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THE OPTIMIZATION OF ADVANCED PRODUCT SYSTEMS USED THE FUZZY ALGORITHM

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Abstract: *Most of the complex problems which appear in the manufacturing domain and the management of manufacturing systems are optimizing problems. Mathematical modeling of optimizing problems offers the opportunity to find the optimal solution, with immediate consequences for the system's economical efficiency increasing. In this paper is presented the model of optimizing advanced product systems. The fuzzy logic is used during the first stages of the flexible manufacturing systems (FMS) designing where more variables and variants don't may be precisely described having in view the high degree of incertitude, unpredictable character of FMS. This is a hierarchic system, featured by different detailing degrees of the information, suited to the use of the fuzzy multitude theory methods and techniques, in the informational analysis of the system and simulation.The functioning algorithm of the system presented hereby, lays on the grounds of editing the simulation program of the flexible manufacturing system for round shafts processing.*

Key words: *flexible manufacturing systems, fuzzy techniques, scheduling*

1. INTRODUCTION

A flexible manufacturing systems (FMS) is production systems consisting of identical multipurpose numerically controlled machines (workstations), automated material handling system, tool, and load and unload stations, inspection stations, storage areas and a hierarchical control system [5]. In the design of a "controller" that takes care of scheduling, several issues must be considered: the multiple objective natures of the problem, the large variability among plants, and the NP-hard nature of the scheduling problem. This makes classical operation research methods generally inadequate and a common way of realizing the controller is by using heuristic rules.

A relatively new approach to the scheduling problem comes from the emerging field of "intelligent manufacturing". Attempts towards intelligent manufacturing show that "human reasoning" is necessary to achieve good scheduling.

It is the authors' opinion 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.

Among all the possible scheduling rules the following are considered: sequencing, selection of a piece among those waiting to receive service from a machine (job selection), and routing decisions concerning the next required workstation.

Two fuzzy logic systems [3] have been used for sequencing and job selection, while a fuzzy multiple attribute decision making technique has been used for the routing problem, thus forming a fuzzy scheduler as explained in Section 2. This scheduler is optimized using a reinforcement-learning paradigm that seeks to maximize a performance index.

In Section 3 is presented the functioning algorithm fuzzy of the flexible manufacturing systems of round shafts processing, [2]. Section 4 contains the conclusions of this work.

Working assumptions. The flexible manufacturing system has been modeled according to the following assumptions. Tool management is not considered. Orders arrive to the FMS as Poisson processes with a fixed mean inter-arrival time. Production of orders occurs in batches, and the movement of the whole batch is considered, so that batch dimensions are not considered. Setup times are independent of the order in which operations are executed, i.e., they are constant and embodied in the operation, therefore every order is random and directly defined for a workstation not for the operation, therefore every operation corresponds directly to the workstation that will execute it. There can be multiple routing choices, i.e., a job can be equivalently sent to different workstations.

Loading, unloading and processing times are random. Due dates are assigned according to the total processing time. Each workstation can work only one job at a time. The transport system is comprised of automated guided vehicles (AGV) that can transport only one job at a time. Every workstation has one input buffer and no output buffer.

2. FUZZY SCHEDULING

The first two rules (sequencing and job selection) set priorities for jobs waiting in a queue (loading station buffer or workstations input buffers), while the third rule (routing) involves a decision between different routing plans (in case of alternatives). The "priority setting" problems (sequencing and job selection) have been approached using two fuzzy logic systems.

