Use of Fuzzy Logic Approaches in Scheduling of FMS: A Review

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Abstract— Scheduling in an flexible manufacturing systems(FMS) environment is more complex and difficult than a conventional manufacturing environment. Therefore, determining an optimal schedule and controlling an FMS is considered a difficult task. To achieve high performance for an FMS, a good scheduling system should make a right decision at a right time according to system conditions. Fuzzy logic approaches easily deal with uncertain and incomplete information, and human experts knowledge can be easily coded into fuzzy rules. Due to these reasons, fuzzy logic approaches are very effective for scheduling of flexible manufacturing systems. This work presents a review on use of fuzzy logic approaches in scheduling of flexible manufacturing systems.

Keywords— Fuzzy logic; Scheduling; FMS.

I. INTRODUCTION

A flexible manufacturing system (FMS) provides the efficiency of automated high-volume mass production while retaining the flexibility of low-volume job shop production. Scheduling in an FMS environment is more complex and difficult than in a conventional manufacturing environment. Scheduling of FMS is NP-hard scheduling problems. Therefore, determining an optimal schedule and controlling an FMS is considered a difficult task. Since the invention of the flexible manufacturing systems, many researchers are working on the topic to find out the solution to scheduling of flexible manufacturing systems and developed number of solution methods by using a wide variety of techniques /models for the scheduling of manufacturing systems. Even though, there are many intelligent techniques are in use for scheduling of FMS, but the prominently used intelligent techniques are: fuzzy logic approaches, artificial neural networks, genetic algorithms .

Fuzzy logic approaches easily deal with uncertain and incomplete information, and human experts knowledge can be easily coded into fuzzy rules. Due to these reasons, in recent years, the use of fuzzy logic approaches in scheduling of flexible manufacturing systems increased. Fuzzy set theory was introduced in 1965 by Zadeh [1].Hintz and Zimmermann [2], are probably the first to propose a production planning and control system that uses fuzzy set theory. They presented an approach to control the releasing of parts into the flexible manufacturing systems and the scheduling of parts and tools in flexible manufacturing systems. The approach bases primarily on fuzzy linear programming and on approximate reasoning. By using simulation the superiority of these approaches over known priority rule scheduling is demonstrated.

II. REVIEW

The use of fuzzy logic approaches for scheduling FMS is considered due to its ability to deal uncertain and incomplete information and with multi-objective problems. Hatono I et al.[3]proposed a method of constructing and revising knowledge bases to accomplish high-variety of objectives in a knowledge-based scheduling. They divided the knowledge base into three modules: a schedule evaluation module, a scheduling policy module, and a dispatching module. All of them are described by fuzzy rules in which fuzzy predicates are included. When we need to change the scheduling objective depending upon the manufacturing environment, the knowledge base in the scheduling system can be easily revised by just adjusting the membership functions of the fuzzy rules in the schedule evaluation module.

Angsana A,Passino M.K.[4], presented, how to design a fuzzy controller for a single machine and show via simulation that its performance is comparable to conventional schedulers. In addition, They introduced an adaptive fuzzy controller which can automatically synthesize itself to achive good throughput rates for the single machine as compare with conventional scheduler. Next they presented via simulation that by using such adaptive fuzzy controller in a distributed fashion can obtain a distributed fuzzy controller which can automatically synthesize itself and lower the maximum buffer lever more effectively than conventional

scheduler. Finally, they illustrated the ability of the Distributed Fuzzy Control **(**DFC), and conventional schedulers to automatically tune themselves in case there are unpredictable machine parameter changes in an FMS.

