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A Critical Review of Machine Loading Problem in Flexible Manufacturing System

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Abstract

Production planning is the foremost task for manufacturing firms to deal with, especially adopting Flexible Manufacturing System (FMS) as the manufacturing strategy for production seeking an optimal balance between productivity-flexibility requirements. Production planning in FMS provides a solution to problems regarding part type selection: machine grouping, production ratio, resource allocation and loading problem. These problems need to be solved optimally for maximum utilization of resources. Optimal solution to these problems has been a focus of attention in production and manufacturing, industrial and academic research since a number of decades. Evolution of new optimization techniques, software, technology, machines and computer languages provides the scope of a better optimal solution to the existing problems. Thus there remains a need of research to solve the problem with latest tools and techniques for higher optimal use of available resources. As an objective, the researchers need to reduce the computational time and cost, complexity of the problem, solution approach viz. general or customized, better user friendly communication with machine, higher freedom to select the desired objective(s) type(s) for optimal solution to the problem. As an approach to the solution to the problem, a researcher first needs to go for an exhaustive literature review, where the researcher needs to find the research gaps, compare and analyze the tools and techniques used, number of objectives considered for optimization and need, and scope of research for the research problem. The present study is a review paper analyzing the research gaps, approach and techniques used, scope of new optimization techniques or any other research, objectives considered and validation approaches for loading problems of production planning in FMS.

Keywords

Flexible Manufacturing Systems (FMS), Machines Loading, Loading Objectives, Production Planning, Optimization

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1. Introduction

Manufacturing is the pilot element within the overall enterprise. Possible manufacturing outputs of the firm to meet pre-determined corporate level goals should be known to remain in competition at global market. Manufacturing strategy writes the script to calculate possible manufacturing outputs. Existence of the manufacturing strategy guides daily decisions and activities with clear understanding of decision-goal relationship of the corporation and provides a vision for the firm to remain aligned with the overall business strategy of the firm. The firms having manufacturing strategies for achieving corporate goals survive for long run. A strategy is also a strong communication tool between different levels of management to bring all operations in line with corporate objectives. Custom manufacturing, continuous manufacturing, intermittent manufacturing, flexible manufacturing, just-in-time manufacturing, lean manufacturing and agile manufacturing are major manufacturing strategies revealed in the literature.

FMS is an automated manufacturing system consisting of computer numerical control (CNC) machines with automated material handling, storage and retrieval system. The aim of FMS is to attain the efficiency of mass production while utilizing the flexibility of job shop simultaneously. FMS is adopted for batch production of mid production volume and mid part variety (flexibility) requirements. Since its evolution, researchers are working for optimality of FMS strategy. FMS is a field of great potential hence a numerous complex planning problems need to be solved. Major complex production planning problems are part type selection: machine grouping, production ratio, resource allocation and loading problem (Stecke, 1983). All the production planning problems need to be optimally solved. The present research is the critical literature review for the loading problem of production planning in FMS.

Tooling individual or group of machine(s) to collectively accomplish all manufacturing operations concurrently for all part type in a batch is termed as loading problem. A solution to the problem specifies the machine(s) to which a job has to be routed in sequence for each of its operation(s) with respective tooling under capacity and technological constraint(s) for all jobs in a batch simultaneously to achieve certain objective(s). Loading is a complex combinational planning problem because a batch of jobs is to be machined simultaneously and each job requires unique set of operations effect on manufacturing cost.

To solve the problem, highly experienced and skilled professionals are required. Without the use of some computational or optimization technique, the solution may or may not be optimal. Thus there arises the need of optimal solution with the help of computational methods using optimization techniques. The paper is a critical review paper analyzing the research gaps, approach and techniques used, scope of new optimization techniques or any other research, objectives considered and validation approaches for loading problems of production planning in FMS.

2. Literature Review of Loading Problems in FMS

In brief, to solve a problem using optimization techniques and computational analysis, objective(s) are first set, the physical system is modelled using certain technique like mathematical modelling, the solution is then derived under given boundary conditions and constraints to achieve the given objectives, the results are then analysed and the solution approach is then validated. Heuristics has been widely used by the researchers. **Table 1** presents the tabulated research review discussing the approach, objectives and results of the loading problems in FMS. Flexible manufacturing is an overall pilot element within an enterprise. Each multinational manufacturing concern has to satisfy business goals to remain in competition with the global market. The manufacturing firm should be aware of the possible manufacturing outputs that will closely match the goals and strategy determined at the corporate level. The existence of a manufacturing strategies guide the daily decisions and activities with clear understanding of how those daily decisions relate to the overall goals of the corporation. The firms having manufacturing strategies for achieving corporate goals survive long. A manufacturing strategy provides a vision to the manufacturing organization for keeping itself aligned with the overall business strategy of the corporation. A strategy is also a strong communication tool between different levels of management to bring all operations in line with corporate objectives. Custom manufacturing, continuous manufacturing, intermittent manufacturing, flexible manufacturing, just-in-time manufacturing, lean manufacturing and agile manufacturing are the major manufacturing strategies which are revealed in literature.

FMS is an automated manufacturing system consisting of numerical control (computer) machines with automated material handling, automated storage and retrieval system. The aim of FMS is to attain the efficiency of

Table 1. Review of machine loading problems in FMS based on heuristics approach.

