Fuzzy Logic Based Approach in an Enterprise Resource Planning System for Hydraulic Cylinders Assembly

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Abstract: Trends in modern industry show a tendency towards demassovization of production as a response to the customers’ specific needs for unique and personalized products. This provokes significant changes in the processes of manufacturing, assembly, and testing. The cost of such a type of production can be reduced by employing highly productive reconfigurable equipment with proper software to enable optimization. This paper presents a decision support extension for directing of hydraulic cylinders to assembly-testing lines using fuzzy logic in the Enterprise Resource Planning system of a small size production in a factory in Bulgaria. Different assembly-testing lines are flexibly assigned to the specific cylinder’s parameters by the developed fuzzy system on the basis of the overlapping of parameters in the hydraulic cylinders classification. The final decision on the line assigned in case of alternatives is made through accounting for the minimal cylinder delay time. The effectiveness of the approach is assessed by simulation. It leads to an increase of the efficiency of the assembly-testing flow lines, a reduction of the time needed for hydraulic cylinders assembling and testing and balanced loading of the modules.

Key words: Enterprise resource planning, fuzzy decision, hydraulic cylinders assembly, simulations, real time operation.

1. Introduction and State-of-the-Art

The modern industrial production is characterized by

- Demassovization, i.e., decrease of the number of the products produced in series. As a result most of modern industry production can be described as small series;
- Reduction of the time needed for commodity production, which is a result of the severe competition on the market and of the need of very fast introduction of the new products;
- Reduction of products prime cost: It is important to reduce the cost in such a way that small series products can compete the mass production.

These features lead to problems that can be solved by the use of flexible production systems run by proper software, known in modern industry as Enterprise Resource Planning (ERP) system [1-2]. Such systems are very popular and intrinsic to every small series production plant. Similar systems for real time management of production are described in Refs. [3-5].

A computational model of a flexible manufacturing cell is developed in Ref. [4]. The parts selection for production and the job shop scheduling is organized on the variation of three variables: delay time, number of setups, and number of the tool switches. A group technology (GT) model was presented in Ref. [5]. It is applied to a shop floor area. A real time Manufacturing Resource Planning II system (MRP II) is used in the assembly area. Both works in Refs. [4-5] deal with real
time scheduling, the parts flow is strictly constant and no changes are possible in real time production. Liverani and Ceruti [3] employ the GT approach for real time search of similar parts in order to make use of the ERP system advantages. For that purpose they suggest a special code for mechanical components standardization, part similarity and cost evaluation. The developed classification though interesting is difficult to implement because of its complexity.

The design of an efficient assembly line is of considerable industrial importance. The work of Zacharia and Nearchou [6] is a good example for the application of fuzzy logic (FL) to assembly. The assembly line balancing problem (ALBP) is a decision problem that arises when an assembly line has to be (re)-configured and consists of optimal partitioning of the assembly work among the workstations in accordance with some objectives. The decision taken to solve ALBPs in modern flow-line production systems affects the final cost of the product manufactured, the product quality and the time-to-market response. The fuzzy job scheduling in Ref. [6] is based on a fuzzy multi-objective ALBP solution. The objectives are fuzzified by introducing fuzzy processing time to describe the real-world uncertain, vague and imprecise data. The line fuzzy cycle time, the fuzzy balance delay time and the fuzzy smoothness index for line workload are optimized using genetic algorithms.

The FL approach is efficient in modelling of expert, vague, uncertain and imprecise knowledge and data [7-11]. It has proven to be perspective for improving the ERP systems by modelling tolerances in assembly processes, parameters of planning, market demand forecasting, selection of shift numbers or suppliers [12-13], etc.

The aim of this work is to increase the efficiency of hydraulic cylinders assembly-testing process in the production of hydraulic cylinders in Bulgarian factory for “Hydraulic Elements and Systems” (HES) in the town of Yambol, by employing the fuzzy logic approach to decision making in balancing the assembly-testing flow lines (ATFLs) workload. The main tasks can be defined as:

- Development of a classification for assigning of hydraulic cylinders to ATFLs accounting for the overlap of groups of parameters, which enables flexible sharing of the assembly lines facilities;
- Development of a fuzzy decision support system to balance assembly-testing flow lines workload and to reduce lines idle time and cylinders delay time;
- Development of a Simulink model for simulation investigations with real data of optimal assigning of cylinders to assembly-testing flow lines combining fuzzy decision with minimization of delay time;
- Assessment of potential ERP improvements with including the fuzzy system.