The work of Saeid Nahavandi, Paul Solomon,[5] shown that, fuzzy logic can be useful for the scheduling problems where the production data such as processing times is fuzzy. The chosen area of application of fuzzy logic is the hybrid control architecture of a Flexible Manufacturing System (FMS). Fuzzy logic is used for prioritization and the ordering of the jobs in the Factory Controller queue. The preliminary results indicate that implementing a fuzzy scheduling system to shop floor scheduling will ease the rather complicated scheduling problems. A fuzzy petri-net algorithm is developed by Xu [6]for scheduling of flexible manufacturing systems with the human operators. The model used the fuzzy reasoning algorithm to achieve the optimum schedule for the FMS. A simple FMS, which deals with 2 job types associated with 2 processes each, 3 machines, and two types of operators are considered as an example of the study. Kazerooni A, Chan F.T.S, Abhary K [7] have developed fuzzy logic for the selection of the scheduling rule to be executed in the dynamic shop floor control using simulation.

Chan F.T.S, Kazerooni A, Abhary K [8] have proposed a multi-objective machine selection rule. The machine selection rule selects the next machine for the operation based on the evaluation of the combined effect of multiple objectives. In this research multiple objectives considered were: i) fewest jobs in the queue, ii) least total work content in the queue, iii) lowest utilization level. Fuzzy-set theory is used to model the rule. Erkmen A.M et al.,[9]focused on the development and implementation of a genetically tuned fuzzy scheduler (GTFS) for heterogeneous FMS under uncertainty. The scheduling system takes input from a table and creates an optimum master schedule. The GTFS uses fuzzy rulebase and inferencing where fuzzy sets are generated by a genetic algorithm to tune the optimization. The fuzzy optimization is based on time criticality in deadline and machine need, taking into account machine availability, uniformity, process time and selectability. Paolo D,Hugh F.V, Maio B.,[10] opinioned that the importance of “common sense” and “human experts” in scheduling, together with fuzzy logic ability to mimic human reasoning, along with the ease of dealing with linguistic variables makes it a suitable and powerful scheduling tool.Naso D, Turchiano B[11], considered the real-time part routing in flexible manufacturing systems. At each production step, each part can autonomously choose its next server according to a fuzzy multiple criteria evaluation of each available destination. The influence of each criterion is graded to improve the effects of part decisions. A simulation study confirms the effectiveness of the approach.Fanti M.P et al[12] deal with the problem of Job scheduling in flexible production systems using fuzzy set theory and genetic algorithms. Fuzzy techniques allow us to define global performance measures expressing different and often conflicting objectives of the production. Moreover, according to
a fuzzy multi-criteria algorithm, they proposed a methodology to combine various heuristics, with different weights, in a single dispatching criterion. A genetic optimization process selects the weights guaranteeing good system performances. A case study and some extensive simulations show the efficiency of the methodology.

Shih H. M, Sekiguchi T.[13], proposed a fuzzy inference-based scheduling decision for flexible manufacturing systems (FMS) with multiple objectives. The objectives have different and dynamic preference levels. It is inferred that the changes in the production environment may be sensed by environmental variables. The detected changes are input in a fuzzy inference mechanism, which outputs the current preference levels of all objectives. A multiple criteria scheduling decision is then made, using the partitioned combination of the preference levels. An example of application is presented. Simulation results show very good performance for the proposed system. Yu et al.[14] proposed an approach to FMS scheduling with multicriteria based on fuzzy inference. The proposed system has the following characteristics: (1) each criteria or objective has a preference level at the scheduling time; (2) all objectives and their preference levels are considered in the decision time; (3) the changes in the conditions of the factory are captured in real time by a fuzzy inference model that maps the changes to the proper preference levels; (4) multi-criteria scheduling is realised using a partition method based on the preference levels obtained from fuzzy inference. The proposed system performed very robustly with respect to shop workload for all used performance measures. Tedford T.D, Lowe C[15], proposed a scheduling system incorporating an adaptive fuzzy logic system, which can be tailored to suit the characteristics and objectives of an organization and maintain its performance by constantly adapting to changes in the production environment. The system developed indicates that its application shows benefits in terms of the resulting schedule performance and with respect to the simplicity of the scheduling algorithms required. The computational overhead of the fuzzy system is also shown to be insignificant, thus permitting real-time operation in a manufacturing situation. Chan F T S, Chan H K, Kazerooni[16] , described an intelligent fuzzy decision support system for real-time scheduling and dispatching of parts in a flexible manufacturing system (FMS), with alternative routing possibilities for all parts. A fuzzy logic approach is developed to improve the

