

# DEVELOPMENT OF A FUZZY-SIMULATION MODEL OF SCHEDULING ROBOTIC FLEXIBLE ASSEMBLY CELLS

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## ABSTRACT

Due to the complexity of scheduling flexible manufacturing systems, the generation of production schedules requires an intelligent technique. Many artificial intelligence techniques such as fuzzy logic, genetic algorithms and neural networks have been successfully applied to the scheduling of advanced manufacturing systems. One such system is Robotic Flexible Assembly Cells (RFACs). Few studies have addressed the problem of scheduling RFACs. The major limitation is that these studies are limited to the assembly of only one product type. The objective of this study is to propose a new intelligent model of scheduling RFACs in a multi-product assembly environment, using fuzzy logic.

**Keywords:** Robotic Cells, Scheduling, Fuzzy Logic, Simulation

## 1. INTRODUCTION

Robotic Flexible Assembly Cells (RFACs) are highly modern systems, structured with industrial robot(s), assembly stations and an automated material handling system, all monitored by computer numerical control (Manivannan, 1993; Marian *et al.*, 2003; Sawik, 1999). The design of RFACs with multi robots leads to increased productivity in a shorter cycle time and with lower production costs (Xidias *et al.*, 2010). However, there are certain difficulties that have arisen with this design concept. For example, more than one robot operating simultaneously in the same work environment requires a complex control system to prevent collisions between robots (Nof and Chen, 2003) and also to prevent deadlock problems (Lee and Lee, 2002). Moreover, industrial robots must be employed as effectively as possible due to high cost of the robots (Xidias *et al.*, 2010). To overcome the above difficulties, efficient scheduling of RFACs is required.

Few studies have been done on the problem of scheduling RFACs. These studies may be categorised into three groups (Abd *et al.*, 2011a). The first group applied

heuristic methods, while the second group investigated simulation as an approach to scheduling RFACs and the third group implemented expert systems to solve scheduling problems in RFACs. The major limitation of the previous studies of scheduling RFACs is that they concentrated on assembling only one type of product at a time. The objective of this study is to propose a new intelligent model of scheduling RFACs in a multi-product assembly environment, using fuzzy logic.

This study is organised as follows. The next section describes an overview of recent studies and how they have been applied fuzzy logic to solving the scheduling problems. In section 3, a new methodology for the scheduling of RFACs is developed. Finally, the conclusions and areas for further work are presented in section 4.

## 2. A REVIEW OF THE LITERATURE

In manufacturing systems, since the scheduling problems are NP-hard, an efficient approach is required to get best results (Buil *et al.*, 2010; Sridhar *et al.*, 2010). Recently, a fuzzy logic approach has been widely applied to the scheduling problems for both conventional

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and flexible manufacturing systems (Canbolat and Gundogar, 2004; Kumar *et al.*, 2004; Srinoi *et al.*, 2006; 2008; Mahdavi *et al.*, 2009).

In this section, the literature review will provide the necessary key points for the development of a conceptual methodology for the scheduling of RFACs. For example, Kumar *et al.* (2004) developed a fuzzy based algorithm to solve the scheduling problems of a FMS. They applied fuzzy membership functions to evaluate the overall contribution of each job type to the objectives according to the attributes and then determine the job sequencing. They used processing time, batch size and required tool slots as the main attributes. Two objectives functions, maximising of throughput and minimising of system imbalance, were considered in this study. The computational results showed that the developed algorithm gives better solutions than those obtained by heuristic approaches.

Canbolat and Gundogar (2004) applied a fuzzy logic approach to solve a multi criteria scheduling problem for a job shop environment. The suggested approach combined three scheduling rules in a new rule named Fuzzy Priority Rule (FPR). The new rule is compared with other traditional scheduling rules such as SPT, EDD, CR, using a simulation program. The simulation results showed the superiority of the FPR over traditional rules in mean flow time and mean tardiness.

Srinoi *et al.* (2006) developed a new approach based on fuzzy logic to generate a scheduling model for solving the resource allocation problem in flexible manufacturing systems. They defined four fuzzy input variables of the model: processing time, due date, setup time and machine priority; the output variable of the model is the job priority. They conducted several experiments to prove the effectiveness of the developed approach. The experimental results indicated that the fuzzy logic approach is a powerful technique for scheduling problems in FMS, based on multi criteria objectives.

