al., 1993); with application of *GA by Tiwari and Vidyarthi in 2000* (M. K. Tiwari & Vidyarthi, 2000) *and Tiwari in 2007* (M K Tiwari et al., 2007); with application of *meta hybrid PSO* by Biswas & Mahapatra in 2009 (Biswas & Mahapatra, 2009); and software *simulation by* Shankar & Tzen *in 1985* (Shankar & Tzen, 1985).

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 of FMS by Buzacott and Shanthikumar in 1980 (Buzacott & Shanthikumar, 1980), modelling of automated manufacturing system by Simpson et al. in 1982 (Simpson, Hocken, & Albus, 1982) and modelling of loading and some other FMS problems by Bell and Bilalis in 1982 (Bell & Bilalis, 1982), Eversheim and Fromm in 1983 (Eversheim & Fromm, 1983) , Stecke in 1983a (Stecke, 1983a) and 1983b (Stecke, 1983b), CAM-I in 1984 (CAM-I, 1984), O'Grady et al. in 1987 (O'Grady, Bao, & Lee, 1987) and O'Grady in 1987 (O'Grady, 1987) has been carried out using hierarchical approach. A hierarchical model for integration of FMS production planning into a closed-loop material requirements planning (MRP) environment was proposed by Mazzola in 1989 (Mazzola, 1989).

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).

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). 0-1 nonlinear MIP formulation of the manufacturing systems was utilized in 1984 by Chatterjee et al. (Chatterjee, Cohen, Maxwell, & Miller, 1984). MIP formulation of the routing mix problem was carried out by Chatterjee et al. in 1984 (Chatterjee et al., 1984). Ammons et al. formulated IP model of loading problems in assembly lines in 1985 (Ammons et al., 1985) and Hwang developed IP model of FMS problems in 1986 (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), Lee et al. in 1997 (D.-H. Lee, Lira, Lee, Jun, & Kim, 1997) and Kim et al. in 2012 (H. Kim et al., 2012) utilized LIP formulation; Stecke in 1983 and 1986 (Stecke, 1983b)(Stecke, 1986) discussed non-linear IP formulation; Wilson in 1992 (Wilson J. M., 1992), Lee and Kim in 1998 (D.-H. Lee & Kim, 1998), 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 1985 (A. S. Kiran & Tansel, 1985), Kiran in 1986 (S. Kiran, 1986), Nayak and Acharya in 1998 (Nayak & Acharya, 1998), Turkcan et al. in 2007 (Turkcan, Akturk, & Storer, 2007), Ozpeynirci and Azizoglu in 2010 (Ozpeynirci & Azizoglu, 2010), Mandal et al. in 2010 (Mandal, Pandey, & Tiwari, 2010)and Kosucuoglu and Bilge in 2012 (Kosucuoglu & Bilge, 2012).

Abazari et al. in 2012 (Abazari, Solimanpur, & Sattari, 2012) discussed linear mathematical programming for the loading problems.

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

0-1 Linear MIP is utilized by Chakravarty and Schtub in 1984 (Chakravarty & Schtub, 1984), Co in 1984 (H. C. Co, 1984), Ammons et al. in 1985 (Ammons et al., 1985), Shankar and Tzen 1985 (Shankar & Tzen, 1985), Greene and Sadowski in 1986 (Greene & Sadowski, 1986) and Sarin and Chen in 1987 (Sarin & Chen, 1987); nonlinear MIP by Berrada and Stecke in 1986 (Berrada & Stecke, 1986)and Stecke and Brian in 1995(Stecke & Brian, 1995); linear MIP by Ventura et al. in 1988 (Ventura, Frank, & Leonard, 1988); and 0–1 MIP by Gamila and Motavalli in 2003 (Gamila & Motavalli, 2003) and Chan et al. in 2004 (Chan, Swamkar, & Tiwari, 2004) for loading problems of FMS.

Nonlinear and integer constraint was utilized by Kouvelis & Lee in 1991 (Kouvelis & Lee, 1991), non linear goal programming model by Kumar et. al. in 1991 (P. Kumar, Singh, & Tewari, 1991) and goal programming model by Atmaca & Erol in 2000 (Atmaca & Erol, 2000) for modelling loading problem of FMS were observed in the literature.