system performance by considering multiple performance measures and at multiple decision points. The characteristics of the system status, instead of parts, are fed back to assign priority to the parts waiting to be processed. A simulation model is developed and it is shown that the proposed intelligent fuzzy decision support system keeps all performance measures at a good level. The proposed intelligent system is a promising tool for dealing with scheduling FMSs, in contrast to traditional rules.

Kacem I, Hammadi S[17],proposed a Pareto approach based on the hybridization of fuzzy logic (FL) and evolutionary algorithms (EAs) to solve the flexible job-shop scheduling problem (FJSP). This hybrid approach exploits the knowledge representation capabilities of FL [[3]] and the adaptive capabilities of EAs. The integration of these two methodologies for the multi-objective optimization has become an increasing interest. The objective considered is to minimize the overall completion time (makespan), the total workload of machines and the workload of the most loaded machine. Pramot Srinoi et al[18],Developed the fuzzy based scheduling model, they only deal with the part routing problem. The model will select the best alternative route with multi-criteria scheduling through an approach based on a fuzzy logic. This model is applicable to the scheduling of a flexible manufacturing cell (FMC) and also a multi-machine flexible manufacturing system (MMFMS).Domingos, J.C. Politano, P.R.[19], proposed an on-line scheduling procedure based on fuzzy logic. whose main characteristic is shop floor tasks scheduling using production rules of an expert to meet several measures of performance. A simulation study was carried out with the objective to verify the applicability of the proposed approach, using a simulation tool integrated with a decision making system (DMS) based on fuzzy logic.Pires M.G. et al[20],presented a technique that uses fuzzy logic to set the best sequence of parts to be processed. The decision of which part will be the next to be processed should take into account some criteria that influences the performance of the FMS. In order to test and validate the proposed approach, a shop floor was tested using the fuzzy system and also a FIFO rule to be compared. Chan F.T.S, Chan H.K, Kazerooni [21]a presented a real-time fuzzy expert system to scheduling parts for a flexible manufacturing system (FMS). First, some vagueness and uncertainties in scheduling rules are indicated and then a fuzzy-logic approach is proposed to improve the system performance by considering multiple performance measures. This approach focuses on characteristics of the system's status, instead of parts, to assign priorities to the parts waiting to be processed. Secondly, a simulation model is developed and it has shown that the proposed fuzzy logic-based decision making process keeps all performance measures at a good level. The proposed approach provides a promising alternative framework in solving scheduling problems in FMSs, in contrast to traditional rules, by making use of intelligent tools. Monfared M.A.S, Yang J.B[22], are integrated the techniques and concepts from fuzzy logic theory, control theory, and optimisation theory together, to provide a novel intelligent manufacturing control system that operates in real-time, and is capable of responding to both structural and order related disturbances in a fully automated manner. They further developed their previous research on a second order intelligent scheduling and control system by performing an extensive sensitivity analysis and parameter optimization in order to achieve an optimal scheduling and control system.

Li Shugang et al.[23], proposed a fuzzy rule based GA, in which a fuzzy logical controller is introduced to adjust the value of crossover probability, mutation probability and crossover length. The HGA (hybrid genetic algorithm), which is integrated with a fuzzy logic controller, can avoid premature convergence, and improve the efficiency greatly. Finally, simulation results of the facility layout problem and job-shop schedule problem are given. The results show that the new genetic algorithm integrated with fuzzy logic controller is excellent in searching efficiency. Srinoi P, shayan E,Ghotb F.[24], proposed flexible manufacturing systems (FMSs) scheduling using a fuzzy logic (FL) approach. Four fuzzy input variables: machine allocated processing time, machine priority, due date priority and setup time priority are defined. The job priority is the output fuzzy variable, showing the priority status of a job to be selected for next operation on a machine. The model will first select the machines and then assign operations based on a multi-criteria scheduling scheme. The performance of the approach is compared against established methods reported in the literature. The performance measures considered average machine utilisation, meeting due dates, setup times, work in process and mean flow times. The test results demonstrate the superiority of the fuzzy logic approach in most performance measures.