The results of the work are in process of implementation in the HES factory. The boundary conditions that reflect the peculiarities of the production in the factory are:

- Type of action: single-acting, double-acting;
- Type of produced hydraulic cylinders: piston, plunger, telescopic, special;
- Diameter: from 25 mm up to 320 mm;
- Stroke length: up to 5,000 mm.

The requirements to the assembly process are:

- Reduction of delay time for cylinders to be assembled and tested;
- Increase of the ATFL loading coefficient;
- Reduction of the time needed for ATFL reconfiguration.

The rest of the paper is organized as follows: A classification of hydraulic cylinders for assembly-testing flow lines is developed in section 2; section 3 explains the design of a Sugeno Fuzzy Decision Support System; simulation investigations and system assessment are shown in section 4 and section 5; section 6 is conclusion.

2. Classification of Hydraulic Cylinders for Assembly-Testing Flow Lines

The equipment needed for assembly and testing has
been unified on the basis of analysis of the production list of hydraulic cylinders produced in the HES factory. All hydraulic cylinders have been classified in assembly groups according to their specific parameters. The analyses are based on the “object orientated approach” [14-15]. The classification divides produced cylinders to assembly groups depending on their

- Functional parameters: type of action (single or double acting) and type of cylinder (piston, plunger, telescopic, special);
- Structural parameters: diameter and stroke length.

The ATFLs are designed to assemble and test all cylinders in the corresponding group considering also the overlapping of assembly groups [16]. A classification structure with possible solutions for hydraulic cylinders assembly and testing, presented in Fig. 1, is developed on the basis of the observations on the produced hydraulic cylinders over the last year at the HES factory. The classification enables to reduce ATFL reconfiguration effort (time and costs needed) and to ensure flexibility by the increased ATFL functionality—possibility via slight adjustment to assemble cylinders from adjacent assembly groups.

The ATFLs operate in a stream regime and each one consists of different zones connected by a transport system. The main zones are the following:

- Warehouse production zone—all parts needed for production of a certain cylinder are delivered here;
- Washing zone—all hydraulic cylinders’ elements are washed before assembly in a specific solution;
- Pre-assembly zone—it is equipped with stands, on which cylinder and gasket are assembled;
- Assembly zone—the piston group is assembled with the cylinder group;
- Testing zone—a quality control for assembled cylinders is carried out. The inner and outer leakage, deaeration and force parameters, given by customer’s order, are measured and controlled.

The ATFL infrastructure is of extreme importance for the proper functioning of the whole system. It provides supply of oil with different pressure, water, electricity, air under pressure, etc. in a proper moment with desired quality and quantity.

Fig. 1 Hydraulic cylinders classification and proposed options for assembly and testing.
Hydraulic cylinders in each assembly group are subdivided in basic groups according to the similar technologies for assembly and testing and according to the similarly used equipment and tools [16]. In each basic group a representative hydraulic cylinder is selected and the complete technology for its assembly and testing is designed. The representative technology can by applied to each member in the basic group by some insignificant changes in equipment, tools, and infrastructure. This approach is a type of group technology [17-18], applied to the process of assembly and testing of hydraulic cylinders.

Thus the introduced flexibility via the developed classification makes appropriate the application of the fuzzy logic approach to finding alternative solutions for balancing of the ATFLs workload.

3. Sugeno Fuzzy Decision Support System

Considering the predetermined specific fixed and shared—to a certain extent—functionality of each ATFL from the classification in Fig. 1, a Sugeno fuzzy model is suggested as a decision support supplement to the existing ERP system. It is developed via Fuzzy Logic Toolbox of MATLAB [19]. The role of the model is to establish the degree of fitness of the ATFLs to process hydraulic cylinders, specified by Diameter (D), Stroke Length (L) and Type (T).

