Approaches for solving machine loading problem in FMS: A Review

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Abstract— Machine loading problem of flexible manufacturing systems(FMS) is specified as to assign the machines, operations of selected jobs, and tools necessary to perform these operations by satisfying the constraints in ordered ensure the ensure the minimum system imbalance and maximize throughput, when system is in operation. This work reviewed the literature on machine loading problem of FMS and classified the articles according to the approaches used to solve the machine loading problem in FMS and presented the gist of literature reviewed.

Keywords— Machine loading; heuristics; genetic algorithms; FMS

I. INTRODUCTION

. Machine-loading problem of a flexible manufacturing system is known for its complexity. The machine loading problem in an FMS is specified as to assign the machines, operations of selected jobs, and the tools necessary to perform these operations by satisfying the technological constraints (available machine time and tool slot constraint) in order to ensure the minimum system imbalance and maximum throughput, when the system is in operation[1]. This problem encompasses various types of flexibility aspects pertaining to part selection and operation assignments along with constraints ranging from simple algebraic to potentially very complex conditional constraints [2]. Most of the articles presented on Machine-loading problem of a flexible manufacturing system before 2000 are prepared by considering mixed integer or 0–1 programming formalization as a starting point, and then tend to modify slightly the model or used heuristic techniques in order to overcome computational problems. It is evident that, in recent publications, the use of Artificial Intelligent(AI) approaches increased. Grieco et al.[3] presented a wide review of different approaches to the FMS loading problems and proposed an analysis of the various aspects that influence the problem formulation, identifying the alternatives available in real systems and possible future evolutions. In their study, articles are classified according to the type of FMS analyzed, the objective function, and the constraint. This work classified the articles according to the approaches used to solve the machine loading problem in FMS and presented the gist of literature reviewed.

II. APPROACHES FOR SOLVING MACHINE LOADING PROBLEM IN FMS

The different approaches have been found in the literature to solve the machine loading problem in FMS. For the convenient, they are divided into the following categories:
1. The Mathematical approaches.
2. The heuristic approaches.
3. The artificial intelligence-based approaches.

The Mathematical approaches: Stecke, K. E[04], defined a set of five production planning problems that must be solved for efficient use of an FMS, and addresses specifically the grouping and loading problems. These two problems are first formulated in detail as nonlinear 0-1 mixed integer programs. In an effort to develop solution methodologies for these two planning problems, several linearization methods are examined and applied to data from an existing FMS. To decrease computational time, the constraint size of the linearized integer problems is reduced according to various methods. Several real world problems are solved in very reasonable time using the linearization that results in the fewest additional constraints and/or variables. The problem characteristics that determine which linearization to use, and the application of the linearized models in the solution of actual planning problems, are also discussed. Berrada M, Stecke KE[05], Considered one called the loading problem. This problem involves assigning to the machine tools, operations and associated cutting tools required for part types that have been selected to be produced simultaneously. The part types will be machined during the upcoming production period (say, of one to three weeks duration on average) and according to a prespecified part mix. This assignment is constrained by the capacity of each machine's tool magazine as well as by the production capacities of both the system, and each machine type. There are several loading objectives that are applicable in a flexible manufacturing situation. This paper considers the most commonly applied one, that of balancing the workload on all machines. They first discussed a nonlinear integer mathematical programming formulation of the loading problem. The problem is formulated in all detail. Then an efficient solution procedure is proposed and illustrated with an example. Computational results are provided to demonstrate the efficiency of the suggested special-purpose procedures. Lashkari, R.S et al[06], extended the formulation of the operation allocation problem to include the important planning aspects of refixturing and limited tool availability. A 0-1 integer programming formulation is proposed with two objective functions and a set of realistic constraints. The computational behavior of the solution is discussed and a number of observations prompted by the solution methodology have been made. Lee S.M., Jung H.[07], studied Production planning for flexible manufacturing systems (FMS) using different methods, including simulation; queueing networks; and several single-objective mathematical programming techniques. The decision making process for production planning in FMS usually involves multiple conflicting objectives. Thus, goal programming (GP) can be effectively applied to this decision problem. Then discussed the superior aspects of the GP model, over other models, when solving the production planning problem for FMS. A GP model is presented and the implementation results of an illustratative problem are analysed. Bretthauer K.M., Venkataramanan M.A.[08], studied the assignment of operations to machines in a flexible manufacturing system (FMS) and the impact on alternate routes through the system. By assigning each operation to more than one machine, alternate routes for the parts being produced become available. If additional tooling is purchased, then more operation assignments can be made which increase the number of possible routes through the FMS. They presented a constrained network model of the machine loading problem and use surrogate and Lagrangian relaxation for solving large scale problems. Computational results are presented. Co H.C et al[09], formulated a mixed-integer programming (MIP) problem to address the flexible manufacturing system batching, loading, and tool configuration problems concurrently. This model results in a great many variables, making its mathematical solution impractical. One introduces a four-pass approach using submodels of the original MIP problem. The approach assumes that the need for batching is primarily that of tool magazine capacity constraints, with balancing and maximizing flexibility as secondary objectives. Modi B. K., Shanker K.[10], addressed a generalized loading problem with the objective of part movement minimization in an FMS with machine, tool and process plan flexibilities. The three flexibilities refer to the ability of machines to perform a variety of operations, ability of tools to perform several operations, and the availability of alternate process plans for a part type, respectively. The resulting problem of integrated process plan selection and operation-tool-machine assignment is formulated as a 0-1 quadratic programming problem. The part movement minimization is achieved by assigning the maximum possible number of successive operations of a part type to the same machine subject to several system configuration and operational constraints. A two-stage heuristic exploiting the special structure of the problem is suggested as solution methodology. Numerical examples are solved to illustrate various steps of the proposed heuristic and to study its computational performance in comparison with Hyper Lindo. The problem is further extended to take into consideration the objective of workload balancing. Guerro F.[11], presented a new approach to the loading problem in flexible manufacturing systems. It focuses on the existence of alternatives routes for each part type. Also, the optimal number of copies of each tool type to be loaded into each tool magazine is directly determined. Thus, the decision variables are the routing mix and the tool allocation. The loading objective is to balance machine workloads. Constraints on the number of available tools and on tool magazine capacities can be imposed. The problem is modelled as a mixed-integer linear program. Also, an extension of the model is formulated that includes part type selection.Mohammed Z. M.[12], proposed two models to overcome the drawbacks of part grouping models: model LM, which does not require part grouping, and model PGLRM (part grouping, loading and routing model), which requires part grouping. The performance of model LM serves as a benchmark. These two models also address machine loading and part routing issues concurrently. Model PGLRM's performance is then compared with the performance of model LM and few other existing part grouping models in terms of makespan and routing flexibility. Their analysis shown that model PGLRM not only results in a lower value of makespan but also imparts higher routing flexibility as compared to existing part grouping models.