Srinoi *et al.* (2008) developed a fuzzy-based mathematical model to deal with scheduling in FMS, based on multi-performance measures. They used processing time, machine priority, due date and setup time as input fuzzy variables, while the job priorities are the output variable. The simulation results pointed out the superiority of the suggested model in most performance measures.

Mahdavi *et al.* (2009) presented a fuzzy approach to solve the scheduling problems of a FMS. They defined

four fuzzy input variables: processing time, workload, setup time and travelling time. In this study, the output fuzzy variable was the optimal route selection to satisfy multi-conflicting objectives. They used the MATLAB fuzzy logic toolbox to determine the route selection. The numerical results showed that the presented approach is easily applicable to finding the optimal flexible routing in FMS. Based on the previous studies, five key points can be extracted:

- Most of the above studies showed that the use of fuzzy logic and simulation tools can be suitable to optimise the scheduling problems for both conventional and flexible manufacturing systems
- The scheduling problems may be divided into three main sub-problems: part type selection, machine loading and resource allocation. Most of the studies dealt with part type selection problems
- The majority of the listed studies took into account the processing time; due date and batch size were the main fuzzy criteria
- Two decision types, parts routing and parts sequencing, can be identified in the above studies. Most of the studies focused on the parts sequencing decision
- Nearly all the studies reviewed above employed more than two performance measures to evaluate the quality of the schedules

This study attempts to use the key points mentioned above to develop an intelligent methodology for the scheduling of RFACs. Therefore, the proposed methodology will include the following: the technique that will be used is fuzzy logic in combination with a simulation tool; the scheduling problem is product type selection; the fuzzy criteria are processing time, due date and batch size; the decision type is products sequencing; and the scheduling output is evaluated using multi performance measures. The next section will describe the proposed methodology in more detail.

### 3. PROPOSED METHODOLOGY

The main purpose of this study is to develop a methodology that will allow the user to model the scheduling of RFACs in an optimal way. The scheduling of the RFACs requires finding a way which determines how to use cell resources in an optimal manner to assemble multi-products. Let us consider an assembly cell in which a set of tasks are performed using a set of

resources to assemble multi-products concurrently. In this section, the proposed methodology for the scheduling of RFACs is described. This methodology has three major modules: (1) pre-processing module: this module helps to define the components of the scheduling problem model. For example, this module determines the system's inputs/output, identifies the objectives and describes the characteristics of RFACs (2) scheduling module: this module is the core of the proposed methodology, which allows the user to generate the schedule for assembling multi products (3) simulation module: this enables the user to build the RFACs as a computer model and then simulates the model under different scenarios, depending on the outcome of the scheduling module. The architecture of the proposed methodology is illustrated in **Fig. 1**. The next sections will present these three modules in more detail.

### 3.1. Pre-Processing Module

The aim of the pre-processing module is to describe all the required components of the scheduling problem model in the RFACs. These components are: parameters, decision variables, constraints and objective functions, as shown in **Fig. 2**. The next paragraphs give the necessary information about these components.

#### 3.1.1. Parameters

The required parameters for the scheduling process can be categorised into two types: system structure parameters and jobs parameters.

The system structure parameters depend on the configuration of the system. In other words, they reflect the physical characteristics of the system. For example, RFACs generally consist of main resources and tools that are used to perform the jobs. These resources are: robots for fetching the assembled parts and placing them at a number of assembly stations ( $AS_1, AS_2, \dots, AS_n$ ); Parts Feeder (PF) for supplying parts to the cell; gripper changing Station (GC); Input Conveyor (IC) for supplying the base parts; and Output Conveyor (OC) for conveying out a final product when assembly processes are completed (Marian *et al.*, 2003; Abd *et al.*, 2012a; 2012b).

Jobs parameters represent inputs data for a system: in other words, input variables that have fixed values. In this study, processing time, batch size and due date are selected as the input variables in the scheduling problems. Also, the number of required stations is suggested as another variable in this research.

#### 3.1.2. Decision Variables

In this research, the decision variable is represented by the job priority, illustrating the priority status of a product to be selected for the next assembly operation in RFACs. The scheduling module section will explain how to determine the job's priority using scheduling rules.

#### 3.1.3. Constraints

Constraints define the feasibility of a schedule. To generate a reliable solution to practical problems, a set of constraints must be satisfied. In this research, the RFACs scheduling problem is subject to three resource constraints: tooling resource constraints, robot movement constraints and robot access constraints (Abd *et al.*, 2011a; 2011b).

