Optimal Fuzzy Logic Based Enterprise Resource Planning System for Hydraulic Cylinders Assembly

Dimitrov V. Lubomir, Yordanova T. Snejana

***Abstract*—**This paper presents a fuzzy logic based improvement of the existing Enterprise Resource Planning system of a small size production factory in Bulgaria in order to ensure optimal balancing of the workload of assembly-testing flow lines for hydraulic cylinders. A Sugeno fuzzy classifier is suggested to provide flexibility in directing cylinders with different specific parameters to proper lines. It is based on a classification scheme that considers possible overlapping of groups of hydraulic cylinders. The decision on the line assigned is made accounting also for the minimal cylinder delay time. The efficiency of the classifier is assessed for two scenarios by simulation using a complex criterion that accounts for lines idle time and cylinders delay time. The fuzzy logic based improvement enables optimization and is an effective way to reduce costs of the modern production, characterized by demassovization and orientation to the customers' unique needs.

***Keywords*—**Enterprise resource planning, Fuzzy system, Hydraulic systems, Optimal search technique, Simulation.

I. Introduction and State-of-the-Art

THE paper is devoted to a solution of a problem in a Bulgarian factory for production of hydraulic cylinders.

The factory produces a great number of cylinders like in mass production - 166 645 pieces for 2007; 135 605 pieces for 2008; 73 270 pieces for 2009 and 107 128 pieces for 2010, but in small series up to 200-300 pieces. For example, for 2008 the average number of cylinders in a series was 22 and for 2009 it was 17. Besides, there is no fixed production list and the production depends on the particular orders (usually unique). The market, however, pushes prices down to the prices the mass production factories. A solution of the problem is the improvement of the local Enterprise Resource Planning (ERP) system by introducing a proper classification system playing its skeleton [1,2]. The classification system should allow addressing each new coming cylinder to a certain group of cylinders with already developed technology. This approach is similar to the "group technology" approach and "cellular manufacturing" approach [3].

Similar systems have been described and have been developed for a particular production. A real time management of production is described in [4,5,6]. In [5] a computational model of a flexible manufacturing cell is shown. 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 is presented in [6]. It is applied to a shop floor area. A real time Manufacturing Resource Planning II system (MRP II) is used in the assembly area. The parts flow in [5,6] is strictly constant and no changes are possible in real time production. The GT approach is employed in [4] 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 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 [7] is based on a fuzzy multi-objective ALBP solution. Introducing fuzzy processing time to describe the real world uncertain, vague and imprecise data fuzzifies the objectives. The line fuzzy cycle time, the fuzzy balance delay time and the fuzzy smoothness index for line workload are optimized using genetic algorithms.

The fuzzy logic approach is efficient in modeling of expert, vague, uncertain and imprecise knowledge and data [8,910]. It is perspective for improving the ERP systems by modeling tolerances in assembly processes, parameters of planning, market demand forecasting, selection of shift numbers or suppliers [11,12], etc.

The aim of this work is to improve the existing local ERP system by design and introduction of a fuzzy logic based classifier and to test it for selection of the optimal between

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two developed scenarios for balancing of the assembly-testing flow lines (ATFLs) workload. The main tasks are:
- design a general classification scheme of hydraulic cylinders for ATFLs considering the tolerance in tuning of fixed assembly and testing lines in order to ensure lines' flexibility and overlapping facilities to process cylinders of adjacent groups
- design of a general fuzzy logic model as a completion of the classification scheme
- development of an implementation model of the fuzzy classifier as a part of the existing ERP system
- study by means of simulation investigations of two developed scenario for optimal distribution of pneumatic cylinders among ATFLs and comparison on the basis of an accepted complex criterion for minimal cost and maximal efficiency.

The efficiency of the assembly process can be identified as:

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

II. Design of Classification Scheme of Hydraulic Cylinders

The main role in arranging the assembly-testing lines in each factory plays the classification of production. This is of crucial importance for small and medium size production. A proper grouping of products allows to use all advantages of group technologies and significantly to reduce the time and cost of production [4,5,6].