Mansour Abou Gamila, Saeid Motavalli [13], addressed the problems of part loading, tool loading, and part scheduling. They assumed that there is a set of tools with known life and a set of machines that can produce a variety of parts. A batch of various part types is routed through this system with the assumption that the processing time and cost vary with the assignment of parts to different machines and assignment of various tool sets to machines. they developed a mathematical model to select machines and assign operations and the required tools to machines in order to minimize the summation of maximum completion time, material handling time, and total processing time. They first integrate and formulate loading, and routing, two of the most important FMS planning problems, as a 0–1 mixed integer programming problem. Then take the output from the integrated planning model and generate a detailed operations schedule. The results reported in this paper demonstrate the model efficiency and examine the performance of the system with respect to measures such as production rate and utilization. Mgwatu et al[14], presented a two-stage sequential methodology aimed at integrating the decisions of part selection, machine loading, machining optimisation and part scheduling sub-problems for flexible manufacturing systems (FMSs) and avoiding disparities of decisions which can be difficult to implement on the FMS shop floor. In this case, two mathematical models were presented and solved. Results from the models show that more interactive decisions and well-balanced workload of the FMS can be achieved when part selection, machine loading, machining optimisation and part scheduling sub-problems are solved jointly. Zeballos L.J et al[15], presented an integrated constraint programming (CP) model to tackle the problems of tool allocation, machine loading, part routing, and scheduling in a flexible manufacturing system (FMS). The formulation, which is able to take into account a variety of constraints found in industrial environments, as well as several objective functions, has been successfully applied to the solution of various case studies of different sizes. Though some of the problem instances have bigger sizes than the examples reported to date in literature, very good-quality solutions were reached in quite reasonable CPU times. This good computational performance is due to two essential characteristics of the proposed model. The most significant one is the use of two sets of two-index variables to capture manufacturing activities instead of having just one set of four indexes. Thus, dimensionality is greatly reduced. The other relevant feature is the fact that the model relies on an indirect representation of tool needs by means of tool types, thus avoiding the consideration of tool copies.