- To fetch and assemble, the hand of each robot should be equipped with the right tool; however, a specific tool may be not available for the two robots simultaneously, due to the restricted number of available tools. These are tooling resource constraints
- Robot arms cannot move from one place to another directly. The reason for this is to avoid collisions with the other robot arms. This is achieved by assigning control points in the cell. Control points  $\{C_1, C_2, C_3, \dots, C_4\}$  are set to simplify path planning and avoid collisions. For example,  $R_1$  cannot move from  $S_5$  to  $S_6$  directly; to move from  $S_5$  to  $S_6$ ,  $R_1$  should move via control point  $C_2$ . These requirements are called robot movement constraints, as shown in **Fig. 3**
- To prevent collisions between robots in a shared area, more than one robot cannot access the same resource at the same time. For instance, just one robot  $R_1$  or  $R_2$  can access transfer table ( $S_4$ ) or tool magazine ( $S_5$ ) or assembly station ( $S_6$ ) or the conveyors IN and OUT. These requirements are named robot access constraints, as shown in **Fig. 3**

#### 3.1.4. Objective Functions

The objective function is a value to be minimised or maximised in any optimisation problems. Examples of objective functions include makespan, system utilisation, lateness/tardiness, production cost.

In the scheduling area, several objective functions are used to evaluate the system's performance under different scheduling strategies. Ramasesh (1990) categorised the objective functions into four types: time-based objectives, work-in-process objectives, due-date-based objectives and cost-based objectives.

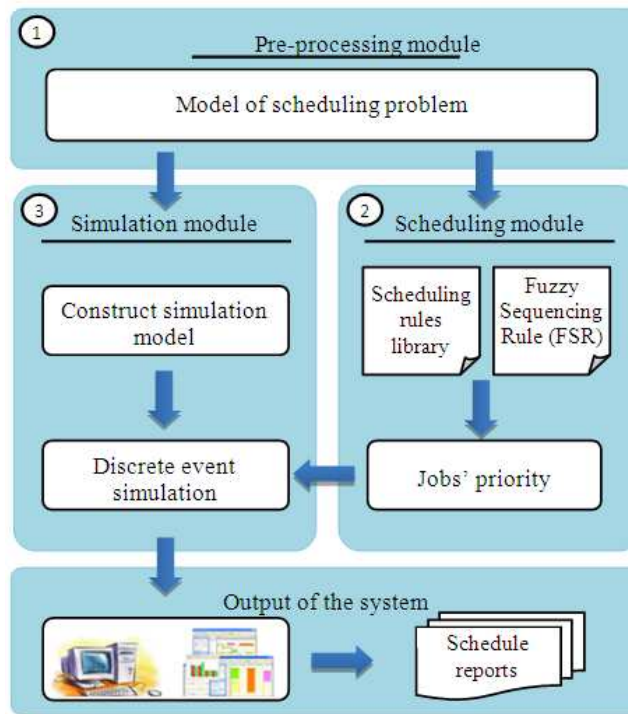


Fig. 1. Architecture of proposed methodology for RFACs scheduling

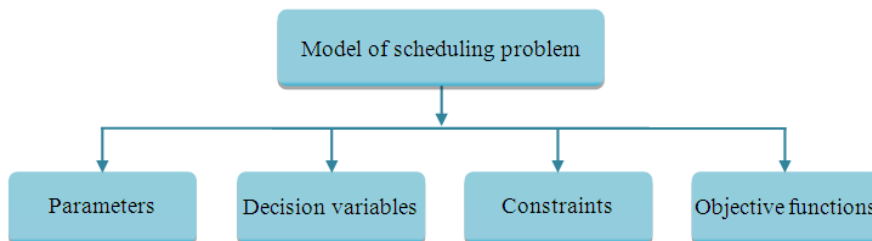


Fig. 2. Model of scheduling problem

In this research, five objective functions, namely makespan, percentage of robots idle time, total tardiness, maximum tardiness and percentage of tardy jobs, are to be minimized, to evaluate the RFACs' performance under different scheduling policies. These objectives are classified into two categories: time based objectives and due date based objectives. The makespan and percentage of robots idle time are in the first category while total tardiness fall into the second category. The following notations are used to formulate the mathematical expressions of the objectives:

- P = Products index ( $p = 1, 2, \dots, i$ ).
- Q = Parts index ( $Q = 1, \dots, j$ )
- R = Robots index ( $R = 1, 2, \dots, k$ )
- S = Resource index ( $S = 1, \dots, l$ )

- OP = Assembly operation index ( $OP = op_{1i}, op_{2i}, \dots, op_{mi}$ ) of product  $i$
- $T_{mi}$  = Time of assembly operation  $m$  of product  $i$
- $T_{(s \rightarrow l)i}$  = Time taken by robot to travel between two resources ( $s \rightarrow l$ ), to assemble product  $i$
- $T_{ji}$  = Time of tool change to transfer/assemble component  $j$  of product  $i$
- $D_i$  = Due date of product  $i$
- $N_i$  = Batch size of product  $i$
- $C_i$  = Completion time of product  $i$
- $U_i$  = Indicator for whether product  $i$  is tardy or not

$$\text{Makespan } C_{\max} = \max(C_i) \forall R \quad (1)$$

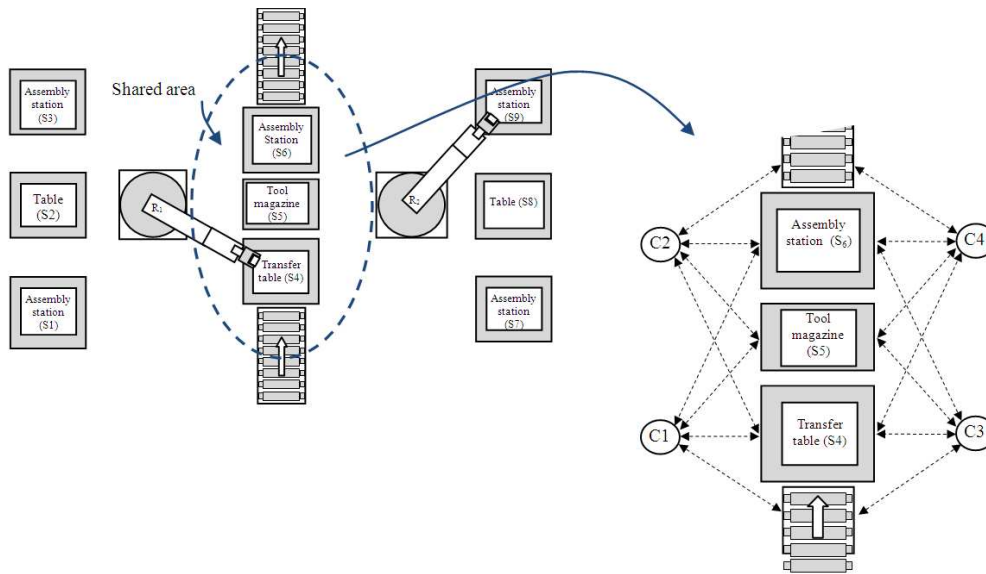


Fig. 3. Robot move and access constraints

Percentage of robots idle time (%I<sub>T</sub>) Equation (2):

$$\% I_T = 1 - \left( \frac{\sum_{OP=1}^m T_{mi} + \sum_{S=1}^l T_{(S \rightarrow l)i} + \sum_{Q=1}^j T_{ji}}{C_{max}} \right) \times 100 \forall i \quad (2)$$

Total tardiness (TD) Equation (3):

$$TD = \sum_{p=1}^i [C_i - D_i, 0] \quad (3)$$

### 3.2. Scheduling Module

In scheduling RFACs, when a robot becomes free and more than one job is waiting for processing, the jobs will be scheduled, from the highest priority to the lowest priority. This can be done using scheduling rules. These rules are used to generate the sequence of job flow to the system. In this research, each product is considered as an independent job. The algorithm of the scheduling module is depicted in Fig. 4. In the proposed methodology, the scheduling module contains two types of rules which allow the decision maker to determine the job sequencing. The first type is the rules that have been commonly used in scheduling for solving scheduling problems. The following is a list of the common scheduling rules used in this thesis.