Both of these fuzzy logic systems are characterized by: singleton fuzzification, max-product inference (product t-norm and max t-co norm), max rule composition, two antecedents for each rule, one consequent, three triangular membership functions for every antecedent and consequent and modified-height defuzzification. Both fuzzy logic systems (FLS) assign the priority to jobs in queues, [3]. The antecedents for the sequencing FLS are total processing time and due date minus time. The antecedents for the job selection FLS are processing time in the corresponding workstation and slack. Each FLS is completely defined once its rules and membership functions are. The routing problem has been approached using a fuzzy multiple attribute decision-making technique. When a piece has been processed and an AGV is available, the routing controller decides to which workstation the piece must go, [5]. The choice is made considering three workstation and low distance of the workstation from the actual piece position. Fuzzy measures of the (degree of) satisfaction of each one of the three objectives are taken for each feasible alternative. These measures are weighted according to the importance of each criterion, obtaining a "score" for the given alternative.

This "score" represents the degree of satisfaction of the overall objective by a certain alternative, and is given by:

$$\mu_0(x_k)=[\mu_{c_1}(x_{k_1})]^{\alpha_1}\cdot[\mu_{c_2}(x_{k_2})]^{\alpha_2}\cdot[\mu_{c_3}(x_{k_3})]^{\alpha_3} \quad (1)$$

In (1) $\mu_0(x_k)$ is the overall objective degree of satisfaction corresponding to the k-th alternative, $\mu_{c_i}(x_{k_i})$ is the degree of satisfaction of the i^{-th} objective (relatively to the k^{-th} alternative) and α_I its weight. The alternative corresponding to the highest overall objective degree of satisfaction is chosen.

The importance of each criterion is given by the weights obtained from a pair wise comparison matrix through the λ_{max} technique. The pair wise comparison matrix (in this case

3 x 3) usually contains human expert linguistic estimates of pair wise comparisons between the objectives importance. This decision structure is completely defined once the pair wise comparison matrix and the membership functions for each objective are given.

The membership function for low workload and low processing time, is piecewise linear at first and then exponential, and is completely defined (for any objective) by three parameters.

The membership function for low distance is a discrete one and it is arbitrarily assigned. It will be assumed that experts already specify the pair wise comparison matrix, e.g.

2.1 Fuzzy rule-types

1. *Fuzzy rules for state estimation.* In the case of MISO (Multi Input Single Output) – type systems, the group of rules shows like:

R1: IF X IS A1,…,& Y IS B1 THEN Z IS C1

R2: IF X IS A2,…,& Y IS B2 THEN Z IS C2

$$\vdots$$

Rn: IF X IS An,…,& Y IS Bn THEN Z IS C1

(2)

where: X, Y, Z are linguistic variables, representing the system state. Ai, Bi, Ci are linguistic values of the linguistic variables x, y and z.

A more general shape is that, where consequences are represented by a function having as variables the process states:

Rt: IF X IS At,…,& Y IS Bt THEN $Z = f_t(x,..,y)$

(3)

and t represents the evolution of the system at different moments.

2. *Fuzzy rules for object estimation.* These rules derive from the experience of the human operator and refer to the fuzzy control rules of the object:

Rt: IF X IS At,…,& Y IS Bt THEN $Z = f_t(x,..,y)$

(4)

In such a situation the decision met with regard to the phenomenon analyzed or the controlling command of such a process represent a satisfaction of the requirements. U command takes numeric values and x and y is performance indexes needed for the 1st rule evaluation; values taken by these indexes are of the type: *good* or *bad*. In expert systems based on knowledge a fuzzy rule has syntax:

→ IF (antecedente) → THEN →(consecințe) →

2.2 Fuzzy interference process

Interference (argument) is defined as a process passing from premises to conclusions (Figure 1), so that, if premises are true, conclusions also true, or very probable true. In the LF case both premises and conclusions are expressed within the rules in a canonic form.

There are two rule-types used for this type of interference, i.e. *GMB (General Modus Ponens)* and *GMT (General Modus Tollens)*, which may be written such as:

GMP
Premise 1: X IS A1
Premise 2 : IF X IS A THEN Y IS B
Consequence: Y IS B1

GMT
Premise 1: Y IS B1
Premise 2 : IF X IS A THEN Y IS B

Consequence: X IS A1 (5)

where: A, A1, B, B1 are fuzzy multitudes and x and y classic numeric values. GMT is reduced to *Modus Tollens* when B1 = notB and A1 = notA, frequent situation in interference processes used in expert systems (for example, in establishing a process diagnosis).