Li D.C. et al.[25], the method to improve the accuracy of machine learning for flexible manufacturing system (FMS) scheduling using small data sets. The study developed a data trend estimation technique and combines it with mega-fuzzification and adaptive-network-based fuzzy inference systems (ANFIS). The results of the simulated FMS scheduling problem indicate that learning accuracy can be significantly improved using the proposed method involving a very small data set. Yaguang Kong, Xiangxin Gong, Jianzhong Wang[26], Flexible Manufacturing systems have been designed to meet market requirements, that demand products that are quality and ready to deliver. In order to meet the market requirements, the methodologies used in the FMS scheduling must consider some constraints. A realtime scheduling policy based on fuzzy logic is proposed in this work. The decision of which part will be the next to be processed should take into account some criteria that influences the performance of FMS. In order to test and validate the proposed approach, a shop floor was tested using the fuzzy system and also a FIFO rule to be compared. Caprihan R, Kumar A, Stecke K.E[27], introduced

a novel fuzzy logic-based dispatching strategy to cope with a specific manifestation of information delays, called status review delay within FMSs. Status review information delays impact system performance adversely because of the obsolescent nature of the information used in the determination of dispatch decisions. A fuzzy dispatching strategy (FDS), designed specifically for deployment within FMSs where information delays are manifest, provides an appropriate alternative to conventional dispatching strategies such as WINQ and NINQ. In the design of an FDS, relevant system-based parameters are fuzzified and an appropriate rule base is designed. Simulation experiments demonstrate the superiority of an FDS over the conventional WINQ dispatching strategy using the mean tardiness, percent tardy, and mean flowtime performance measures. Chan, Swarnkar[28] presented a fuzzy goal programming approach for the machine tool selection and operation allocation problem of FMS. It determined the optimal machine tool combination and the assignment of the operation for the given part types to the available machines while maintaining the machining cost, material handling cost and set-up cost within certain limits. Caprihan R, Kumar S, Gursaran, Das, A.[29], introduces a fuzzy associative memory-based control strategy, the generalised fuzzy sequencing strategy (GFSS), to cope with status information delays. In demonstrating the use of GFSS for the single machine, three queue dynamic sequencing problem wherein information delays manifest in the form of machine setup times, the paper identifies suitable input and output control variables and suggests their appropriate fuzzification. They defined the relative work-in-process, relative setup time, relative service rate, and relative traffic intensity as four input fuzzy control variables. The output fuzzy variable is the queue confidence level. Using the input and output fuzzy variables, the design of GFSS is described together with its implementation in an object-oriented environment. Simulation results for the average part flowtime and average work-in-process level performance measures demonstrate the efficacy and potential of using fuzzy control in situations where machine setup times are significant. Importantly, although designed for the three-queue single-machine dynamic sequencing problem, GFSS is generalizable for the n-queue case in a straightforward manner.