HEURISTIC APPROACH						
Sr. Year	Researcher Name	Approach	Objectives	Results	Validation approach	
1 1983	K. E. Stecke & F. Brian Talbot [2]	Heuristic methods	➢ Minimizing part movements ➢ Balancing of workload ➢ Unbalancing of workload	Determined how machine tool magazine in a FMS can be loaded to meet simultaneous requirements of a number of different parts	Computational results are presented	
2 1985	K. Shankar & Y. J. Tzen [14]	Heuristic methods	➢ Minimizing system unbalance ➢ Number of late jobs ➢ Balancing of workload	Computational results presented gives improved results	performance is compared with previous results from literature	
3 1988	J. A. Ventura, F. F. Chen, & M. S. Leonard [15]	Heuristic algorithms	➢ Minimizing make span	Improved Performance	The performance of each of the proposed algorithms is evaluated by testing on two hypothetical FMSs.	
4 1990	B. Ram, S. Sarin, & C. S. Chen [16]	Fast heuristic algorithms	➢ Maximizing throughput	FMS loading problem can be solved near optimally in short time	Computational results are produced and compared with previous results	
5 1992	S. K. Mukhopadhyay, S. Midha, & V. Murlikrishna [17]	Heuristic procedure	➢ Minimizing system unbalance ➢ Maximizing throughput	Results show that algo developed is very reliable and efficient	tested on ten problems and are compared with existing results	
6 1993	K. Kato, F. Oba, & F. Hashimoto [18]	Heuristic approach	➢ Minimizing total number of cutting tools required ➢ Maximizing utilization rate of each machine	Computational results shows improved effectiveness	Computational results are given to demonstrate the effectiveness of the proposed method	
7 1995	E. K. Steeke & F. Brian Talbot [19]	Heuristic Algorithms	➢ Minimizing part movements ➢ balancing of workload ➢ unbalancing of workload	Results are computationally demonstrated & found improved significantly	Computational results are produced and compared with previous results	
8 1997	M. K. Tiwari *et al.* [20]	Heuristic solution approach	➢ Maximizing throughput ➢ Minimizing system unbalance	Graphical representation and subsequent model validation	Computational results are produced and compared with previous results	
9 1998	G. K. Nayak & D. Acharya [21]	Heuristics and mathematical programming approaches	➢ Maximizing part types in each batch ➢ Maximizing routing flexibility of batches	Heuristic proposed for part type selection & simple mathematical programs for other two problems	Computational results are compared with existing results	
10 2000	D.-H. Lee & Y.-D. Kim [22]	Heuristic algorithms	➢ Minimizing maximum workload of machines	Results show that suggested algos perform better than existing	Simulation results are compared with existing results	
11 2006	N. Nagarjunaa, O. Maheshb, & K. Rajagopal [23]	Heuristic based on multi stage programming approach	➢ Minimizing system unbalance	Bring together productivity of flow lines and flexibility of job shops	Tested on 10 sample problems available in FMS literature and compared with existing solution methods	
12 2006	M. Goswami & M. K. Tiwari [24]	Heuristic-based approach	➢ Minimizing system unbalance ➢ Maximizing throughput	Loading problem is crucial link between tactical planning and operational decisions	Extensive computational experiments have been carried out to assess the performance of the proposed heuristic and validate its relevance	
13 2007	M. K. Tiwari, J. Saha, & S. K. Mukhopadhyay [25]	Heuristic Solution Approaches	➢ Minimizing system unbalance ➢ Maximizing throughput	GA based heuristic are found more efficient and outperform in terms of solution quality	tested on problems representing three different FMS scenarios from available literature	

mass production while utilizing the flexibility of job shop simultaneously. Most of the researches are focused on increasing the production volume of FMS with increased part varieties. FMS is an interesting field of research to solve the issues and problems encountered by industries. Though FMS has great potential benefits, a numerous control and planning problem need to be taken care of. Kathryn E. Stecke in 1983 described five complex productions planning problems namely part type selection problem, Machine Grouping Problem, production ratio problem, resource allocation problem and loading problem [1].

Loading means allocation of the operations and required tools to a part types among the set of machine(s), subjected to resource & technological constraints to collectively accomplish all manufacturing operations for each pat type machined concurrently. The allocation of workloads to the existing production facilities for manufacturing products with several constraints in order to perform production activities according to the production plan established, it is essential to adjust the workload for each of the facilities and workers in each time period so they are not assigned work exceeding the given capacity. A solution to this problem specifies the tools which must be loaded in each machine tool magazine and the machine(s) to which a part can be routed for each of its operations before production begins. A variety of products are manufactured simultaneously in FMS, where each part requires potentially unique set of operations, and loading problem is declared as a combinational problem by Kathryn E. Stecke [2] which is highly complex, time-consuming and tedious in nature & requires highly experienced process planners.

Machine loading is one of the most critical production planning problems of FMS. It concerns with the time spend by the job(s) on machine(s) and the manufacturing cost. Manufacturing cost is the sum of fixed and variable costs. Variable cost varies with the level of production output. As output increases, variable cost increases. Once invested, we can't play around the fixed cost; hence to reduce the manufacturing cost, researcher has to minimize the variable cost while maximizing the output. This is done by developing and optimizing a virtual model of manufacturing by some conventional or non-conventional technique for certain number of objectives with their individual weightage accordingly. A researcher has to solve the manufacturing model to minimize the time spent by the job on machine, number of tool used, and movements of tool and job. FMS is a group technology concept hence all the operations on the group jobs are required to be completed at once keeping in view that no machine should be idle or overloaded at any instance of time. Thus the optimized solution of the machine loading problem for certain objectives under technological and capacity constraints is required. The solution to the machine loading problem is to minimize the manufacturing cost as a whole.

Increasing part varieties with raised productivity is necessary to be in competition and to maintain the demand of the product, which is possible by continuous research and optimized solutions to each of the production planning problem. This paper presents a research review of the optimization techniques and the objectives for which the machine loading problem in FMS has been solved, and scope of the research in the field.

Before presenting literature review, an introduction to the optimization techniques and their classification seems necessary to be discussed here for better understanding of the subject. Optimization is the approach for ideal solution. Accuracy of the solution depends on the approach, modeling, computational time and capacity, and nature of the problem. Optimization is classified into six categories: function, and trial and error, single variable and multiple variables, static and dynamics, continuous and discrete, constrained and unconstrained, and random and minimum seeking.

A functional optimization is for theoretical approach where a mathematical formula describes the objective function. Trial-and-error optimization is for experimental optimization with change in the variables which affect output without knowing much about the process. An optimization can be single variable for one dimensional analysis, and multi variables for multi-dimensional analysis. As the number of variables increases, the complexity of the problem also increases. Static optimization is independent of time and dynamic optimization as a function of time. Discrete optimization has a finite number of variables with all possible values, while continuous optimization has infinite number of variables with all possible values. Values are incorporated in equalities and inequalities to an objective of variable function in constrained optimization while the variables can take any value in unconstrained optimization. Random optimization finds sets of variables by probabilistic calculations while minimal seeking is the traditional optimization algorithms which are generally based on calculus methods and minimizes the function by starting from an initial set of variable values.

These optimization approaches can be further sub-categorized as stochastic programming, integer programming, linear programming, nonlinear programming, bound programming, network programming, least squares methods, global optimization, and non-differential optimization.