Further on the *Operator Rule – Mamdani* minimum is presented, related to the above mentioned but permitting a clearer representation of the decisional process. Two rules are taken into consideration:

R1: IF X IS A1 AND Y IS B1 THEN Z IS C1

R2: IF X IS A2 AND Y IS B2 THEN Z IS C2

(6)

In a process, the fuzzy states are playing an important part in fixing the final decision, reason imposing the conversion of input data (fuzzy multitudes) into classic values of singleton size form. In this case the estimation for a R_i rule shows like:

$$\mu_{Ci}(w) = \alpha_i \wedge \mu_{Ci}(w) \quad (7)$$

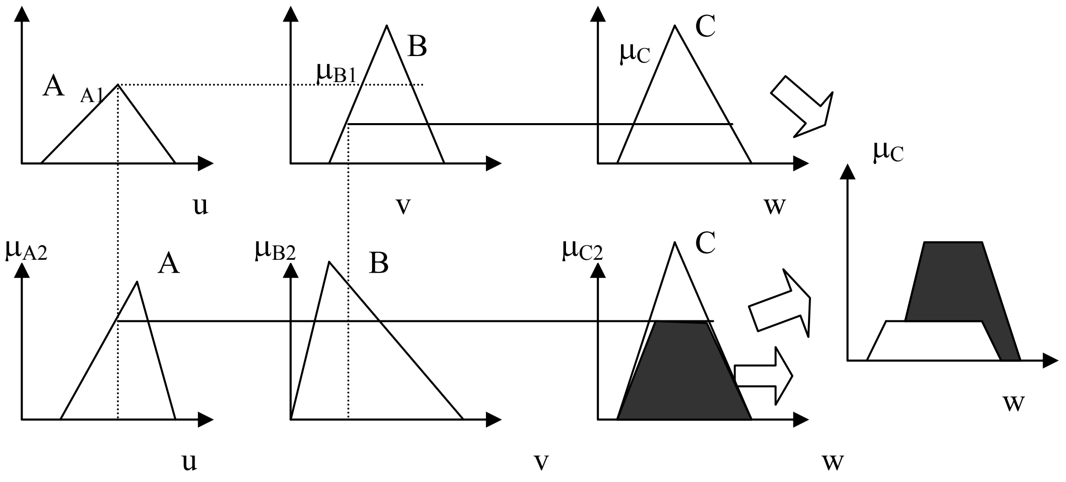

Fig. 1. Fuzzy interference process

where: αi represents the measure of the i rule's contribution to the decisional process. In the case of the two rules as above, the minimal *Mamdani's operator* appears as:

$$\alpha_1 = \mu_{A1}(x_0) \wedge \mu_{B1}(y_0)$$
$$\alpha_2 = \mu_{A2}(x_0) \wedge \mu_{B2}(y_0) \quad (8)$$

where $\mu_{A1}(x_o)$ and $\mu_{B1}(y_o)$ show the degree of recovering the data used for in the data base. Under these terms the consequence belonging function c becomes:

$$\mu_c(w) = [\alpha_1 \wedge \mu_{C1}(w)] \vee [\alpha_2 \wedge \mu_{C2}(w)] \quad (9)$$

3. THE FLEXIBLE MANUFACTURING SYSTEM FUNCTIONING FUZZY ALGORITHM

A specific algorithm of treating the information [4] features the fuzzy modeling. In Figure 2 the working manners in controlling systems based on analogical methods, respectively on fuzzy concepts are presented comparatively.