The Sugeno model has 3 inputs: D, L, T, and 10 outputs: the assembly-testing flow lines—Line k, k = 1,2,3,4,5] correspondingly. The MAX and the MIN operators are employed for ‘OR’ and ‘AND’, respectively, and weighted average is selected as a defuzzification method.

The membership functions (MFs) for the inputs “Diameter” and “Stroke length” are shown in Fig. 2. By D1-D6 are denoted the terms for the cylinder diameter, by L1-L6—the terms for the cylinder stroke length (or shortly length). The five terms for the type of cylinder T1 for type 1—single-acting piston and single-acting plunger cylinders, T2 for type 2—single-acting telescopic, T3 for type 3—double-acting piston, T4 for type 4—double-acting telescopic and T5 for type 5—double-acting special are described by singletons at [1,2,3,4,5] correspondingly.

The model fuzzy rule base, presented in Fig. 3, describes the relationships in Fig. 1. It consists of 17 rules and is not complete due to the restrictions on the possible parameters of the cylinders.

The model input-output surfaces, valid for L < 2.5 m, for type 3 are given in Fig. 4. They show correct classification, i.e., ATFL selection.

The fuzzy model follows the data from Fig. 1 and puts together two independent fuzzy units (FUs):

- One for type 1 and type 2 with rules 1÷8 and outputs Line1=Line3 and Line10, and type 4 and type 5 with rules 15÷17 and outputs Line9 and Line10;
- Another for type 3 with rules 9÷14 and outputs Line4=Line8 (Line5 and Line6 are identical).

The rule activation for selecting the most proper ATFL for an input cylinder with parameters D = 45 mm, L = 1.38 m and T = 3 is seen in Fig. 5. The rules are enumerated from 1 to 17. The first three columns correspond to the inputs and describe the MFs in each rule. The rest of the columns are the ten lines (outputs),
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1. IF (Diameter is D1) AND (Length is L1) AND (Type is T1) THEN (Line1 is Line11)
2. IF (Diameter is D1) AND (Length is L2) AND (Type is T1) THEN (Line2 is Line21)
3. IF (Diameter is D2) AND (Length is L1) AND (Type is T1) THEN (Line3 is Line31)
4. IF (Diameter is D2) AND (Length is L2) AND (Type is T1) THEN (Line4 is Line41)
5. IF (Diameter is D3) AND (Length is L1) AND (Type is T1) THEN (Line5 is Line51)
6. IF (Diameter is D3) AND (Length is L2) AND (Type is T1) THEN (Line6 is Line61)
7. IF (Diameter is D4) AND (Length is L3) AND (Type is T2) THEN (Line7 is Line71)
8. IF (Diameter is D4) AND (Length is L4) AND (Type is T2) THEN (Line8 is Line81)
9. IF (Diameter is D5) AND (Length is L1) AND (Type is T3) THEN (Line9 is Line91)
10. IF (Diameter is D5) AND (Length is L2) AND (Type is T3) THEN (Line10 is Line101)
11. IF (Diameter is D6) AND (Length is L1) AND (Type is T3) THEN (Line11 is Line111)
12. IF (Diameter is D6) AND (Length is L2) AND (Type is T3) THEN (Line12 is Line121)
13. IF (Diameter is D7) AND (Length is L1) AND (Type is T3) THEN (Line13 is Line131)
14. IF (Diameter is D7) AND (Length is L2) AND (Type is T3) THEN (Line14 is Line141)
15. IF (Diameter is D8) AND (Length is L5) AND (Type is T4) THEN (Line15 is Line151)
16. IF (Diameter is D8) AND (Length is L6) AND (Type is T4) THEN (Line16 is Line161)
17. IF (Type is T5) THEN (Line17 is Line171)

Fig. 3 Model fuzzy rule base.

which are depicted as singletons according to the rules in Fig. 3. The degree of certainty, with which each line is selected as proper for the input cylinder, appears numerically on the top and graphically with thin line at the bottom. For the specific cylinder rules 9 and 10 are activated. They show selection of Line4 and Line7 with equal degrees of certainty 0.167 and Line8 with degree of certainty 0.833. These three lines are suitable for the assembly of the cylinder but to a different extent.

4. Simulation Investigations

The simulation investigations aim at proving the efficiency of the fuzzy decision support system in reducing of the delay time by properly assigning ATFLs to each cylinder. They are carried out using collected data from the plant operation for two days and a specially developed Simulink model.