The heuristic approaches: Mukhopadhyay S.K.[16], suggested a heuristic solution to the loading problem by developing the concept of essentiality ratio for the objective of minimizing the system unbalance and thereby maximizing the throughput. The proposed heuristic is tested on ten problems and the results show that the algorithm developed is very reliable and efficient. Kuhn H. [17], considered the loading problem in flexible manufacturing systems (FMSs). This problem involves the assignment to the machine tools of all operations and associated cutting tools required for part types that have been selected to be produced simultaneously. The loading problem is first formulated as a linear mixed 0–1 program with the objective to minimize the greatest workload assigned to each machine. A heuristic procedure is presented in which an assignment of operations to machine tools is obtained by solving a parameterized generalized assignment problem with an objective function that approximates the use of tool slots required by the operations assigned to the machines. The algorithm is coded in FORTRAN and tested on an IBM-compatible personal computer. Computational results are presented for different test problems to demonstrate the efficiency and effectiveness of the suggested procedure.Sawik T[18], presented a heuristic approach for material flow control in a flexible machining system, where several different part types are manufactured. The system is composed of various machine types and a set of automated guided vehicles that permit each part to move between any pair of machines. The problem objective is to simultaneously schedule machines and vehicles so as to meet production requirements for selected part types in a minimum time. A two-level loading and scheduling approach is proposed with a single-pass scheduling heuristic based on a family of complex dispatching rules. Computational examples are included to illustrate the scheduling procedure. Lee D, Kim Y[19], focused on the loading problem resulting from partial grouping, in which each machine is tooled differently but each operation can be processed by one or more machines. Two types of heuristic algorithms are suggested for the loading problem with the objective of minimizing the maximum workload of the machines. Performances of the suggested loading algorithms are tested on randomly generated test problems and the results show that the suggested algorithms perform better than existing ones. In addition, it is found from simulation experiments that loading plans from partial grouping give significantly better performance than those from total grouping.Nagarjuna N et al[20], considered the loading problem in random type FMS, which is viewed as selecting a subset of jobs from the job pool and allocating them among available machines. A heuristic based on multi-stage programming approach is proposed to solve this problem. The objective considered is to minimize the system unbalance while satisfying the technological constraints such as availability of machining time and tool slots. The performance of the proposed heuristic is tested on 10 sample problems available in FMS literature and compared with existing solution methods. It has been found that the proposed heuristic gives good results. Goswami M, Tiwari M. K[21], evolved a comprehensive heuristic solution to include all the three segments of a machine loading problem of flexible manufacturing systems. These are part type sequence determination, operation allocation on machines and reallocation of part types. The machine loading problem has been formulated keeping in view two well-known objective functions, namely minimization of system unbalance and maximization of throughput. In addition to constraints related to machine time and tool slots availability, this research considers one more constraint related to material handling, i.e. number of AGVs available in the system. The part type sequence determination has been carried out by evaluating the contribution of part type to characteristics such as batch size, total processing time, and the AGV movement. Decisions pertaining to operation allocation are taken based on the enumeration of priority index. An iterative reallocation procedure has been devised to ensure minimum positive system unbalance and maximum throughput. A test problem is simulated to represent the real shop floor environment and the same has been solved using various steps of the proposed algorithm. Tiwari M.K et al[22], , attempted to address the combined job sequencing and machine loading problem using minimization of system unbalance and maximization of throughput as objective functions, while satisfying the constraints related to available machining time and tool slots. This research describes two heuristics to deal with the problems. Heuristic I uses predetermined fixed job sequencing rules as inputs for operation allocation decision on machines, whereas heuristic II uses genetic algorithm based approach for simultaneously addressing job sequences and operation machine allocation issues. Performance of these heuristics has been tested on problems representing three different FMS scenarios. Heuristic II (Genetic algorithm based) has been found more efficient and outperformed heuristic I in terms of solution quality. Tiwari M.K et al[23], formulated an exact and efficient heuristic-based solution methodology, which covers three segments of the machine-loading problem, i.e., part-type sequence determination, operation allocation decision and reallocation of part-type in a flexible manufacturing environment. An iterative reallocation procedure has been devised to ensure minimum positive system unbalance and maximum throughput. The proposed heuristic aims to achieve these objectives in the presence of constraints posed by availability of machining time and tool slot in a given planning horizon. Computational results on test problems indicate the supremacy of proposed heuristic which shows a significant improvement over existing methods. Kim H.W et al[24], considers the loading problem for flexible manufacturing systems with partially grouped machines, i.e., machines are tooled differently, but multiple machines can be assigned to each operation. Loading is the problem of allocating operations and their associated cutting tools to machines for a given set of parts. As an extension of the existing studies, they consider unrelated machines, i.e., processing time of an operation depends on the speed of the machine where it is allocated. They also consider the practical constraints associated with cutting tools: (a) tool life restrictions; and (b) available number of tool copies. An integer linear programming model is suggested for the objective of balancing the workloads assigned to machines. Then, due to the complexity of the problem, they suggested two-stage heuristics in which an initial solution is obtained and then it is improved. The heuristics were tested on some test instances, and the results are reported. Srivastava B, Wun-Hwa Chen[25], addressed the part type selection problem. The problem is to determine a subset of part types having production requirements for immediate and simultaneous processing over the upcoming period of the planning horizon, subject to the tool magazine and processing time limitation. Several versions of tabu search (TS) algorithm are proposed for solving the problem. A systematic computational test is conducted to test the performance of the TS algorithms. The best TS algorithm developed is compared to a simulated annealing algorithm. Srinivas et al[26], addressed the flexible manufacturing system machine-loading problem where job selection and operation allocation on machines are to be performed such that there is a minimization of system unbalance and a maximization of throughput. The methodology of winner determination using the combinatorial auction process is employed to solve the flexible manufacturing system machine-loading problem. In the combinatorial auction, allowing bidding on a combination of assets offers a way to enhance the efficiency of allocating the assets. The performance of the proposed approach is tested on 10 sample problems and the results thus obtained are compared with the existing models in the literature