Most of the researches are focused on solving the machine loading problem by global optimization algorithms. Global optimization algorithms are generally categorized into two approaches: deterministic and probabilistic. Deterministic are sub-categorized into static space search (1992) [3], branch and bond and algebraic geometry algorithms. Probabilistic is sub-categorized as Monte Carlo algorithms, soft computing and Artificial Intelligence (AI). Monte Carlo algorithms includes two classes, one covers Stochastic (hill climbing) (2002) [4], Random optimization (1963) [5], Simulated Annealing (SA) (1953) [6], Tabu Search (TS) (1989) [7], Parallel tempering, Stochastic tunneling and Direct Monte Carlo Sampling, and second class includes Evolutionary Computation (EC). EC can be performed by Monte Carlo algorithms or soft computing or AI. EC is further classified as Evolutionary Algorithms (EA), Memetic Algorithms (hybrid Algorithms) (1989) [8], Harmonic Search (HS), Swarm Intelligence (SI). EA is sub-classified as Genetic Algorithms (GA) (1962) [9], Learning Classifier System (LCS) (1977) [10], Evolutionary Programming, Evolution Strategy (ES), Genetic Programming (GP) (1958) [11]. ES includes Differential Evolution (DE), and GP includes Standard GP, Linear GP and Grammar Guided GP. SI includes Ant Colony Optimization (ACO) (1996) [12] and Particle Swarm Optimization (PSO) (1995) [13]. The above discussed classifications scheme will be used for classifying the optimization techniques for solving the machine loading problems of FMS in the paper. Figure 1 shows the evolution of the major optimization techniques along the time axis.

3. Literature Review of Machine Loading Problems in FMS

An exhaustive research review has been carried out for study of approaches and optimization techniques for machine loading problems in FMS. A. Baveja, A. Jain, A. K. Singh, A. Kumar, A. M. Abazari, A. Murthy, A. Prakash, A. Srinivasulu, A. Turkcan, C. A. Yano, C. Basnet , C.S. Chen, D. Acharya, D. Kosucuoglu, D.H. Lee, F. Brian Talbot, F. F. Chen, F. Guerrero, F. Hashimoto, F. Oba, G. K. Nayak, G.C. Lee, H. C. Co, H. Sattari, H. Yong, H.B. Jun, H.-K. Roh, J. A. Ventura, J. Larranaeta, J. S. Biermann, J. Saha, J. G. Shanthikumar, J. N. D. Gupta, K Chandrashekara, K. E. Stecke, K. Kato, K. M. Bretthauer, K. Rajagopal, K. Shankar, L. H. S. Luong, L. S. Kiat, M. A. Gamila, M. A. Venkataramanan, M. Arıkan, M. Berrada, M. Goswami, M. I. Mgwatua, M. K. Pandey, M. K. Tiwari, Ming Liang, M. M. Aldaihani, M. S. Akturk, M. S. Leonard, M. Savsar, M. Solimanpur, M. Yogeswaran, N. K. Vidyarthi, N. Khilwani, N. Kumar, N. Nagarjunaa, N. K. Vidyarthi, O. Maheshb, Prakash, R. P. Sadowski, R. Budiarto, R. D. Matta, R. H. Storer, R. M. Marian, R. R. Kumar, R. Shankar, R. Swarnkar, S. Biswas, S. Deris, S. Erol, S. G. Ponnambalam, S. K. Mandal, S. K. Mukhopadhyay, S. Kumar, S. Lozano, S. Midha, S. Motavalli, S. P. Dutt, S. Rahimifard, S. S. Mahapatra, S.C. Sarin, S.K. Chen, S.K. Lim, S.T. Newman, T. J. Greene, T. J. Sawik, T. Koltai, T. L. Morin, T. Sawik, U. Bilge, U. K. Yusof, V. H. Nguyen, V. M Kumar, V. Murlikrishna, V. N. Hsu, V. Tyagi, W. F. Mahmudy, Y. Cohen, Y. D. Kim, Y. J. Tzen and Z. Wu are key researchers for solving the loading problem of production planning in FMS.

The tabulated research review discussing the approach, objectives, results and validation approach for machine loading problems in FMS is discussed in **Tables 1-3**. The literature review is classified into three groups: (1) heuristics; (2) global optimization; and (3) other optimization techniques.

Table 1 presents the review of machine loading problems of FMS based on heuristics approach. The heuristics approach has been significantly used for solving the research problem. Research has gained significant acceleration with the evolution and growth of global optimization techniques.

Table 2 presents the review of machine loading problems in FMS based on global optimization algorithms. Global optimization techniques have been explored rigorously by the researchers. The natural selection techniques have reported good results compared to others. The application of global optimization techniques for solving machine loading problem is increasing with growth of natural optimization techniques. The results reported by natural optimization techniques are more acceptable. Natural optimization techniques, GA and PSO are widely used techniques.

Table 3 presents the review of machine loading problems in FMS based on optimization techniques not falling in the above classification. Since the major focus is on heuristics and global optimization techniques, thus other techniques are grouped in a single table. These techniques have been adopted from time to time for solving the machine loading problem as shown year wise in **Table 3**.

Optimization techniques and approaches under the classification of global optimization scheme are discussed in **Table 2**.

Optimization techniques and approaches not falling under the above classifications are discussed in **Table 3**.

Table 4 has been formulated on regressive analysis of Tables 1-3, for the analysis of the loading objectives to be fulfilled while solving the loading problem. It is a year-wise tabulation and analysis of the loading objectives.

Table 2. Review of machine loading problems in FMS based on global optimization algorithms.