- Short Processing Time (SPT): select job with minimum processing time first

- Long Processing Time (LPT): select job with maximum processing time first
- Random (RAND): jobs are sequenced randomly
- Earlier Due Date (EDD): jobs are sequenced according to their due dates
- Critical Ratio (CR): select job with minimum critical ratio first
- Minimise Slack Time (MST): jobs are sequenced according to their urgency

The second type is a rule developed for scheduling RFACs in a multi-product assembly environment, called a Fuzzy Sequencing Rule (FSR) which is constructed by combining all the input variables using fuzzy logic technique. In this research, the job sequence determination is carried out by evaluating the normalisation of each job variable such as processing time, batch size, due date and number of required stations. The normalisation of the four inputs to the system can be defined, using the following notations:

- $\mu_T^i$  Normalisation of the processing time T of product i
- $\mu_D^i$  Normalisation of the due date D of product i
- $\mu_N^i$  Normalisation of the batch size N of product i
- $\mu_S^i$  Normalisation of the number of required stations S for product i

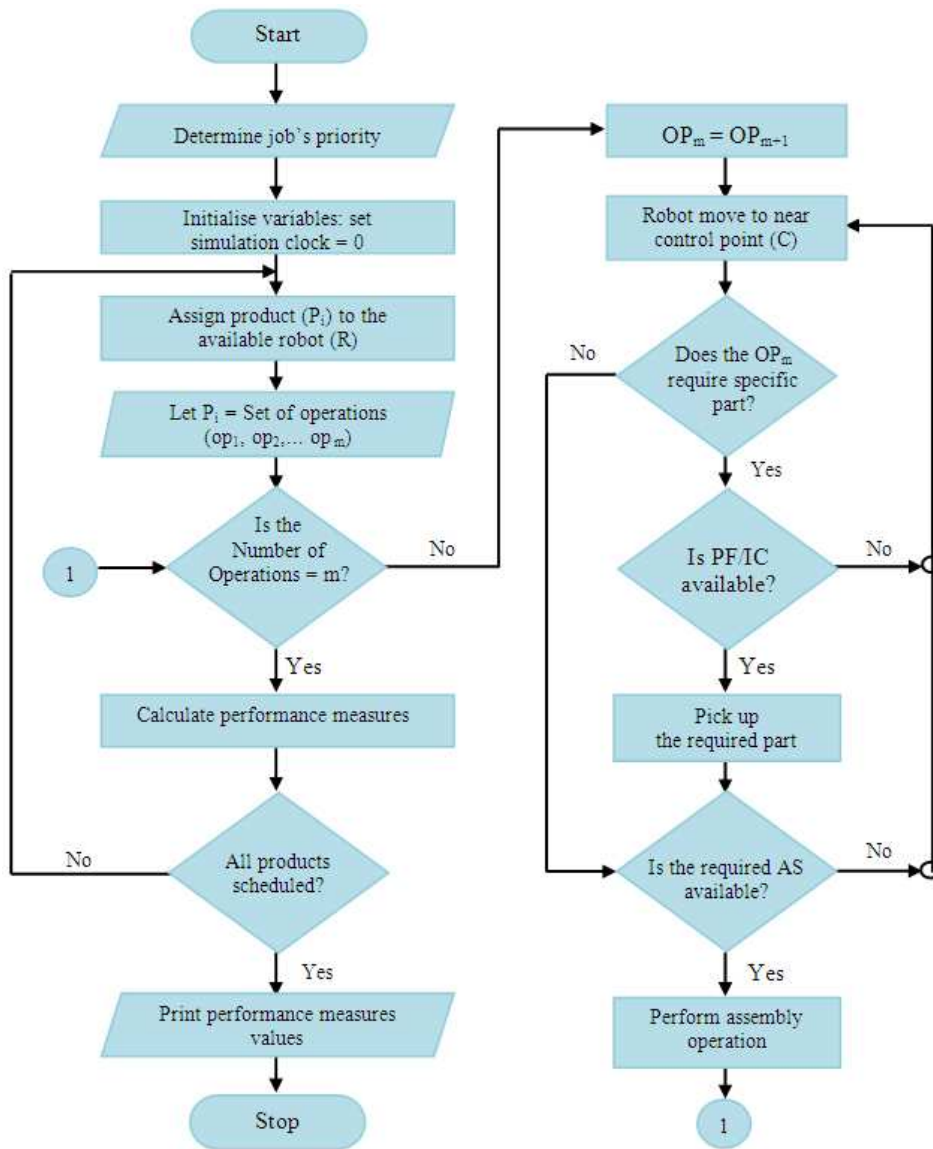


Fig. 4. Flow chart of the algorithm of the scheduling module

The normalisation of the total processing time  $\mu_T^i$  of product  $i$  is defined as the ratio of the difference between the total processing time of product  $i$  and the minimum total processing time to the difference between the maximum and minimum total processing times of the same product, as shown in Equation (4):

$$\mu_T^i = \frac{[(T_i) - \text{Min}(T_i)]}{[\text{Max}(T_i) - \text{Min}(T_i)]} \quad 0 \leq \mu_T^i \leq 1 \quad (4)$$