The mathematical formulated problems have been solved with application of *branch and bound algorithm* by Berrada and Stecke in 1986 (Berrada & Stecke, 1986); with application of *linearization methods by Stecke in 1981* (Stecke, 1981) *and 1983* (Stecke, 1983b), *and* Jahromi and Tavakkoli *in 2012* (Jahromi & Tavakkoli-Moghaddam, 2012); with application of *lagrangian approach* by Kinemia and Gershwin in 1985 (Kinemia & Gershwin, 1985), Sarin and Chen in 1987 (Sarin & Chen, 1987), Bilgin and Azizoglu in 2006 (Bilgin & Azizoglu, 2006) and Ozpeynirci and Azizoglu in 2010 (Ozpeynirci & Azizoglu, 2010); with application of *min-max approach* by Kumar et al. in 1987 (Kumar P., Singh N., & Tewari N. K., 1987); with application of *heuristics* by Ventura et al. in 1988 (Ventura et al., 1988), Stecke and Brian in 1995 (Stecke & Brian, 1995), Nayak and Acharya in 1998 (Nayak & Acharya, 1998), Lee and Kim in 2000 (D.-H. Lee & Kim, 2000), Dobson and Nambimadom in 2001 (Dobson & Nambimadom, 2001), Nagarjuna et al. and, (Nagarjuna et al., 2006) Goswami and Tiwari (Goswami & Tiwari, 2006) in 2006, and Kim et al. in 2012 (H. Kim et al., 2012).

The loading problem has been solved with application of *genetic algorithm (GA)* by Ozdamarl and Barbarosoglu in 1999 (Ozdamarl & Barbarosoglu, 1999), Kumar and Shanker (N. Kumar & Shanker, 2000) and Sawik (Sawik, 2000) in 2000, Yang and Wu in 2002 (Yang & Wu, 2002), Kumar et al. in 2006 (A. Kumar et al., 2006), Mandal et al. in 2010 (Mandal et al., 2010), and Yusof et al. (Yusof et al., 2012), Kosucuoglu and Bilge (Kosucuoglu & Bilge, 2012), and Abazari et al. (Abazari et al., 2012) in 2012; with application of *simulated annealing (SA) by* Ozdamarl and Barbarosoglu *in 1999* (Ozdamarl & Barbarosoglu, 1999), Chan et al. (Chan et al., 2004) *and* Tadeusz (Tadeusz, 2004) *in 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 in 2008 (Ponnambalam & Kiat, 2008); with application of *Harmony Search algorithm (HS)* by Yusof in 2011 (Yusof, Budiarto, & Deris, 2011); with application of *box complex method* by Kumar et al. in 1991 (P. Kumar et al., 1991); with application of *approximation technique* by Wilson in 1992 (Wilson J. M., 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. Lee & Kim, 1998).

The loading problem of FMS has also been solved by techniques like *TS–SA hybrid algorithm* by Swarnkar and Tiwari in 2004 (Swarnkar & Tiwari, 2004), *GA-SA Hybrid algorithm* by Yogeswaran et al. in 2009 (Yogeswaran et al., 2009), *GA-HS hybrid algorithm* by Yusof et al. in 2011 (Yusof, Budiarto, & Venkat, 2011), *GA-PSO hybrid heuristic algorithm* by Kumar et al. in 2012 (V. M. Kumar et al., 2012), *TS-SA hybrid algorithm* by Murat & Erol in 2012 (Murat & Erol, 2012), *constraint method* by Sujono and Lashkari in 2007 (Sujono & Lashkari, 2007), *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., 2010).

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).

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 & Shanthikumar, 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) and Vinod and Sabbagh in 1986 (Vinod & Sabbagh, 1986), with *OQN by* Shanthikumar & Stecke *in 1984* (Shanthikumar & Stecke, 1984), with *CANQ by* Stecke and Solberg (Stecke & Solberg, 1985) and Stecke and Morin (Stecke & Morin, 1985) *in 1985 and* Afentakis *in 1989* (Afentakis, 1989).

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 for queueing network models, to overcome the 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 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).

Perturbation modelled FMS loading problem has been solved with application of SA in by Mukhopadhyay et al. 1998 (Mukhopadhyay et al., 1998).

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).