Fuzzy systems are processing information according to an own philosophy, carrying out of principle on grounds of the following flow:

{input variables} ⇒ *(fuzification)* ⇒ *(interference)* ⇒ *(composition)* ⇒ *(defuzification)* ⇒*{output variables}*

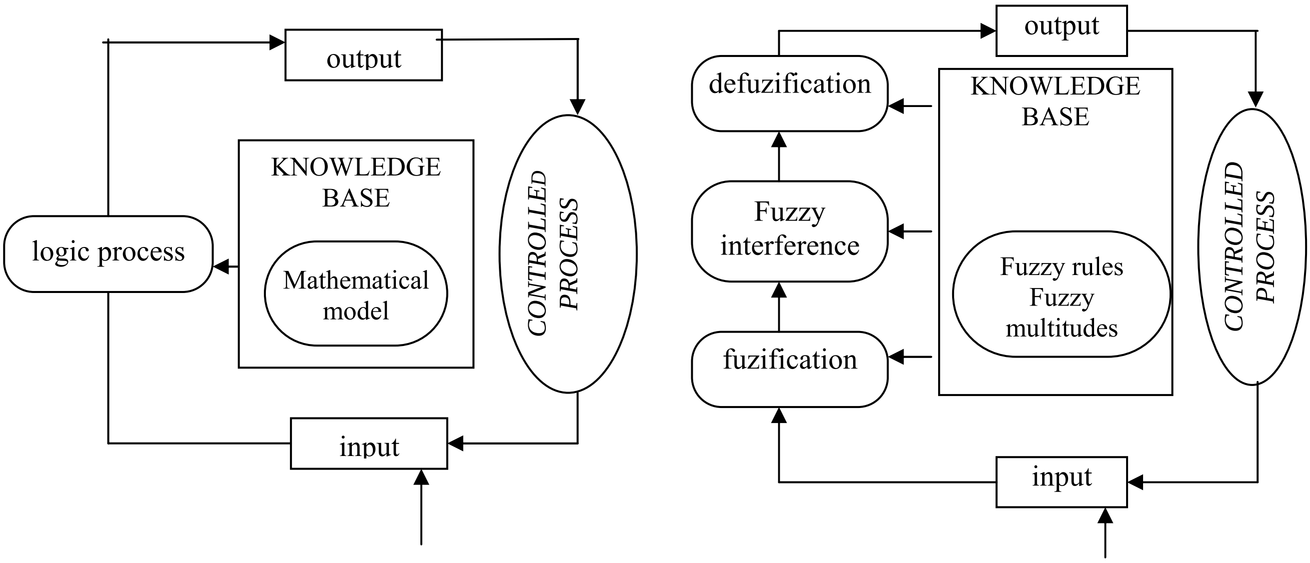

Fig. 2. Processing information in fuzzy systems

In view of structural analysis of a FMS for round shafts processing, former [2] the decomposition of the system into component sub-systems was carried out, connections among these and the transfer function were established. On grounds of the structural decomposition draft the fuzzy model may be elaborated [2], which shall contain a linguistic equation group (group of rules), model that is used in achieving the functioning algorithm. Finally for the connected sub-systems within the FMS for round shafts processing, the final group of rules shall be generated, out of which the system outputs may be extracted. The program is written as a set of the rules due to each sub-system (work stations, robots, conveyors, stocks).

The fuzzy model is elaborated on macro-level, for connections between adjacent sub-systems. Fuzzy logic is a general conclusion of the classic, bivalent logic, replacing its discrete character in (0, 1) with one of continuous nature. The fundamental fuzzy logic is made of the multivalent logic. So as for the deterministic bivalent logic "1" is associated to TRUE and "0" is labeled FALS, in the fuzzy logic for a deterministic positive real number variable, the associated linguistic variable may have linguistic degrees: BIG, AVERAGE, SMALL. Because of the expression by linguistic variables, mathematical modeling by fuzzy logic may be easily approached within the complex structure study, such as FMS for round shafts processing.