The Artificial Intelligent approaches: In the literature of machine loading problem of FMS, The AI approaches found are: Genetic algorithms, Fuzzy logic approaches, Simulated annealing, Particle swarm optimization , Ant colony optimization and hybrids of these approaches. Out of these approaches Fuzzy logic approaches and Genetic algorithms are prominently found. In this work, for the convenient, the AI approaches are classified as 1). Fuzzy logic approaches, 2). Genetic algorithms 3). Other AI approaches

Fuzzy logic approaches: Vidyarthi N.K , Tiwari M.K.[27], formulated a fuzzy-based solution methodology to address the machine-loading problem in a flexible manufacturing system. The objectives considered are minimization of system unbalance and maximization of throughput, whereas the systems technological constraints are posed by availability of machining time and tool slots. The job ordering/job sequence determination before loading is carried out by evaluating the membership contribution of each job to its characteristics such as batch size, essential operation processing time and optional operation processing time. The operation–machine allocation decisions are made based on the evaluation of membership contribution of operation machine allocation vector. The formulation of membership function is based on logical derivations and enjoys reasonable analytical support. The proposed heuristic is tested on 10 problems adopted from literatures and the results reveal substantial improvement in solution quality over, some of existing heuristic-based approaches. Rai S, et al[28], addressed application of a fuzzy goal-programming concept to model the problem of machine–tool selection and operation allocation with explicit considerations given to objectives of minimizing the total cost of machining operation, material handling and set-up. The constraints pertaining to the capacity of machines, tool magazine and tool life are included in the model. A genetic algorithm (GA)-based approach is adopted to optimize this fuzzy goal-programming model. An illustrative example is provided and some results of computational experiments are reported. Kumar R.R et al [29], developed a fuzzy-based solution approach to address a machine-loading problem of a flexible manufacturing system (FMS). The proposed solution methodology effectively deals with all the three main constituents of a machine loading problem, viz. job sequence determination, operation machine allocation and the reallocation of jobs. The main objectives of the FMS loading problem considered here are minimisation of system imbalance and maximisation of throughput; the constraints to be satisfied are the available machining time and tool slots. An analytical argument has been provided to support the membership function related to the operation machine allocation vector. Computational results revealed the superiority of the proposed algorithm over other heuristics when it is tested on a standard data set adopted from literature. A new class of petri net model called the "Extended neuro fuzzy petri net" is constructed to capture clearly the various details of the machine loading problem which can be further extended to learn from experience and perform inferences so that truly intelligent system characteristics can be realised. Chan F.T.S. et al[30], presented a fuzzy goal-programming approach to model the machine tool selection and operation allocation problem of flexible manufacturing systems. The model is optimized using an approach based on artificial immune systems and the results of the computational experiments are reported. Chan F.T.S, Swarnkar R [31], presented a fuzzy goal programming approach to model the machine tool selection and operation allocation problem of FMS. An ant colony optimization (ACO)-based approach is applied to optimize the model and the results of the computational experiments are reported