Lee K.K[30] proposed a fuzzy rule-based system for an adaptive scheduling, which dynamically selects and applies the most suitable strategy according to the current state of the scheduling environment. The adaptive scheduling problem is generally considered as a classification task since the performance of the adaptive scheduling system depends on the effectiveness of the mapping knowledge between system states and the best rules for the states. A rule base for this mapping is built and evolved by the proposed fuzzy dynamic learning classifier based on the training data cumulated by a simulation method. Distributed fuzzy sets approach, which uses multiple fuzzy numbers simultaneously, is adopted to recognize the system states. The developed fuzzy rules may readily be interpreted, adopted and, when necessary, modified by human experts. An application of the proposed method to a job-dispatching problem in a hypothetical flexible manufacturing system (FMS) shows that the method can develop more effective and robust rules than the traditional job-dispatching rules and a neural network approach. Imit Bilge et al[31] introduced three new approaches, including a fuzzy logic approach, for dynamic part routing. The fuzzy part routing system adapts itself to the characteristics of a given flexible manufacturing system (FMS) installation by setting the key parameters of the membership functions as well as its Takagi-Sugeno type rule base, in such a way to capture the bottlenecks in the environment. Thus, the model does not require a search or training for the parameter set. The proposed approaches are tested against several crisp and fuzzy routing algorithms taken from the literature, by means of extensive simulation experiments in hypothetical FMS environments under variable system configurations. The results show that the proposed fuzzy approach remains robust across different system configurations and flexibility levels, and performs favourably compared to the other algorithms. The results also reveal important characteristic behaviour regarding routing flexibility. [32]The scheduling of production in flexible manufacturing systems has been extensively researched over the past years. There are many models such as MODM and heuristics, have been developed by researchers for scheduling a FMS. Scheduling a FMS is a MCDM problem contains many criteria. Also there are many dispatching rules for scheduling. They developed a model for selecting the best dispatching rule with respect to criteria and system conditions. In most conditions there some inner dependencies among criteria so we cannot use AHP. They also developed an ANP model to consider the inner decencies among criteria. Finally, they applied the proposed model to prove the applicability of the model.

Restrepo I.M,Balakrishnan S.[33],proposed a fuzzy logic based methodology for generating the sequence of part movements in a multi-product batch processing through a computerized machine cell. A number of production objectives are taken into account. Two fuzzy based strategies: fuzzy-job and fuzzy-machine are proposed and their performance is compared to two well known dispatching rules such as SPT (Shortest Processing Time) and WEED (Weighted Earliest Due Date). The sequencing algorithm was implemented on a standard personnel computer and the scheduler was interfaced to a robot controller for implementing loading and unloading strategy within the cell. The proposed fuzzy-based methodologies especially fuzzy-job shows a superior performance compared to the traditional dispatching rules considered. Venkateswaran P.R, et al[34], designed a supervisory controller using fuzzy logic for Flexible manufacturing systems. This makes it possible for the handling of the speed of the system in effective manner increasing productivity. The controller structure is layered so as to bring about the required flexibility in the approach. The

advantage is that the productivity of the system can be improved. The improvement possible is the rule base can be fine tuned to suit the different production schedules. Mahdavi I. et al.[35], presented a fuzzy rule based approach to investigate flexible routing in FMS as it is previously less focused in the literature. The objective is to find appropriate route due to jobs which should be operated on available machines in production line. The approach is to consider IF- Then rules based on real cases which may be actually occurred on the shop. After running fuzzy rule base system, appropriate route is therefore investigated. The approach is highly reliable for manufacturer who wishes to investigate proper flexible routing due to real situations in FMS environment. A numerical illustration also is given to demonstrate applicability of the proposed approach. Ming-Shan Lu,Ying-Jie Lie [36]proposed a dynamic dispatching strategy for multiple performance measures based on fuzzy inference. First, the variables affecting the system performance are identified. Then, the fuzzy membership functions and the fuzzy inference rules are established based on the simulation data. According to the statuses of environment variables, the fuzzy inference is performed to find an appropriate dispatching rule at each decision point to meet the best multiple performance measures. An example of the application is presented. The simulation results indicate that the proposed fuzzy-based dynamic dispatching strategy has a very good and robust performance.

III. CONCLUSION

This paper has reviewed the most of the research papers, that contributed to scheduling of flexible manufacturing systems using fuzzy logic approach As fuzzy logic approaches easily deal with uncertain and incomplete information, and human experts knowledge can be easily coded into fuzzy rules, It was found that these approaches given a very good and robust performance. It is also observed that use of fuzzy logic approaches has been successfully applied in integration with other meta heuristics like genetic algorithms, evolutionary algorithms, for FMS scheduling problems.

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