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* Cohen et al. *in 1983* (Cohen et al., 1983), with *Petri nets* by Narahari and Viswanadham in 1985 (Narahari & Viswanadham, 1985), with generalized *stochastic Petri nets* (GSPN) by Narahari et al. in 1990 (Narahari et al., 1990), with *stochastic Petri nets by* Vishwanadham et al. *in 1992* (Vishwanadham et al., 1992), with *Petri net* combined with heuristic by Lee and DiCesare in 1994 (D. Y. Lee & DiCesare, 1994), with *fuzzy coloured Petri nets* (CPNs) by Yeung et al. in 1996 (Yeung, Liu, Shiu, & Fung, 1996), with *colored Petri net* (CPN) based hierarchical model by Al-Titinchi and Al-Aubidy in 2004 (Al-Titinchi & Al-Aubidy, 2004). *Petri net* modelling has been used for loading problems of FMS by Tiwari et al. in 1997 (Tiwari M. K., Hazarika B., Vidyarthi N.K., 1997). Solution of the loading problem modelled using Petri nets has been done using *heuristics by Tiwari et al. in 1997* (Tiwari M. K., Hazarika B., Vidyarthi N.K., 1997).

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).

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 object-oriented paradigm, and implemented with QUEST/IGRIP software by Kim and Choi in 2000 (S. Kim & Choi, 2000). Computer simulation package Simfactory II.5 has been used for modelling loading problem of FMS by Gupta in 1999 (Gupta, 1999).

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).

Table 1: Distribution density of FMS modelling methods

	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
1																			
2													√						
3											√		√						
4							√		√	√	√	√	√		√	√	√	√	
5						√	√	√			√		√						
6																√			
7					√	√	√	√	√	√	√	√		√	√	√			√
8											√								
9	√		√	√				√	√	√	√		√	√		√			
10																			
11							√		√					√		√			
12																	√	√	
13																			
14															√				

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
1						√	√		√		√		√					√
2																		
3																		
4		√		√	√							√		√				
5																		
6										√								
7	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
8																		
9													√					
10			√															
11	√	√							√									
12														√				
13				√	√													
14																		

Notations used in table 1

1. Artificial Intelligence
2. Branch and Backtrack Approach
3. Branch and Bound Approach
4. Heuristic Approaches
5. Hierarchical Model
6. Markov Chains
7. Mathematical Modelling
8. Multi-Criterion Programming
9. Network Modelling
10. Perturbation Approach

11. Petri Nets
12. Sequential Approach
13. Simulation Models
14. Unit Operation Approach

Figure 1: Modelling methods for the loading problems of FMS (1981-2013)