The sample of 197 batches, containing 2,935 cylinders, used for the assessment of the potential improvements that the fuzzy decision support system can offer, is analysed in Fig. 6 with respect to: the type of the cylinders produced (Fig. 6a) and the line adjustment and testing (or processing) time required for each batch (Fig. 6b). The longest processing time is 605 min for batch 134 of 30 cylinders. Further Line8 processes this batch. A Simulink model is developed to

Fig. 4 Model input-output surfaces for hydraulic cylinders of type 3.
assign cylinders to ATFLs using the fuzzy model for cylinder classification and in case of alternatives to take final decision for a line from the requirement for least cylinder delay time.

In the development of the Simulink model, the following assumptions are accounted for: (1) There is a continuous flow of cylinders so that every minute a cylinder arrives at the fuzzy system to be classified and directed towards the specified line; (2) The cylinders move in batches, a batch contains one or more cylinders of identical parameters; (3) A batch of cylinders is inseparable and cylinders are processed one after another by the same line with single adjustment; (4) Parameters of the cylinders are D, L, T; (5) The line adjustment takes 5 minutes regardless of the type of the line or the cylinder and is included as a part of the batch processing time; (6) The fuzzy selection may result in several alternatives, from which only one final line is selected—the one that ensures a minimal delay time; (7) From several lines with equal
minimal delay times, the first (the line with the lower number) is selected; (8) The loading of the ATFL follows the fixed scenario, suggested in Fig. 1, and is objectively and automatically determined.

The Simulink model has the block diagram, given in Fig. 7. The algorithm performed corresponds to a mixed continuous and discrete event queuing systems deterministic simulation—the time between arrivals and the servicing time is given and fixed [20].

The computation of the servicing (or processing) start-time \( t_o \), the servicing end-time \( t_f \) as well as the cylinder delay and the line idle times \( t_w \) and \( t_{wl} \) of the batches is based on the following relations:

\[
\begin{align*}
    t_{on} &= \max(t_{an}, t_{fn-1}), \\
    t_{fn} &= t_{on} + t_{pn}, \\
    t_{wn} &= t_{on} - t_{an}, \quad \text{for } t_{on} > t_{an} \\
    t_{wn} &= t_{on} - t_{on}, \quad \text{for } t_{on} \leq t_{an}
\end{align*}
\]

where the times \( t_{an}, t_{pn}, t_{o}, \) and \( t_{f} \) as explained in Fig. 7 are the batch arrival, processing, start-of-servicing and end-of-servicing times, respectively. The number of the batch is identified by \( n, n = 1 \ldots 197. \)

The fuzzy line selection computes the degree of selection (fitness) [0-1] of the lines for processing of the current batch of cylinders. The selected lines with nonzero degree are considered equivalent alternatives after the conversion of the degree of selection into 1. The final selection is based on the line that ensures minimal batch delay time. In case several lines ensure one and the same minimal batch delay time, the first in order is selected. Thus a selection pattern is constructed, presented by a matrix of \( n \) rows, corresponding to the number of the batches that have passed, and 10 columns, corresponding to the ten ATFLs, with elements ‘1’ for a selected line and ‘0’ otherwise. In each row appears only one ‘1’, which corresponds to the only one selected line for the batch.

Input data to the Simulink model are the parameters of the cylinders in the 197 batches, the sizes of the batches, the processing and the arrival time of each batch. Output data is the selection pattern, the pattern distribution of the total number of the processed cylinders, the batches delay time and the lines idle time, and the processing time along lines and batches.

The simulation results are further statistically processed and graphically represented to make easy the analysis, discussion and recommendations and to conclude on the efficiency of the fuzzy decision support system in improving the existing ERP system.

Fig. 8 shows a comparison of the loading of the lines in the HES system and in the simulated new fuzzy system. In the HES system lines 4 and 7 as well as 5
and 6 are identical and not distinguished, so the processed cylinders are counted for Line4 and Line5, lines 1 and 2 are united as Line1 and Line6 was temporarily not used. The distribution of the processing time along lines in the fuzzy system is given in Fig. 9.