A fuzzy rule appears when it exist a premise concerning the event, which implies a certain logic consequence (conclusion):

IF (conditions, restrictions) THEN (effect / consequences) ELSE (consequences / risks).

The fuzzy rule base is built up by putting fuzzy multitudes associates to output variables, in logic contact with fuzzy multitudes of the input variables [1].

The fuzzy rule group modeling as linguistic equations the FMS for round shaft processing function is presented further on. This set of rules was written on grounds of the functional connections between sub-systems (inputs – x_{pi} and outputs – y_{qi}) established within the decomposition draft and coupling matrixes between sub-systems, former elaborated [2].

The set of rules was drawn up for processing three round shaft families: FR_1 (compact round shaft family) – of high complexity; FR_5 (threaded shaft family) – average complexity and FR_4 (family of axles and spindles) – law complexity. The set of rules for system stockings also was elaborated [2].

Further on selectively, sequences of the functioning algorithm of the analyzed system for processing a more complex item family – FR_1, are presented, similarly being elaborated also the algorithm for the other five item families FR_2 ... FR_6 processed within the flexible manufacturing system of round shafts processing.

For example, the rule group for processing the item family FR_1 – compact round shafts is as follows:

T001 IF $\exists R_1$ AND$x_{33} = y_{21} \& K_{23} = 1$AND $x_{31} = y_1 \& K_{18} = 1$ THEN $y_{33} = 1R_1$ ELSE $y_{33} = 1\ R_2$ OR $y_{33} = 1R_3$

T002 IF $x_{45} = y_{33}\ \&\ K_{34} = 1$ AND $x_{46} = y_{32}\ \&\ K_{34} = 1$ AND $x_{41} = y_{12}\ \&\ K_{14} = 1$ AND $x_{42} = y_{53}\ \&\ K_{54} = 0$ AND $x_{43} = y_{52}\ \&\ K_{54} = 0$ AND $x_{44} = y_{13,8}\ \&\ K_{13,4} = 0$ THEN $y_{43} = 1$

T003 IF $x_{53} = y_{43}\ \&\ K_{45} = 1$ AND $x_{52} = y_{42}\ \&\ K_{45} = 1$ AND $x_{51} = y_{13}\ \&\ K_{15} = 1$ THEN m_{FC1} OR m_{FC2} OR … OR $m_{FCp} = 1$

T004 IF $T_o = \Delta t = 1s$ AND $x_{51} = y_{13}\ \&\ K_{15} = 1$ AND m_{FC1} OR m_{FC2} OR … OR $m_{FCp} = 0$ THEN $y_{52} = 1$

T005 IF $x_{42} = y_{53}\ \&\ K_{54} = 1$ AND $x_{43} = y_{52}\ \&\ K_{54} = 1$ AND $x_{41} = y_{12}\ \&\ K_{14} = 1$ AND $x_{46} = y_{32} \& K_{34} = 1$ AND $x_{45} = y_{33}\ \&\ K_{34} = 0$ AND $x_{44} = y_{13,8}\ \&\ K_{13,4} = 0$ THEN $y_{44} = 1$

⋮

T051 IF $x_{52,1} = y_{1,41}\ \&\ K_{1,52} = 1$ AND $x_{52,2} = y_{50,4}\ \& K_{50,52} = 1$AND $x_{52,3} = y_{50,3}\ \&\ K_{50,52} = 1$THEN $y_{52,3} = 1$

In Figure 3 is presented the structural decomposition draft of FMS analyzed.