GLOBAL OPTIMIZATION ALGORITHMS						
a. Deterministic approach						
1. Branch and bound						
Sr. Year	Researcher Name	Approach	Objectives	Results	Validation approach	
1 1986	M. Berrada & K. E. Stecke [26]	Branch and bound approach	➢ Balancing of workload	Computational results gives fruitful results	Computational results are produced and demonstrated the efficiency of suggested procedures	
2 1989	K. Shankar & A. Srinivasulu [27]	Branch & backtrack procedure and Heuristic procedures	➢ Maximizing assigned workload ➢ Maximizing throughput ➢ Minimizing workload unbalance	Each procedure is illustrative by numerical example and results are with improved performance	An illustrative numerical example	
3 1994	Y. D. Kim & C. A. Yano [28]	New branch and bond algorithm	➢ Maximizing throughput	Improved efficiency	Computational results are produced and compared with previous results	
2. Algebraic Geometry						
4 1986	T. J. Greene & R. P. Sadowski [29]	Mixed integer programming	➢ Minimizing make span ➢ Minimizing mean flow time ➢ Minimizing mean lateness	Explained simple numeric example	a simple numeric example	
5 1987	S.C. Sarin & C.S. Chen [30]	Mathematical model	➢ Minimizing overall machining cost	Computational results are reported	Computational results are compared with literature results	
6 1990	K. M. Bretthauer & M. A. Venkataramanan [31]	Linear Integer Programming	➢ Maximizing weighted sum of number of operation to machine assignments	Computational results are satisfactory with improved performance	Computational results are produced	
7 1990	H. C. Co, J. S. Biermann, & S.K. Chen [32]	Mixed-integer programming (MIP)	➢ Balancing of workloads	Results were found practical	Computational results are produced	
8 1990	M. Liang & S. P. Dutt [33]	Mixed-Integer Programming	➢ Minimizing production cost	Demand for change on optimal solution	An example problem is solved	
9 1993	Ming Liang [34]	Non-linear programming	➢ Maximizing system output	production cost can be significantly reduced using this approach	Computational results with an illustrative example is demonstrated	
10 1994	Ming Liang [35]	Non-linear programming	➢ Maximizing system output ➢ minimizing production cost	Production cost can be significantly reduced using this approach	An illustrative example is solved using the suggested approach	
11 1997	V. N. Hsu & R. D. Matta [36]	Lagrangian-based heuristic procedure (MIP problem formulation)	➢ total processing cost	finds a good loading solution	iteratively compared different scenarios	
12 1998	T. J. Sawik [37]	Integer programming & approximative lexicographic approach	➢ Balancing workloads ➢ Minimizing total interstation transfer time	Results of computational experiments are reported	illustrative example and some results of computational experiments	
13 1999	F. Guerrero, S. Lozano, T. Koltai, & J. Larranaeta [38]	Mixed-integer linear program	➢ Balancing of workload	New approach to loading problem	Computational results are produced	
14 2001	N. Kumar & K. Shanker [39]	Mixed integer programming	➢ Balancing of Workload	Results are in agreement with previous findings	Computational results are compared with the previous findings	

Continued

15	2003	M. A. Gamila & S. Motavalli [40]	mixed integer programming	➢ Minimizing completion time ➢ Minimizing Material handling time ➢ Minimizing total processing time	Results reported increased efficiency and performance of system	Computational results are compared with the previous findings
16	2004	T. Sawik [41]	Mixed integer programming	➢ Minimizing production time	Computational results reported better performance	Numerical examples and some computational results are compared with available literature
17	2011	M. I. Mgwatua [42]	Linear Mathematical Programming	➢ Maximizing throughput ➢ Minimizing make span	More interactive decisions and well-balanced workload of the FMS can be achieved when sub-problems are solved jointly	Compared with results from previous literature
18	2012	A. M. Abazari, M. Solimanpur, & H. Sattari [43]	Linear mathematical programming	➢ Minimizing System unbalance	Genetic algorithm (GA) is proposed and performance of proposed GA is evaluated based on some benchmark problems	Performance is evaluated based on some benchmark problems adopted from the literature
				b. Probabilistic		
				3. Monte Carlo algorithms		
19	1998	S. K. Mukhopadhyay *et al.* [44]	Simulated annealing (SA) approach	➢ Minimizing system imbalance	Tried to give global optimum solution	Computational results are compared with existing results
20	2004	R. Swarnkar & M. K. Tiwari [45]	Hybrid tabu search and simulated annealing based heuristic approach	➢ Minimizing system unbalance ➢ Maximizing throughput	Results reported better performance	Tested on Standard problems and the results obtained are compared with those from some of the existing heuristics from literature
21	2005	M. M. Aldaihani & M. Savsar [46]	Stochastic model	➢ Minimizing total (FMC) flexible manufacturing cell cost per unit of production	Results reported better performance	Computational results were presented
22	2006	M. K. Tiwari, S. Kumar, S. Kumar, Prakash, & R. Shankar [47]	Constraints-Based Fast Simulated Annealing (SA) Algorithm	➢ Minimizing system unbalance ➢ Maximizing throughput	Proposed algorithm enjoys the merits of simple SA and simple genetic algorithm	The application of the algorithm is tested on standard data sets
23	2012	M. Arıkan & S. Erol [48]	Hybrid simulated annealing-tabu search algorithm	➢ Maximizing weighted sum ➢ Minimizing system unbalance ➢ Balancing of workload	Results shows improved system performance compared to earlier results in literature	The results are compared with those developed earlier by the authors
				4. Evolutionary Computation (EC)		
				✓ Evolutionary algorithms (EA)		
24	2000	N. Kumar & K. Shanker [49]	Genetic algorithm (GA)	➢ Maximizing number of part types in a batch ➢ Maximizing number of parts selected a batch ➢ Maximizing mean machine utilization	Results reported reduced computational requirements	comparative study of Computational results
25	2002	H. Yong & Z. Wu [50]	GA-based integrated approach	➢ Balancing of workloads	Results shows that suggested approach perform better than existing	Computational results are compared with the previous findings