The overall normalisations are combined to determine which product must be assembled first. The products with low  $\mu_T^i$ , early  $\mu_D^i$ , low  $\mu_N^i$  and high  $\mu_S^i$  will take high priority. In this part of the research, a mathematical model is developed to calculate the jobs' priority, using fuzzy logic. Section 3.4 will explain the implementation of the fuzzy-based mathematical model. As mentioned in paper two, Fuzzy Logic Systems (FLS) consist of four main components: knowledge base, fuzzification, inference engine and defuzzification, as shown in Fig. 5.

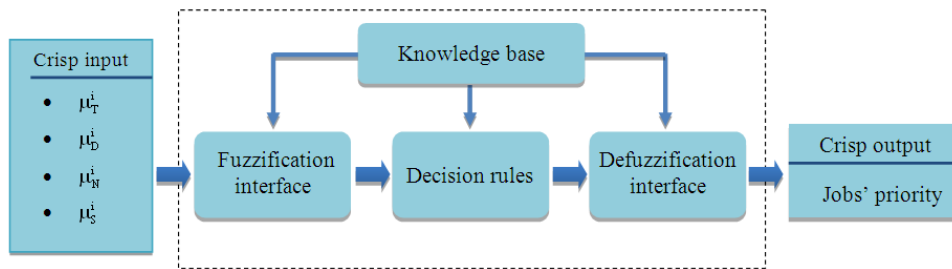


Fig. 5. Fuzzy logic system configuration for job selection



Fig. 6. Simulation process in simprocess

### 3.3. Simulation Module

Once the scheduling parameters, objective functions, constraints and decision variables are determined, the simulation module is defined and constructed. In this module, a computer simulation model of the RFACs is built, to evaluate the system performance under different scheduling strategies. In this research, simulation software called SIMPROCESS is used to build and simulate the assembling processes (Swegles, 1997; CACI, 2006). The process of simulation RFACs is achieved through main four stages, using SIMPROCESS software. These stages are shown in Fig. 6.

## 4. CONCLUSION

This study proposed, a new methodology for scheduling RFACs with the objective of minimising makespan, robots idle time, total tardiness, maximum tardiness and number of tardy jobs. The developed methodology was divided into three main modules, namely pre-processing, scheduling and simulation.

Pre-processing module, the required components of modelling the scheduling problems in the RFACs were defined and described. These components were: parameters, objective functions, constraints and decision variables.

Scheduling module, the schedule for assembling multi products was generated via a new and sophisticated scheduling rule, namely Fuzzy Sequencing Rule (FSR). FSR was constructed using a fuzzy-based mathematical model. This model used the membership functions to

find the contribution of each product type to the output (job’s priority) and then generate the sequence of products flow to the RFACs. The sequence generation was determined by normalisation of each job variable such as processing time, batch size, due date and number of required stations.

Simulation module, a computer simulation model of the RFACs was built in SIMPROCESS and then simulated under different scenarios, depending on the outcome of the scheduling module.

The methodology developed in this study has been applied for scheduling RFACs, which will be presented in the companion paper titled “Application of New Model to Scheduling Problem in Robotic Flexible Assembly Cells”.

## 5. ACKNOWLEDGMENT

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## 6. REFERENCES

Abd, K., K. Abhary and R. Marian, 2011a. A scheduling framework for robotic flexible assembly cells. *Asian Int. J. Sci. Technol. Product. Manuf. Eng.*, 4: 30-37.  
 Abd, K., K. Abhary and R. Marian, 2011b. Scheduling and performance evaluation of robotic flexible assembly cells under different dispatching rules. *Adv. Mechan. Eng.*, 2: 31-40.