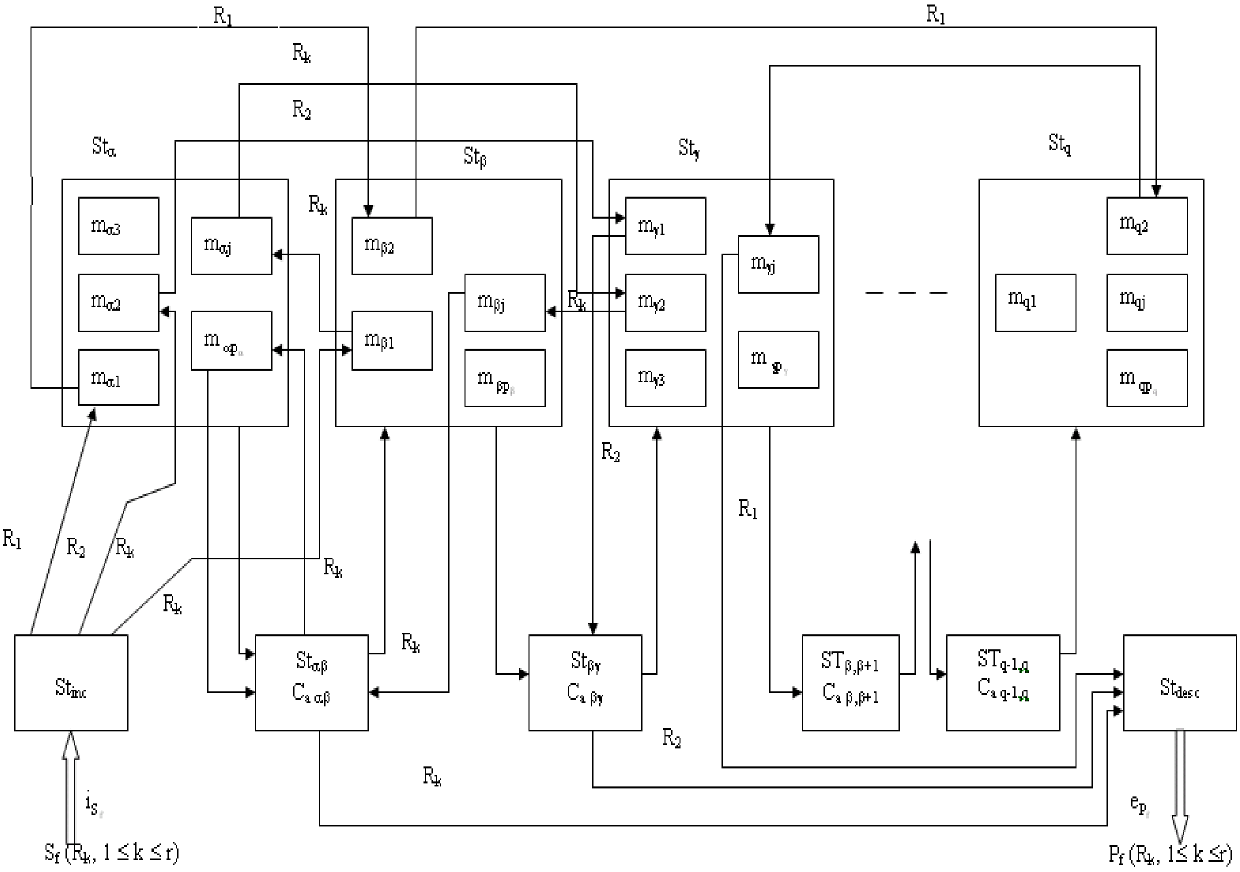

Fig. 3. The structural draft of FMS

4. CONCLUSION

This paper addresses the short-term control of flexible manufacturing systems proposing a fuzzy scheduler and a reinforcement-learning approach to tune its parameters. The learning procedure is based on evolutionary programming techniques and uses a performance index containing the degree of satisfaction of multiple and possibly conflicting objectives. Performance comparison with commonly used heuristics shows some improvement due to fuzzy techniques in scheduling, along with slower performance degradation for decreasing orders inter-arrival time.

The fuzzy logic enjoys of a modern informational support. The functioning algorithm of the system presented hereby, lays on the grounds of editing the simulation program of the flexible manufacturing system for round shafts processing.

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