Genetic algorithms: Kumar N, Shanker K[32], solved Part type selection (PTS) and machine loading problems by the use of genetic algorithms (GAs). They exploited the problem's MIP (mixed integer programming) model to make their GA more meaningful and less computation-intensive. The GA strategy is developed in three parts: solution coding, solution generation and solution recombination. In solution coding, they replaced the original binary routing variables with integer variables and thus reduce the chromosome length significantly. In solution generation, the level of feasibility is the main concern. They divided the constraints into two categories: direct and indirect. The direct constraints involve only two variables each and are easily satisfied by context-dependent genes. Since the direct constraints form the major chunk of constraints, their satisfaction controls infeasibility to a large extent. The remaining indirect constraints are handled by the penalty function approach. The solution recombination involves crossover and mutation. The crossover is performed in two steps, the PTS swap followed by the routing swap, so that the feasibility level is not disturbed. With a similar intent, the mutation is allowed to operate only on selective genes. All the steps are illustrated with examples. Their GA is able to achieve optimum or near-optimum performance on a variety of objectives. A parametric study of GA factors is also carried out, indicating population size and mutation probability as influential parameters. Yang et al[33], examined the development and application of a hybrid genetic algorithm (HGA) to the open shop scheduling problem. The hybrid algorithm incorporates a local improvement procedure based on tabu search (TS) into a basic genetic algorithm (GA). The incorporation of the local improvement procedure enables the algorithm to perform genetic search over the subspace of local optima. The algorithm is tested on randomly generated problems, and benchmark problems from the literature. Computational results show that the HGA is able to find an optimum solution for all but a tiny fraction of the test problems. Some of the benchmark problems in the literature are solved to optimality for the first time. Moreover, the results are compared to those obtained with list scheduling heuristic, insertion heuristic (IH), simulated annealing and pure TS algorithms. The HGA significantly outperforms the other methods in terms of solution quality. Tiwari M.K., Vidyarthi N.K[34], proposed, a Genetic Algorithm (GA) based heuristic to solve the machine loading problem of a random type FMS. The objective of the loading problems is to minimize the system unbalance and maximize the throughput, satisfying the technological constraints such as availability of machining time, and tool slots. The proposed GA-based heuristic determines the part type sequence and the operation-machine allocation that guarantee the optimal solution to the problem, rather than using fixed predetermined part sequencing rules. The efficiency of the proposed heuristic has been tested on ten sample problems and the results obtained have been compared with those of existing methods. Yang H, Wu Z[35], formulated a strict mixed-integer programming (MIP) model that integrates part type selection and machine loading together is formulated. The MIP takes into account the constraints such as magazine capacity, tool life, available machine time, etc. The objective is to minimize the difference between maximum and minimum workloads of all the machine resources in each batch. A genetic algorithm-based method is developed to obtain the solution of the problem effectively. Concepts of virtual job and virtual operation are introduced in the encoding scheme, and a chromosome is composed of both these strings. Among each chromosome, the partition symbol list is mainly used to handle the part type selection problem, while the virtual job list mainly used to cope with the loading problem. Special crossover and mutation operators are designed to adapt to the problem. Their approach can simultaneously balance the workloads in different batches. At last, illustrative examples are presented, and a comparison between standard MIP algorithm and a genetic algorithm method is given. Akhilesh Kumar et al [36], extended the simple genetic algorithm and proposes a new methodology, constraint-based genetic algorithm (CBGA) to handle a complex variety of variables and constraints in a typical FMS-loading problem. To achieve this aim, three new genetic operators—constraint based: initialization, crossover, and mutation are introduced. The methodology developed here helps avoid getting trapped at local minima. The application of the algorithm is tested on standard data sets and its superiority is demonstrated. The solution approach is illustrated by a simple example and the robustness of the algorithm is tested on five well-known functions. Choudhary A.K et al[37], modelled a machine-loading problem, taking into consideration several technological constraints related to the flexibility of machines, availability of machining time, tool slots, etc. A new kind of genetic algorithm, termed a genetic algorithm with chromosome differentiation, has been used to address a well-known machine-loading problem. The proposed algorithm overcomes the drawbacks of the simple genetic algorithm and the methodology reported here is capable of achieving a better balance between exploration and exploitation and of escaping from local minima. The proposed algorithm has been tested on ten standard test problems adopted from literature and extensive computational experiments have revealed its superiority over earlier approaches. Tyagi V, Jain A[38],addressed the problem of FMS loading and part type selection, when flexible process plans for each part type are available. A Genetic Algorithm based methodology is adopted that selscts the part types along with their process plans in order to minimize system unbalance while satisfying the constraints of tool slots, avialble tool copies and planning period duration. An example of FMS is taken in to consideration results indicates that availability of flexible process plans(FPP) during the FMS loading assist the planner in reducing the system unbalance. Other interesting conclusions, such as for given number of tool copies of each tool type tool loading is affected by the availability of FFPs, are drawn. Ayten Turkcan et al[39], considered flexible manufacturing system loading, scheduling and tool management problems simultaneously. Their aim is to determine relevant tool management decisions, which are machining conditions selection and tool allocation, and to load and schedule parts on non-identical parallel CNC machines. The dual objectives are minimization of the manufacturing cost and total weighted tardiness. The manufacturing cost is comprised of machining and tooling costs (which are affected by machining conditions) and non-machining cost (which is affected by tool replacement decisions). They used both sequential and simultaneous approaches to solve the problem to show the superiority of the simultaneous approach. The proposed heuristics are used in a problem space genetic algorithm in order to generate a series of approximately efficient solutions.