Continued

26	2006	A. Kumar, Prakash, M. K. Tiwari, R. Shankar, & A. Baveja [51]	Constraint based genetic algorithm (CBGA)	➢ Balancing machine processing time ➢ Minimizing number of movements ➢ Balancing of workload ➢ Unbalancing of workload ➢ Filling the tool magazines as densely as possible ➢ Maximizing sum of operations priorities	The methodology developed here helps avoid getting trapped at local minima	The application of the algorithm is tested on standard data sets from available literature.
27	2007	A. Turkcan, M. S. Akturk, & R. H. Storer [52]	Genetic Algorithm (GA)	➢ Minimizing manufacturing cost ➢ Total weighted tardiness	Approach improves CNC machine efficiency & responsiveness to customer due date requirements	compared with the performance of most commonly used approach in the literature
28	2008	V. Tyagi & A. Jain [53]	Genetic algorithm based methodology	➢ Minimizing system unbalance	For a given number of tool copies of each tool type tool loading is affected by the availability of flexible process plans	An illustrative example
29	2012	U. K. Yusof, R. Budiarto, & S. Deris [54]	Constraint-chromosome genetic algorithm	➢ Minimizing system unbalance ➢ Maximizing throughput	Overall combined objective function increased by 3.60% from previous best result	tested on 10 sample problems available in the FMS literature and compared with existing solution methods
				✓ Memetic (hybrid) Algorithms		
30	2000	M. K. Tiwari & N. K. Vidyarthi [55]	Genetic Algorithm (GA) based (HA) Heuristic Approach	➢ Minimizing system unbalance ➢ Maximizing throughput	Optimal solution to problem	Tested on ten sample problems and the computational results obtained have been compared with those of existing methods
31	2009	M. Yogeswaran, S. G. Ponnambalam, & M. K. Tiwari [56]	Hybrid genetic algorithm simulated annealing algorithm (GASAA)	➢ Minimising system unbalance ➢ Maximising throughput	Results support better performance of GASA over algorithms reported in literature	results compared with reported in the literature
32	2010	S. K. Mandal, M. K. Pandey, & M. K. Tiwari [57]	Genetic algorithm simulated annealing Heuristics approach	➢ Minimizing breakdowns ➢ Minimizing system unbalance ➢ Minimizing make span ➢ Maximizing throughput	Results incurred under breakdowns validate robustness of developed model for dynamic ambient of FMS	Compared with dataset from previous literature
33	2012	V. M Kumar, A. Murthy, & K Chandrashekara [58]	Meta-hybrid heuristic technique based on genetic algorithm and particle swarm optimization	➢ Minimizing system unbalance ➢ Maximizing throughput	Model efficiency and performance of system is comparable with results compared to literature	Computational results are presented
34	2012	C. Basnet [59]	Hybrid genetic algorithm	➢ Minimizing system unbalance	Better solutions for system unbalance	Computational comparison between the genetic algorithm and previous algorithms is presented
35	2012	D. Kosucuoglu & U. Bilge [60]	Genetic algorithm based mathematical programming (GAMP)	➢ Minimizing total distance travelled by parts during production	GALP integration works successfully for this hard-to-solve problem	tested through extensive numerical experiments
				✓ Swarm Optimization		
36	2007	S. Biswas & S. S. Mahapatra [61]	Swarm Optimization Approach	➢ Minimizing system unbalance	Results reported improved system balance	compared with existing techniques for ten standard problems available in literature representing three different FMS scenarios

Continued

37	2008	S. Biswas & S. S. Mahapatra [62]	Modified particle swarm optimization	➢ Minimizing system unbalance	Proposed algorithm produces promising results in comparison to existing methods	comparison to existing methods for ten benchmark instances available in the FMS literature
38	2008	S. G. Ponnambalam & L. S. Kiat [63]	Particle Swarm Optimization (PSO)	➢ Minimizing system unbalance ➢ Maximizing throughput	Performance of PSO is satisfactory compared with heuristics reported in literature	tested by using 10 sample dataset and the results are compared with the heuristics reported in the literature
				✓ Artificial intelligence		
39	2001	N. K. Vidyarthi & M. K. Tiwari [64]	Fuzzy-based Heuristic Approach	➢ Minimizing system unbalance ➢ Maximizing throughput	Substantial improvement in solution quality over some existing heuristic-based approaches	Tested on 10 problems adopted from literatures and computational results are compared with the previous findings
40	2004	R. R. Kumar, A. K. Singh, & M.K. Tiwari [65]	Fuzzy based algorithm	➢ Minimizing system unbalance ➢ Maximizing throughput	Extended neuro fuzzy petri net is constructed	Computational results are compared with standard data set adopted from literature
41	2008	A. Prakash, N. Khilwani, M. K. Tiwari, & Y. Cohen [66]	Modified immune algorithm	➢ Maximizing throughput ➢ Minimizing system unbalance	Good results as compared to best results reported in literature	compared to the best results reported in the literature

The table is showing the list of objectives for which the loading problem is solved. The tick mark (√) in the table shows the density for repeatability of the objectives.

Abbreviations used in **Table 4**:

1) Minimizing system unbalance
2) Maximizing throughput
3) Balancing of workload in the system configured of groups composed of machines of equal size
4) Minimizing make span
5) Meeting delivery dates
6) Minimizing manufacturing cost/Minimizing total processing cost/ Minimizing total flexible manufacturing cell cost per unit of production
7) Minimizing tardiness
8) Minimizing production cost
9) Unbalancing the workload per machine for a system of groups of pooled machines of unequal sizes
10) Minimizing part movements
11) Maximizing part types in each batch
12) Minimizing subcontracting costs
13) Maximizing weighted sum of number of operation to machine assignments
14) Minimizing flow time
15) Minimizing late jobs (number)/ lateness
16) Minimizing machine processing time
17) Minimizing production time
18) Filling the tool magazines as densely as possible
19) Maximizing assigned workload
20) Maximizing routing flexibility of batches
21) Maximizing the sum of operations priorities
22) Minimizing material handling time
23) Minimizing total distance travelled by parts during production
24) Minimizing total number of cutting tools required
25) Minimizing workload of machines
26) Minimizing breakdowns
27) Minimizing earliness

After regressive analysis of the loading objectives of various researchers the optimization approaches and

Table 3. Review of machine loading problems in FMS based on optimization techniques not falling in the above classification.