- Abd, K., K. Abhary and R. Marian, 2012a. Intelligent modeling of scheduling robotic flexible assembly cells using fuzzy logic. Proceedings of the 12th WSEAS International Conference on Robotics, Control and Manufacturing Technology, (URO '12), Stevens Point, Wisconsin, pp: 202-207.
- Abd, K., K. Abhary and R. Marian, 2012b. Efficient scheduling rule for robotic flexible assembly cells based on fuzzy approach. Proceedings of the 45th CIRP Conference on Manufacturing Systems, (CMS' 12), Elsevier B.V. Selection, pp: 483-488. DOI: 10.1016/j.procir.2012.07.083
- Buil, R., M.A. Piera and P.B. Luh, 2010. Improvement of lagrangian relaxation convergence for production scheduling. IEEE Trans. Automation Sci. Eng., 9: 137-147. DOI: 10.1109/TASE.2011.2168817
- CACI, 2006. User's manual: Simprocess. CACI.
- Canbolat, Y.B. and E. Gundogar, 2004. Fuzzy priority rule for job shop scheduling. J. Intell. Manufact., 15: 527-533. DOI: 10.1023/B:JIMS.0000034116.50789.df
- Kumar, R.R., A.K. Singh and M.K. Tiwari, 2004. A fuzzy based algorithm to solve the machine-loading problems of a FMS and its neuro fuzzy Petri net model. Int. J. Adv. Manufact. Technol., 23: 318-341. DOI: 10.1007/s00170-002-1499-4
- Lee, J.K. and T.E. Lee, 2002. Automata-based supervisory control logic design for a multi-robot assembly cell. Int. J. Comput. Integr. Manufact., 15: 319-334. DOI: 10.1080/09511920110078097
- Mahdavi, I., F. Moghaddam, A.H. Azar and M. Bagherpour, 2009. Applying fuzzy rule based to flexible routing problem in a flexible manufacturing system. Proceedings of the IEEE International Conference on Industrial Engineering and Engineering Management, Dec. 8-11, IEEE Xplore Press, Hong Kong, pp: 2358-2364. DOI: 10.1109/IEEM.2009.5373001
- Manivannan, S., 1993. Robotic collision avoidance in a flexible assembly cell using a dynamic knowledge base. IEEE Tran. Syst. Man Cybernetics, 23: 766-782. DOI: 10.1109/21.256548
- Marian, R.M., A. Kargas, L.H.S. Luong and K. Abhary, 2003. A framework to planning robotic flexible assembly cells. Proceedings of the 32nd International Conference on Computers and Industrial Engineering, (CIE' 03), Limerick, Ireland.
- Nof, S.Y. and J. Chen, 2003. Assembly and disassembly: An overview and framework for cooperation requirement planning with conflict resolution. J. Intell. Robotic Syst., 37: 307-320. DOI: 10.1023/A:1025466401869
- Ramasesh, R., 1990. Dynamic job shop scheduling: A survey of simulation research. Int. J. Manage. Sci., 18: 43-57. DOI: 10.1016/0305-0483(90)90017-4
- Sawik, T., 1999. Production Planning and Scheduling in Flexible Assembly Systems. 1st Edn., Springer, Poland, New York, ISBN-10: 3540649980, pp: 207.
- Sridhar, S., T. Prabakaran and M. Saravanan, 2010. Optimisation of sequencing and scheduling in hybrid flow shop environment using heuristic approach. Int. J. Logistics Econ. Globalisation, 2: 331-351. DOI: 10.1504/IJLEG.2010.037520
- Srinoi, P., E. Shayan and F. Ghotb, 2006. A fuzzy logic modelling of dynamic scheduling in FMS. Int. J. Product. Res., 44: 2183-2203. DOI: 10.1080/00207540500465493
- Srinoi, P., P. Minyong E. Shayan and F. Ghotb, 2008. Routing and sequencing determination in flexible manufacturing system using a fuzzy logic approach. Asian Int. J. Sci. Technol. Product. Manufact., 1: 127-138.
- Swegles, S., 1997. Business process modeling with SIMPROCESS. Proceedings of the Winter Simulation Conference, Dec.8-11, IEEE Xplore Press, pp: 530-534. DOI: 10.1109/WSC.1996.873328
- Xidias, E.K., P.T. Zacharia and N.A. Aspragathos, 2010. Time-optimal task scheduling for articulated manipulators in environments cluttered with obstacles. J. Syst. Control Eng., 224: 845-855. DOI: 10.1017/S0263574709005748