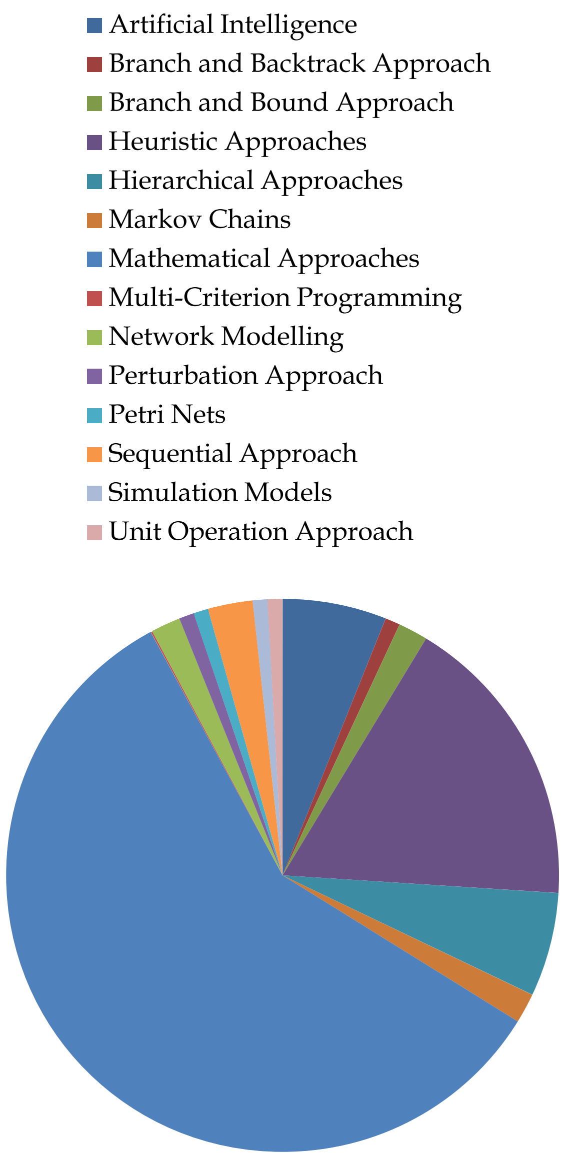
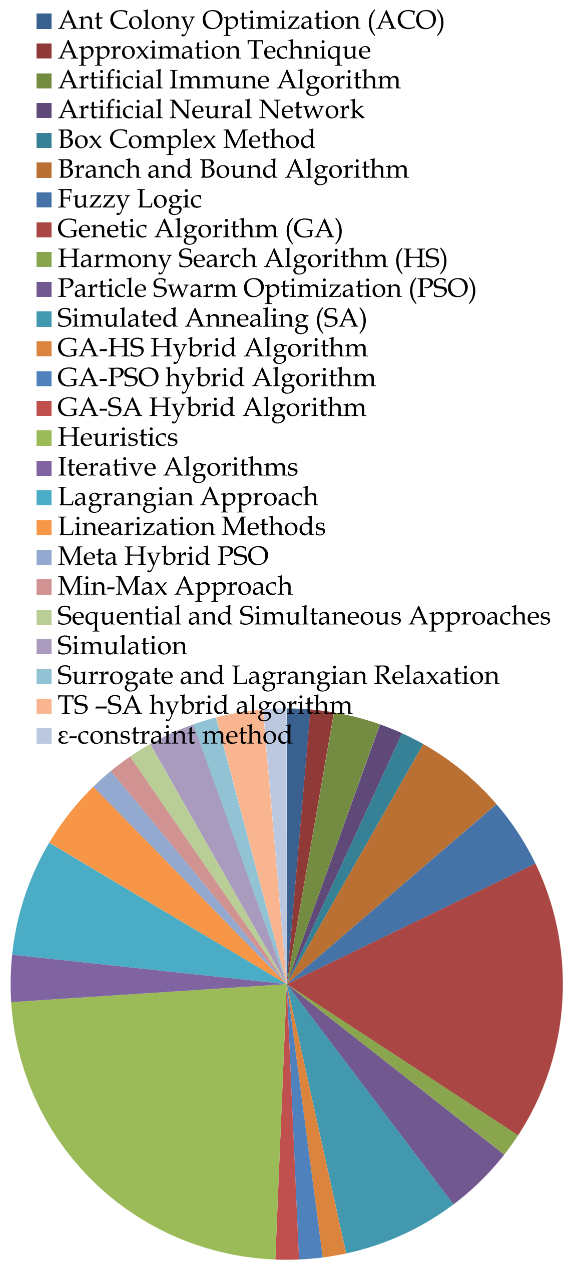
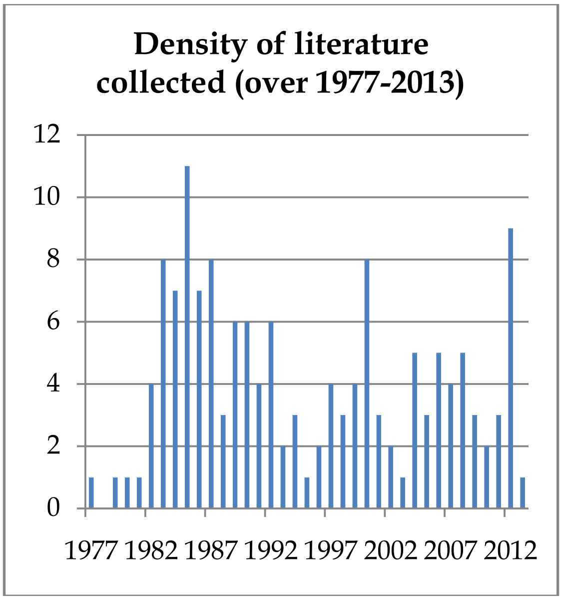


Figure 2 : Solution methodologies for loading problems of FMS





Accuracy, results acceptability and adaptability, computational time and cost are the major factors for selection of the type of modelling for a particular application, particularly loading problems of FMS.

III. 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 ε-constraint method.

Heuristics solutions do not assure optimal solution (Manoj Kumar Tiwari, Kumar, Kumar, Prakash, & Shankar, 2006), 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.

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