OTHER OPTIMIZATION TECHNIQUES						
1	1984	K. E. Stecke & T. L. Morin [67]	Single server closed queueing network model	➢ Balancing of workload	Maximizes expected production of FMS	Results are compared and contrasted with previous models of production systems
2	1986	K. E. Stecke [68]	Hierarchical approach	➢ Maximizing throughput	Nonlinear integer programs models	Ties with some previous results & use of the proposed models to solve realistic loading problems is discussed
3	1986	J. G. Shanthikumar & K. E. Stecke [69]	Dynamic approach	➢ Balancing of workload	Result maximizes expected production	results obtained here complement previous results from literature
4	1993	Y.-D. Kim [70]	Due-Date Based Loading methods	➢ Maximizing throughput	Results reported reduced tardiness and makespan & in-creased throughput	Computational tests
5	1997	H.-K. Roh & Y-D. Kim [71]	Due-Date Based Loading methods	➢ Minimizing total tardiness	Iterative approach performs better than others	Computational tests on randomly generated problems
6	1997	D. H. Lee, S. K. Lim, G. C. Lee, H. B. Jun, & Y. D. Kim [72]	Iterative algorithms	➢ Minimizing subcontracting costs	Solved part selection and loading problems	computational experiments on randomly generated test problems
7	1997	Y. D. Kim and C. A. Yano [73]	Queueing network model	➢ Maximizing throughput ➢ Maximizing make span ➢ Balancing of workload	Reducing number of machine groups and balancing workloads among machines help to reduce make span	Computational results are produced
8	1998	D.-H. Lee & Y.-D. Kim [74]	Iterative procedures	➢ Minimizing earliness ➢ Minimizing tardiness ➢ Minimizing subcontracting costs	Computational experiments on randomly generated test problems are produced	computational experiments are done on randomly generated test problems and the results are compared with existing results
9	1999	J. N. D. Gupta, L. H. S. Luong, & V. H. Nguyen [75]	Dispatching approach	➢ Minimizing make spans ➢ Minimizing average flow time ➢ Minimizing tardiness	Satisfactory performance of given dispatching algorithm	Simulation results are compared with existing results
10	2000	S. Rahimifard & S.T. Newman [76]	Combined machine loading (CML) algorithms	➢ Meeting delivery dates ➢ Minimising production costs	Adoption of algorithms within an application is dependent on number of manufacturing constraints	Computational results are produced and performance measure is carried out in virtual environment
11	2012	W. F. Mahmudy, R. M. Marian, & L. H. S. Luong [77]	Real coded genetic algorithms (RCGA)	➢ Maximizing throughput ➢ Minimizing system unbalance	RCGA improves FMS performance & minimizes required computational time	Results are compared to the previous literature work

techniques utilized by researchers for problem formulation and its solution are identified and tabulated in **Table 3**.

The tick marks (√) shows the density of repetitive occurrence of the optimization techniques and approaches for solving the machine loading problem.

Abbreviations used in **Table 5**:

1) Genetic Algorithm (GA): GA, Hybrid GA, Constraint based GA, Constraint-chromosome GA, Real coded GA, integrated approach based on GA

2) Heuristic Algorithm (HA): HA, Fast HA, Fuzzy based HA, GA based HA, Hybrid TS and SA based HA, Lagrangian based HA, GA and PSO based Meta-hybrid HA, multi stage programming approach based HA

3) Simulated annealing (SA): SA, Constraints-Based Fast SA, GA based SA, Hybrid GA-SA & SA-TS algorithm

Table 4. Objectives of machine loading in FMS.

Sr.	Year	Researcher Name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	1983	K. E. Stecke & F. B. Talbot [2]			√						√	√																	
2	1984	K. E. Stecke & T. L. Morin [67]			√																								
3	1985	K. Shankar & Y. J. Tzen [14]	√		√												√												
4	1986	M. Berrada & K. E. Stecke [26]			√																								
5	1986	K. E. Stecke [68]		√																									
6	1986	J.G.S. Kumar & K. E. Stecke [69]			√																								
7	1986	T. J. Greene & R. Sadowski [29]				√										√	√												
8	1987	S.C. Sarin & C.S. Chen [30]								√																			
9	1988	J. A. Ventura *et al.* [15]				√																							
10	1989	K. Shankar & A. Srinivasulu [27]		√							√										√								
11	1990	B. Ram *et al.* [16]						√																					
12	1990	K. M. Bretthauer *et al.* [31]													√														
13	1990	H. C. Co *et al.* [32]			√																								
14	1990	M. Liang & S. P. Dutt [33]								√																			
15	1992	Y. D. Kim & C. A. Yano [28]		√																									
16	1992	S. K. Mukhopadhyay *et al.* [17]	√	√																									
17	1993	K. Kato *et al.* [18]	√																							√			
18	1993	Ming Liang [34]		√																									
19	1993	Y-D. Kim [70]		√																									
20	1994	Ming Liang [35]		√						√																			
21	1995	E. K. Steeke & F. B. Talbot [19]			√						√	√																	
22	1997	M. K. Tiwari *et al.* [20]	√	√																									
23	1997	V. N. Hsu & R. D. Matta [36]						√																					
24	1997	H.-K. Roh & Y.-D. Kim [71]							√																				
25	1997	D. H. Lee *et al.* [72]												√															
26	1997	Y. D. Kim and C. A. Yano [73]		√	√	√																							
27	1998	S. K. Mukhopadhyay *et al.* [44]	√																										
28	1998	D.-H. Lee & Y.-D. Kim [74]							√					√															√
29	1998	G. K. Nayak & D. Acharya [21]											√									√							
30	1998	T. J. Sawik [37]			√							√																	
31	1999	F. Guerrero *et al.* [38]			√																								
32	1999	J. N. D. Gupta *et al.* [75]				√			√							√													
33	2000	N. Kumar & K. Shanker [49]	√										√																
34	2000	D.-H. Lee & Y.-D. Kim [22]																									√		
35	2000	S. Rahimifard & S. Newman [76]					√			√																			

Continued

36	2000	M. K. Tiwari & N. Vidyarthi [55]	√	√																								
37	2001	N. Kumar & K. Shanker [39]			√																							
38	2001	N. K. Vidyarthi & M. K. Tiwari [64]	√	√																								
39	2002	H. Yong & Z. Wu [50]			√																							
40	2003	M. Gamila & S. Motavalli [40]																√						√				
41	2004	R. R. Kumar *et al.* [65]	√	√																								
42	2004	T. Sawik [41]																	√									
43	2004	R. Swarnkar & M. K. Tiwari [45]	√	√																								
44	2005	M. Aldaihani & M. Savsar [46]						√																				
45	2006	N. Nagarjunaa *et al.* [23]	√																									
46	2006	M. Goswami & M. Tiwari [24]	√	√																								
47	2006	M. K. Tiwari *et al.* [47]	√	√																								
48	2006	A. Kumar *et al.* [51]			√						√	√						√		√			√					
49	2007	A. Turkcan *et al.* [52]						√	√																			
50	2007	M. K. Tiwari *et al.* [25]	√	√																								
51	2007	S. Biswas & S. Mahapatra [61]	√																									
52	2008	A. Prakash *et al.* [66]	√	√																								
53	2008	S. Biswas & S. Mahapatra [62]	√																									
54	2008	S. Ponnambalam & L. Kiat [63]	√	√																								
55	2008	V. Tyagi & A. Jain [53]	√																									
56	2009	M. Yogeswaran *et al.* [56]	√	√																								
57	2010	S. K. Mandal *et al.* [57]	√	√		√																						√
58	2011	M. I. Mgwatua [42]		√		√																						
59	2012	V. M Kumar *et al.* [58]	√	√																								
60	2012	C. Basnet [59]	√																									
61	2012	M. Arıkan & S. Erol [48]	√		√										√													
62	2012	U. K. Yusof *et al.* [54]	√	√																								
63	2012	D. Kosucuoglu & U. Bilge [60]																							√			
64	2012	A. M. Abazari *et al.* [43]	√																									
65	2012	W. F. Mahmudy *et al.* [77]	√	√																								