Fig. 10 facilitates the comparison of the batches delay time (total, average, and maximal)—Fig. 10a, taken at batch’s arrival at the corresponding line, and lines idle time—Fig. 10b. The batches delay time after the batch arrival decreases with time till the next arrival of a batch at the same line upon selection. So, delay and idle times in Fig. 10 are at the time the line is selected. Fig. 11 gives the distribution along batches of the delay/idle time for the most loaded lines and for the lines with the longest cylinders delay time Line3 and Line8 and for one normally loaded line—Line5.

5. Fuzzy Decision Support System Assessment

The simulation results, obtained for the fixed scenario of 10 lines, tuned according to Fig. 1, allow the following assessment analysis of the fuzzy developed decision support system.

(1) In the fuzzy support system lines 3 and then 8 process the greatest number of cylinders. Lines 9, 2 and 10 process only few cylinders and have very small loading in total processing time. In the real HES system the heaviest loaded lines are 4, followed by 5 and 3.
ensures more uniform loading for line 8 till batch 152 as seen also from the line selection, while line 5 is loaded in the range between batches 55 and 160 and line 3—for the batches after 165.

(10) The heavy loading of line 8 is predetermined by the flow of cylinders with given parameters \([D, L, T]\) since line 8 has processed 31 batches of cylinders with no alternative line and only 1 batch where there were alternative lines. This means that the industrial demand for cylinders that can be assembled and tested by this line is great and adding a new line can reduce the cylinders delay time.

(11) The relatively great batches delay time is due to the restriction that a batch is inseparable.

The total processing time for all the lines is 17,376 min, approximately 5.92 min per cylinder. The total batches delay time for all lines is 114,150 min or 3.89 min per cylinder per line. The total line idle time for all lines is 13,175 min, which makes about 11.5% of total batches delay time for all lines and also about 75.8% of the total processing time.

Table 1 shows the coincidence of the decision on selection of proper processing line made subjectively in HES and objectively and automatically in the fuzzy system. The percentage of batches, for which there is no alternative to the selected line, is 36% for the fuzzy system against 45% for HES.

<table>
<thead>
<tr>
<th>Line number</th>
<th>Number of batches (cylinders)</th>
<th>Cylinder type</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>4 (45)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>27 (721)</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>
| 4 & 7       | 25 (333)                      | 3             | For 3 batches (151 cylinders) out of 25, the fuzzy system offers one alternative more than HES.
| 5 & 6       | 47 (501)                      | 3             | For all the 47 batches the fuzzy system offers one or two alternatives more than HES. |
| 8           | 16 (112)                      | 3             |          |
| 10          | 2 (10)                        | 2             |          |
| Total       | 121 (1722) or 61% (59%)       | 50 batches with more alternatives at the fuzzy system than at HES. |
The fuzzy model can be used as a part of a real ERP system, implemented in HES factory in Yambol. The fuzzy decision support system can add to the ERP flexibility with reduction of decisions without alternative with 9%. The decisions taken using the fuzzy system are different from those taken in HES for 41% of the total number of cylinders as shown on Table 1, which can lead to potential improvement.

Besides, cylinders average delay time is smaller and the cylinder distribution over ATFLs is more even.

6. Conclusions

The main contribution of our investigation could be summed up as follows:

(1) A classification for linking hydraulic cylinders to assembly-testing flow lines is suggested. It takes into account assembled elements functional and structural specifics and the overlapping of lines facilities, which introduces flexibility and new options.

(2) A fuzzy logic decision support system for ATFL assignment to cylinders has been developed. It helps to optimize the loading of assembly-testing flow lines offering alternative lines and thus enabling the reduction of the cylinders delay time in the lines.

(3) A Simulink model has been constructed to study by simulation the facilities of the fuzzy decision support system and to assess the potential improvements it can cause to the existing ERP in HES prior to its implementation.

(4) The simulation investigations prove that the developed fuzzy system allows to plan and to carry out in real time assembly and testing of every single hydraulic cylinder and group of cylinders as well.

(5) The use of the fuzzy decision support system in an ERP system for assembly-testing process leads to
   • A reduction of the time needed for ATFL reconfiguration;
   • A reduction of delay time;
   • An increase of the ATFL loading coefficient.

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