Analyzing the production in the factory the general classification scheme from Fig.1 is suggested [13,14,15]. It covers from one side the approximate annual production list and from the other site - and the equipment available for assembly and testing of a certain group of hydraulic cylinders. Hydraulic cylinders are classified in the beginning according their functions: single acting and double acting. Type of action requires a special equipment to be installed in lines where these cylinders will be assembled and tested. Next branch in the classification system is devoted to the type of cylinders: piston type, plunger type, telescopic type, and special. Following cylinders are subdivided according their sizes. Main considerations taken into account in final arranging the assembly-testing lines are:

- Big cylinders are heavy and in their assembly-testing line a device for lifting should be integrated;
- For the long cylinders horizontal assembly-testing stand is required while for the short cylinders assembly the assembly stands could be vertical.
- Assembly and testing of small (in diameter) and short cylinders could be organized in one line. Stands for them could be with more than one testing place, so in that way the production could be increased.
- Telescopic hydraulic cylinders have specifications in assembly and testing and they have to be in a separate group.
- There are specifications in assembly and testing in double acting cylinders, therefore they will another separate group.

The structure of the automatic system for assembly and testing of hydraulic cylinders is presented in Fig.2. Formally the whole system could be subdivided into two parts: hardware part and software part. Hardware part consists of stands for storing, assembly stands, testing rigs, transport system, cranes, washing machines and others. Software part includes methodic for testing, automatic development of technological routing for assembly and testing, automatic managing of the processes of assembly and testing, automatic printing of certificates and others.

Current ERP system in the factory considers 7 assembly-testing lines. Suggested by us classification scheme, shown in the Fig.2, unites 2 scenarios: scenario 1 is close to the current ERP system in the factory on 7 lines, and scenario 2, based on 10 lines – the extra-added lines [14]. They have to overcome the shortcomings of the first scenario. In a similar way the classification can be modified to reflect other suggested scenarios.

III. Design of Fuzzy Logic Classifier

A general fuzzy logic model of type Sugeno, called Sugeno fuzzy classifier (SFC), is developed on the basis of the classification scheme from Fig.1 using MATLAB™ [16] as a generalization of the fuzzy model in [14]. The SFC considers the fixed and shared functionality of each ATFL in the two scenarios suggested as well as the specific restrictions about the parameters of the hydraulic cylinders to be assembled – Diameter (D), Stroke Length (L), Type (T). The SFC has 3 inputs D, L, and T, and N outputs – the number k, $k = 1 \div N$ of the ATFLs with $N = 7$ in scenario 1 and $N = 10$ in scenario 2. 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 are shown in Fig.3. There in correspondence with Fig.1 by D1-D6 are denoted the terms for the cylinder

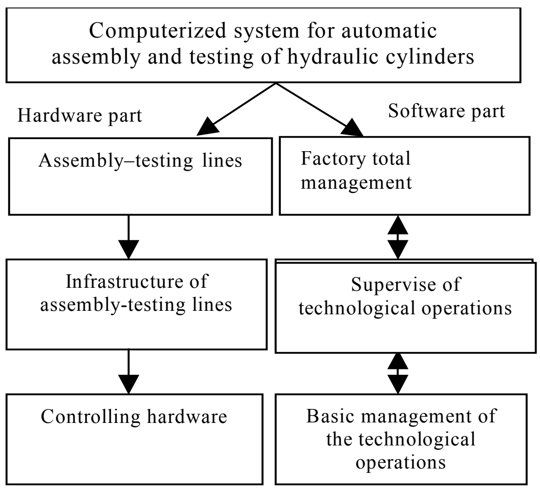


Fig 2. The overall structure of the system for automatic assembly and testing of hydraulic cylinders.