4) Mathematical programming (MP): MP, Linear MP, Non-linear MP, GA based MP
5) Swarm Optimization (SO): SO, Particle SO (PSO), Modified PSO
6) Queueing network model (QNM): QNM, Single server closed QNM
7) Mixed-integer programming (MIP): MIP, GA based MIP
8) Branch and bound algorithms (B&BA) : B&BA, New B&BA
9) Integer programming (IP): IP, linear IP
10) Non-linear programming
11) Stochastic model

Table 5. Optimization techniques used for solving machine loading problems in FMS.

Sr.	Year	Researcher Name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	1983	K. E. Stecke & F. B. Talbot [2]		√																			
2	1984	K. E. Stecke & T. L. Morin [67]						√															
3	1985	K. Shankar & Y. J. Tzen [14]		√																			
4	1986	M. Berrada & K. E. Stecke [26]								√													
5	1986	K. E. Stecke [68]															√						
6	1986	J.G.S. Kumar & K. E. Stecke [69]																				√	
7	1986	T. J. Greene & R. Sadowski [29]							√														
8	1987	S. C. Sarin & C. S. Chen [30]				√																	
9	1988	J. A. Ventura *et al.* [15]		√																			
10	1989	K. Shankar & A. Srinivasulu [27]		√														√					
11	1990	B. Ram *et al.* [16]		√																			
12	1990	K. M. Bretthauer *et al.* [31]									√												
13	1990	H. C. Co *et al.* [32]							√														
14	1990	M. Liang & S. P. Dutt [33]							√														
15	1992	Y. D. Kim & C. A. Yano [28]								√													
16	1992	S. K. Mukhopadhyay *et al.* [17]		√																			
17	1993	K. Kato *et al.* [18]		√																			
18	1993	Ming Liang [34]										√											
19	1993	Y.-D. Kim [70]																			√		
20	1994	Ming Liang [35]										√											
21	1995	E. K. Steeke & F. B. Talbot [19]		√																			
22	1997	M. K. Tiwari *et al.* [20]		√																			
23	1997	V. N. Hsu & R. D. Matta [36]		√																			
24	1997	H.-K. Roh & Y.-D. Kim [71]																			√		
25	1997	D. H. Lee *et al.* [72]														√							
26	1997	Y. D. Kim and C. A. Yano [73]						√															
27	1998	S. K. Mukhopadhyay *et al.* [44]			√																		
28	1998	D.-H. Lee & Y.-D. Kim [74]														√							
29	1998	G. K. Nayak & D. Acharya [21]		√		√																	
30	1998	T. J. Sawik [37]									√				√								
31	1999	F. Guerrero *et al.* [38]							√														
32	1999	J. N. D. Gupta *et al.* [75]																		√			
33	2000	N. Kumar & K. Shanker [49]	√																				
34	2000	D.-H. Lee & Y.-D. Kim [22]		√																			
35	2000	S. Rahimifard & S. Newman [76]																	√				

Continued

36	2000	M. K.Tiwari & N.Vidyarthi [55]		√																			
37	2001	N. Kumar & K. Shanker [39]							√														
38	2001	N. K. Vidyarthi & M. K. Tiwari [64]		√																			
39	2002	H. Yong & Z. Wu [50]	√						√														
40	2003	M. Gamila & S. Motavalli [40]																					
41	2004	R. R. Kumar *et al.* [65]																					√
42	2004	T. Sawik [41]							√														
43	2004	R. Swarnkar & M. K. Tiwari [45]		√																			
44	2005	M. Aldaihani & M. Savsar [46]											√										
45	2006	N. Nagarjunaa *et al.* [23]		√																			
46	2006	M. Goswami & M. Tiwari [24]		√																			
47	2006	M. K. Tiwari *et al.* [47]			√																		
48	2006	A. Kumar *et al.* [51]	√																				
49	2007	A. Turkcan *et al.* [52]	√																				
50	2007	M. K. Tiwari *et al.* [25]		√																			
51	2007	S. Biswas & S. Mahapatra [61]					√																
52	2008	A. Prakash *et al.* [66]												√									
53	2008	S. Biswas & S. Mahapatra [62]					√																
54	2008	S. Ponnambalam & L. Kiat [63]					√																
55	2008	V. Tyagi & A. Jain [53]	√																				
56	2009	M. Yogeswaran *et al.* [56]			√																		
57	2010	S. K. Mandal *et al.* [57]	√	√	√																		
58	2011	M. I. Mgwatua [42]				√																	
59	2012	V. M Kumar *et al.* [58]		√			√																
60	2012	C. Basnet [59]	√																				
61	2012	M. Arıkan & S. Erol [48]			√																		
62	2012	U. K. Yusof *et al.* [54]	√																				
63	2012	D. Kosucuoglu & U. Bilge [60]							√														
64	2012	A. M. Abazari *et al.* [43]				√																	
65	2012	W. F. Mahmudy *et al.* [77]	√																				

12) Modified immune algorithm
13) Approximative lexicographic approach
14) Iterative algorithms
15) Hierarchical approach
16) Branch & backtrack procedure
17) Combined machine loading algorithms
18) Dispatching approach
19) Due-Date Based Loading methods

20) Dynamic approach
21) Fuzzy Logic

4. Conclusion Arrived on Machine Loading Objectives and Optimization Techniques in FMS

Detailed study of the machine loading problem is conducted by the authors. The conclusions of the research throttled are divided into three sections as below.