Other AI approaches: In this categoty, this work considered all the other AI approaches that are found in the literature of machine loading in FMS. Particle swarn optimization, Ant Colony optimization, Simmulated annealing and hybrid approaches of these AI approaches considered in this category. Mukhopadhyay SK et al[40], considered the problem of FMS machine loading with the objective of minimizing the system imbalance using a simulated annealing (SA) approach. New job sequences are generated with a proposed perturbation scheme named the 'modified insertion scheme' (MIS). These sequences are used in the proposed simulated annealing algorithm to arrive at a near global optimum solution. A new approach for temperature variation in the SA algorithm is also suggested in which temperature is assumed to be parabolic. The SA algorithm using the proposed MIS and the assumed temperature variation proved to be giving substantial improvement in system imbalance as against conventional sequences. Tiwari M.K et al[41], modeled the machine loading problem by taking into account objective functions and several constraints related to the flexibility of machines, availability of machining time, tool slots, etc. Minimization of system unbalance (SU), maximization of system throughput (TH), and the combination of SU and TH are the three objectives, whereas two main constraints to be satisfied are related to time and tool slots available on machines. Proposed a new algorithm termed as constraints-based fast simulated annealing (SA) to address a well-known machine loading problem available in the literature. The proposed algorithm enjoys the merits of simple SA and simple genetic algorithm and is designed to be free from some of their drawbacks. The enticing feature of the algorithm is that it provides more opportunity to escape from the local minimum. The application of the algorithm is tested on standard data sets, and superiority of the same is witnessed. Intensive experimentations were carried out to evaluate the effectiveness of the proposed algorithm, and the efficacy of the same is authenticated by efficiently testing the performance of algorithm over well-known functions. Swarnkar, Rahul and Tiwari, M.K.[42], discussed a machine loading problem of a flexible manufacturing system (FMS) having the bicriterion objectives of minimizing system unbalance and maximizing throughput in the presence of technological constraints such as available machining time and tool slots. A generic 0–1 integer programming formulation with the objective functions and constraints described above has been proposed. A hybrid algorithm based on tabu search and simulated annealing (SA) is employed to solve the problem. The main advantage of this approach is that a short-term memory provided by the tabu list can be used to avoid revisiting the solution while preserving the stochastic nature of the SA method. The proposed methodology has been tested on ten standard problems and the results obtained are compared with those from some of the existing heuristics. Yogeswaran M et al[43], discussed a machine loading problem in a flexible manufacturing system (FMS) with bi-criterion objectives of minimising system imbalance and maximising system throughput in the occurrence of technological constraints such as available machining time and tool slots. A mathematical model is used to select machines, assign operations and the required tools in order to minimise the system's imbalance while maximising the throughput. An efficient evolutionary algorithm by hybridising the genetic algorithm (GA) and simulated annealing (SA) algorithm called GASA is proposed. The performance of the GASA is tested by using 10 sample dataset and the results are compared with the heuristics reported in the literature. The influence of genetic operators on the evolutionary search in GASA is studied and reported. Two machine selection heuristics are proposed and their influence on the quality of the solution is also studied. Extensive computational experiments have been carried out to evaluate the performance of the proposed evolutionary heuristics and the results are presented in tables and figures. The results clearly support the better performance of GASA over the algorithms reported in the literature. Mandal S.K et al[44], addressed the machine loading problem of FMS with a view to maximise the throughput and minimise the system unbalance and makespan. They employed an on-line machine monitoring scheme and an off-line machine monitoring scheme in conjunction with reloading of part types to cope with the breakdowns. The proposed model bears similarity with the dynamic environment of FMS, hence, termed as the dynamic machine loading problem. Furthermore, to examine the effectiveness of the proposed model, results for throughput, system unbalance and makespan on different dataset from previous literature has been investigated with application of intelligence techniques such as genetic algorithms (GA), simulated annealing (SA) and artificial immune systems (AIS). The results incurred under breakdowns validate the robustness of the developed model for dynamic ambient of FMS. Prakash, A et al[45], developed a special Immune Algorithm (IA) named 'Modified immune algorithm (MIA)'. IA is a suitable method due to its self learning capability and memory acquisition. They improves some issues inherent in existing IAs and proposes a more effective immune algorithm with reduced memory requirements and reduced computational complexity. In order to verify the efficacy and robustness of the proposed algorithm, they presented comparisons to existing immune algorithms with benchmark functions and standard data sets related to the machine loading problem. In addition proposed algorithm has been tested at different noise level to examine the efficiency of algorithm on different platforms. The comparisons show consistently that the proposed algorithm outperforms the existing techniques. For all machine loading dataset proposed algorithm has shown good results as compared to the best results reported in the literature. Prakash A, Tiwari M.K, Shankar R[46], proposed an Adaptive Hierarchical Ant Colony Optimization (AHACO) to resolve the traditional machine loading problem in Flexible Manufacturing Systems (FMS). The machine loading problem is formulated in order to minimize the system unbalance and maximize the throughput, considering the job sequencing, optional machines and technological constraints. The performance of proposed AHACO has been tested over a number of benchmark problems taken from the literature. Computational results indicate that the proposed algorithm is more effective and produces promising results as compared to the existing solution methodologies in the literature. The evaluation and comparison of system efficiency and system utilization justifies the supremacy of the algorithm. Further, results obtained from the proposed algorithm have been compared with well known random search algorithm viz. genetic algorithm, simulated annealing, artificial Immune system, simple ant colony optimization, tabu search etc. In addition, the algorithm has been tested over a randomly generated problem set of varying complexities; the results validate the robustness and scalability of the algorithm utilizing the concepts of 'heuristic gap' and ANOVA analysis. Jae Yun Kim, Yeo Keun Kim[47], proposed a new method of solving integrated and multileveled problems. The proposed method is named Multileveled Symbiotic Evolutionary Algorithm (MSEA). MSEA is an evolutionary algorithm that imitates the process of symbiotic evolution, including endosymbiotic evolution. It is designed to promote the balance of population diversity and population convergence. To verify its applicability, MSEA is applied to loading problems of flexible manufacturing systems with various flexibilities. Through computer experiments, the features of MSEA are shown and their effects on search capability are discussed. The proposed algorithm is also compared with existing ones in terms of solution quality. The experimental results confirm the effectiveness of their `approach. Ponnambalam S.G, Low Seng Kiat[48], proposed a particle swarm optimization (PSO) algorithm to solve machine loading problem in flexible manufacturing system (FMS), with bicriterion objectives of minimizing system unbalance and maximizing system throughput in the occurrence of technological constraints such as available machining time and tool slots. A mathematical model is used to select machines, assign operations and the required tools. The performance of the PSO is tested by using 10 sample dataset and the results are compared with the heuristics reported in the literature. The results support that the proposed PSO is comparable with the algorithms reported in the literature. Sandhyarani Biswas, Mahapatra S.S [49],proposed a meta-heuristic approach based on particle swarm optimization (PSO) to improve the solution quality and reduce the computational effort. However, PSO has the tendency to suffer from premature convergence. Therefore, the PSO algorithm has been modified through the introduction of a mutation operator to improve efficiency of the algorithm. The proposed algorithm attempts to minimize the system unbalance while satisfying the technological constraints, such as the availability of machining time and tool slots. The proposed algorithm produces promising results in comparison to existing methods for ten benchmark instances available in the FMS literature. Sandhyarani Biswas, Mahapatra S.S [50],proposed, a metaheuristic approach based on Particle Swarm Optimisation (PSO) to solve the machine loading problem. Mutation has been introduced in PSO in a novel way so that the trapping of solutions at local minima can be avoided. The comparative study of the proposed algorithm with existing methods for ten benchmark instances available in the literature suggests that the results obtained in the proposed algorithm are quite encouraging.