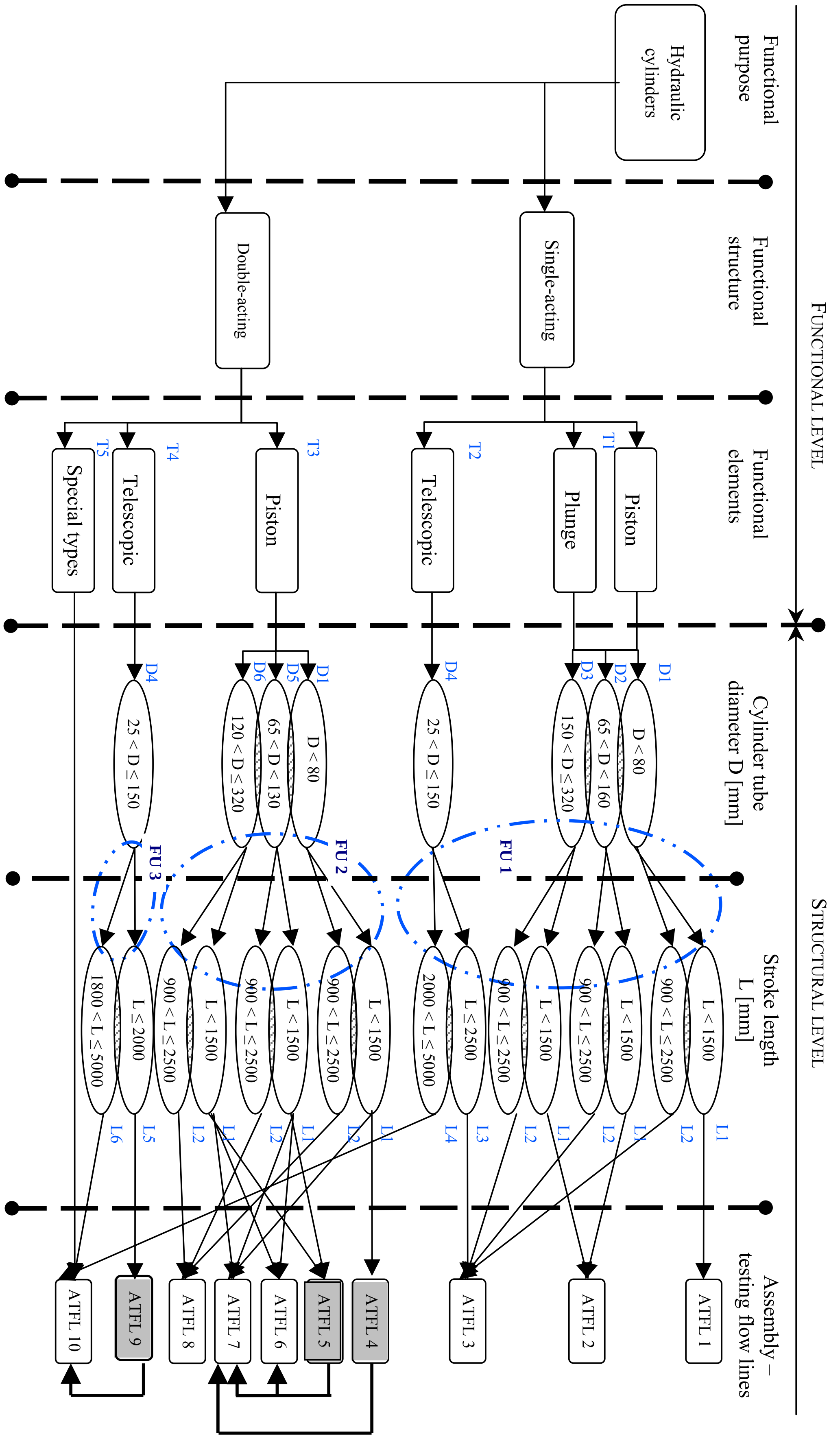


Fig.1 Hydraulic cylinders classification and proposed options for assembly and testing

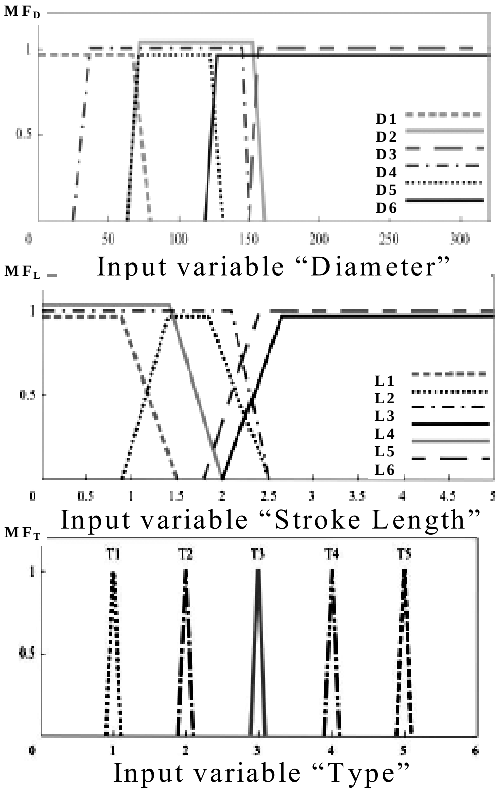


Fig.3 Membership functions for the inputs terms automatically, driven by the information from the database