4.1. Conclusion on Machine Loading Objectives

On exhaustive study, twenty eight loading objectives are observed in the reviewed literature. Tick marks (√) in **Table 4** are showing the density for repeatability of the machine loading objectives, which concludes that a research with maximum loading objectives is still required for solving the machine problem. Maximizing expected production rate (throughput) & unbalancing the workload per machine for a system of groups of pooled machines of unequal sizes are the two objectives on which most of the researchers have worked. Balancing of workload on machines for a system of groups of pooled machines of equal sizes is the second most researched loading objective. Minimizing make span is the third most researched loading objective. Minimizing job tardiness is fourth loading objective in the order. Minimizing mean job flow time & minimizing production cost are found at fifth position in the order. Loading objectives observed at sixth rank are maximizing profitability, maximizing the assigned workload, maximizing the part types in each batch, maximizing utilization of system, minimizing subcontracting costs and minimizing the total number of cutting tools required. Material handling time, maximizing routing flexibility of the batches, minimizing earliness, minimizing mean lateness, minimizing mean machine idle time, minimizing overall machining cost, minimizing production time, minimizing the effect of breakdowns, minimizing the maximum workload of the machines, minimizing the number of late jobs, minimizing total flexible manufacturing cell cost per unit of production, minimizing total inter-station transfer time, minimizing total processing time, minimizing part movements and minimisation of the total distance travelled by parts during their production are the loading objectives that are least considered.

4.2. Conclusion on Optimization Techniques in FMS

The categorized literature review concludes that the researcher's major emphasis and contribution are towards the use and application of global optimization techniques and with natural optimization techniques, too. Heuristic Algorithms is the mostly used optimization technique by researchers, followed by Genetic Algorithms (GA). Mixed Integer Programming (MIP) & Simulated Annealing (SA) approach are the third mostly used optimization techniques. Linear Mathematical Programming (LMP) is next in the queue succeeded by Integer Programming (IP). At sixth level is Particle Swarm Optimization (PSO) approach. The least used optimization techniques are Tabu search, Swarm Optimization Approach, Branch and backtrack procedure, Branch and bound approach, Combined machine loading (CML) algorithms, Dispatching approach, Due-Date Based methods, Dynamic approach, Fuzzy Logic, Global criterion approach, Hierarchical approach, Artificial immune algorithm, Iterative algorithms, Lexicographic approach, Non-linear programming, Queueing network model and Stochastic model.

4.3. Conclusion on validation approaches

A few research problems are solved and the results are compared with previous research results. The results are validated by comparing with literature available results.

4.4. Methodologies Findings and Interpretations

A problem when solved for a limited or less number of objectives, it is rather a customized solution for a problem. For general solution, the problem needs to be solved for all possible objectives. On extreme analysis of the machine loading problem and objectives, and on discussion with the academicians and industrialists, the authors emphasise to solve the loading problem for maximization of throughput, part types in a batch, routing flexibility, balancing/unbalancing of system and workload, and minimization of make-span, delivery dates (covering lateness, tardiness and earliness), part movements, subcontracting costs, machine processing time, tool magazine capacity, number of cutting tools required, breakdowns, non-splitting of jobs, time spend by job on machines in one study. Machine loading problem should be solved for general solution to the problem, for maximum number of objectives. All these objectives are having a common goal of optimizing the production and manufacturing costs.

The literature review reports the application of heuristics, global optimization techniques and some other optimization techniques for solving the loading problem for the listed objectives. Among these approaches, the global optimization techniques were more frequently adopted and the results as founded by the researchers were more accurate and acceptable. Based on regressive analysis of the available literature, and skills and concluding remarks, the authors suggest for the use of natural optimization techniques like swarm optimization for further research. The results of swarm optimization were found more reliable and acceptable as compared to GA, and PSO has attractive characteristics. PSO retains knowledge of all previous particles, which is destroyed in GA when the population changes. PSO is a mechanism of constructive cooperation and information-sharing between particles. Due to the simple concept, ease of implementation, and quick convergence, PSO has gained much attention and has been successfully applied to a wide range of applications.

5. Research Gaps and Scope of Research in Loading of Machines in FMS

There exists a research gap among the literature available. There are several future scopes that are still not worked out, or still to be worked in a more optimized manner. Based on our observation and exhaustive study such revealed research gap are listed below: Need of integration of loading with other decisions in the neighbourhood of loading (K. Shankar & A. K. Agrawal, 1991); need to reduce excessive computing times (Y. D. Kim & C. A. Yano, 1989); further need of optimization (N. K. Vidyarthi & M. K. Tiwari, 2001, M. K. Tiwari *et al.*, 2007; Amir Musa Abazari *et al.*, 2012); research is required to develop planning softwares (D. H. Lee *et al.*, 1997); PLC controller needs to be enhanced (M. C. Zhou *et al.*, 1993); waiting time for parts and idling time for machines need attention [Mussa I. Mgwatu, 2011]; research by imposing constraints on the availability of resources *i.e.* jigs, fixtures, pallets, material handling devices needs to be carried out (K. Kato, 1993, N. K. Vidyarthi & M. K. Tiwari, 2001; N. Nagarjuna *et al.*, 2006; Akhilesh Kumar *et al.*, 2006; M. K. Tiwari *et al.*, 2007; Sandhyarani Biswas & S. S. Mahapatra, 2007; Sandhyarani Biswas & S. S. Mahapatra, 2008; Santosh Kumar Mandal *et al.* 2010; Amir Musa Abazari *et al.*, 2012); new solution methodology needs to be proposed (Santosh Kumar Mandal *et al.* 2010); need of AI in the field of FMS) Chinyao Low *et al.*, 2006; Sandhyarani Biswas & S. S. Mahapatra, 2008); Need to use dedicated robot (Majid M. Aldaihani & Mehmet Savsar, 2005); need of simulation studies for FMS (K. Shankar & A. K. Agrawal, 1991; N. K. Vidyarthi & M. K. Tiwari, 2001). Availability of a number of research gaps and that too identified by various eminent researchers from time to time evacuates the need of vast research for solving the observed PPC problems i.e. machine loading problems in FMS.

The authors are working to solve the loading problem with more number of objectives in a single study and for the development of knowledge base system for the machine loading problem. The authors suggest for the development of a knowledge base for all five productions planning problems; part type selection problem, machine grouping problem, production ratio problem, resource allocation problem and loading problem in a single study incorporating the individual objectives of the five individual problems and their respective technological and capacity constraints.

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