III. CONCLUSION COMMENTS:

This paper reviewed the literature on different approaches used to solve machine loading problem in FMS. Then the approaches were categorized as 1).The Mathematical approach. 2). The heuristic approach. 3). The artificial intelligence-based approaches and presented the gist of reviewed papers in these categories.

The Mathematical approach are proposed by many authors. Most of the authors considered mixed integer or 0–1 programming [Stecke[4], Lashkari et al.[6], Co et al [9], Gamila & Motavalli,[13], Mgwatu et al.[14]], Berrada & Stecke[5] considered a branch-and-bound algorithm , Lee & Jung[7]] considered goal programming, Bretthauer &Venkataramanan[8], considered Langrangian relaxation models to tackle the problems machine loading in a flexible manufacturing system (FMS). Some authors (Stecke[4] Berrada, Stecke[5], Bretthauer & Venkataramanan[8], Modi,Shanker [10]) considered only balancing the workloads as objective function and some others [Lashkari et al.[6], Lee, Jung[7], Co et al [9], Guerro et al [11], Mohammed et al[12], Gamila & Motavalli,[13], Mgwatu et al.[14], Zeballos L.J. et al [15]]considered balancing the workloads along with one or more other objective like minimization of throughput time of parts, tool allocation, routing, and scheduling.

Heuristic approaches are proposed my many authors [[16] to [26]], most of the authors considered the objectives as minimization of system unbalance and a maximization of throughput, but with different constraints. Kim H.W. et at[24], considered the practical constraints associated with cutting tools: (a) tool life restrictions; and (b) available number of tool copies. Tiwari M.K, Saha J., Mukhopadhyay S.K [23] considered the objectives in the presence of constraints availability of machining time and tool slot in a given planning horizon. Tiwari M.K. et al[22], considered the objectives by satisfying the constraints related to available machining time and tool slots. Goswami M, Tiwari M. K[21]considered the objectives in the presence of constraints related to machine time and tool slots availability, constraint related to material handling. Nagarjuna et al [20] considered the objective, minimizing the system unbalance while satisfying constraints such as the availability of tool slots and machining time.Fuzzy based approaches are also used by some authors. Vidyarthi N.K, Tiwari M.K [27], considered the objectives minimization of system unbalance and maximization of throughput in the presence of constraints are posed by availability of machining time and tool slots. Kameshwaran,Tiwari[28] considered the objective minimizing the total cost of machining operations used fuzzy goal-programming based GA. Chan et al. [30] used fuzzy goal-programming based artificial immune systems, Chan F.T.S, Swarnkar R., [31] used fuzzy goal-programming based ant colony optimization (ACO) for the machine tool selection and operation allocation problem of FMS.

Use of Genetic algorithms based approaches for machine loading problem are observed in many papers[[32] to[39]]. Kumar, Shanker [32] used integer programming approach to model and solved part type selection and machine loading of FMS using GA. Yang, Wu[35] formulated a strict mixed integer programming (MIP) model and a GA-based method is developed to obtain the solution of the problem effectively. Akhilesh Kumar et al.[36] proposed a new methodology, constraint-based genetic algorithm (CBGA), Choudhary A.K. et al[37] proposed a new kind of genetic algorithm, termed a genetic algorithm with chromosome differentiation. Yogeswaran et al. [38] proposed a hybrid algorithm using genetic algorithm and simulated annealing (GASA) algorithm for for machine loading problem. Mukhopadhyay et al. [40], Tiwari M.K et al[41], applied a simulated annealing (SA)- based algorithm to solve the machine loading problem. Swarnkar R, Tiwari M.K.[42] applied a hybrid algorithm based on tabu search and simulated annealing (SA), Prakash et al. [45] proposed a special Immune Algorithm (IA) named Modified immune algorithm (MIA), Prakash A, Tiwari M.K, Shankar R[47],proposed an Adaptive Hierarchical Ant Colony Optimization (AHACO), Chan,Swarnkar [31] presented a fuzzy goal programming approach based an ant colony optimization

(ACO), Ponnambalam S.G, Low Seng Kiat,[48], Sandhyarani Biswas, Mahapatra S.S[49,50] proposed a particle swarm optimization (PSO) for machine loading problem in Flexible Manufacturing Systems (FMS.

Most of the articles presented on Machine-loading problem of flexible manufacturing systems are prepared by considering mixed integer or 0–1 programming formalization as a starting point, and then tend to modify slightly the model or used heuristic techniques or AI approaches in order to overcome computational problems. In recent years, the use of AI approaches like Genetic algorithms, fuzzy logics, simulated annealing, particle swarm optimization (PSO), Ant Colony Optimization is prominently found for solving machine loading problem.

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