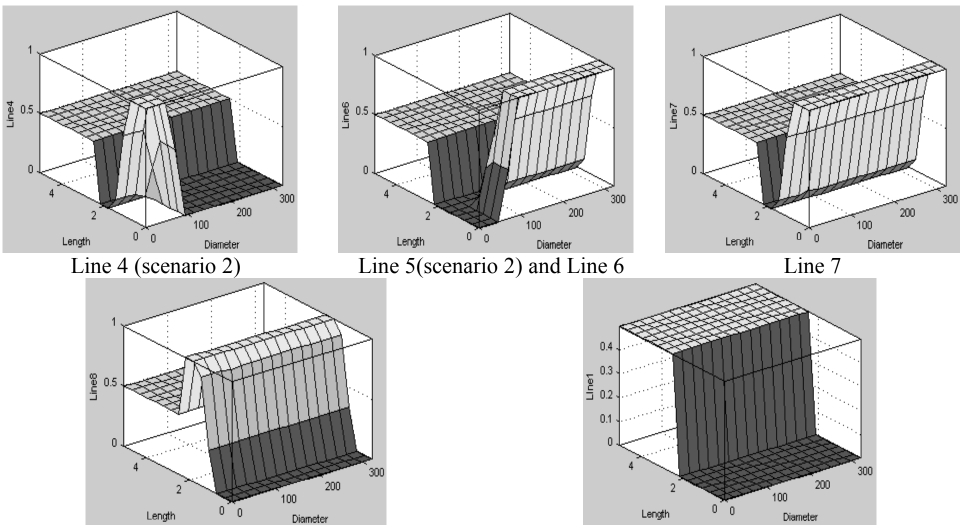
	Diameter		Length		Type		
1. IF	D1	**AND**	L1	**AND**	T1	**THEN**	($Line_1$ is $Line_{11}$)
2. IF	D1	**AND**	L2	**AND**	T1	**THEN**	($Line_3$ is $Line_{31}$)
3. IF	D2	**AND**	L1	**AND**	T1	**THEN**	($Line_2$ is $Line_{21}$)
4. IF	D2	**AND**	L2	**AND**	T1	**THEN**	($Line_3$ is $Line_{31}$)
5. IF	D3	**AND**	L1	**AND**	T1	**THEN**	($Line_2$ is $Line_{21}$)
6. IF	D3	**AND**	L2	**AND**	T1	**THEN**	($Line_3$ is $Line_{31}$)
7. IF	D4	**AND**	L3	**AND**	T2	**THEN**	($Line_3$ is $Line_{31}$)
8. IF	D4	**AND**	L4	**AND**	T2	**THEN**	($Line_{10}$ is $Line_{101}$)
9. IF	D1	**AND**	L1	**AND**	T3	**THEN**	($Line_4$ is $Line_{41}$) **AND** ($Line_7$ is $Line_{71}$)
10. IF	D1	**AND**	L2	**AND**	T3	**THEN**	($Line_8$ is $Line_{81}$)
11. IF	D5	**AND**	L1	**AND**	T3	**THEN**	($Line_5$ is $Line_{51}$) **AND** ($Line_6$ is $Line_{61}$) **AND** ($Line_7$ is $Line_{71}$)
12. IF	D5	**AND**	L2	**AND**	T3)	**THEN**	($Line_8$ is $Line_{81}$)
13. IF	D6	**AND**	L1	**AND**	T3	**THEN**	($Line_5$ is $Line_{51}$) **AND** ($Line_6$ is $Line_{61}$) **AND** ($Line_7$ is $Line_{71}$)
14. IF	D6	**AND**	L2	**AND**	T3	**THEN**	($Line_8$ is $Line_{81}$)
15. IF	D4	**AND**	L5	**AND**	T4	**THEN**	($Line_9$ is $Line_{91}$)
16. IF	D4	**AND**	L6	**AND**	T4	**THEN**	($Line_{10}$ is $Line_{101}$)
17. IF	T5	**THEN**	($Line_{10}$ is $Line_{101}$)				

Fig.4 Model fuzzy rule base

diameter, by L1-L6 – the terms for the cylinder stroke length (henceforth referred here to as length). The five terms for the cylinder type are: T1 (type 1) - single-acting piston and single-acting plunger cylinders; T2 (type 2) - single-acting telescopic; T3 (type 3) - double-acting piston; T4 (type 4) - double-acting telescopic; T5 (type 5) - double-acting special. The MFs for the N outputs are singletons – for each output k, $Line_k$=[$Line_{k1}$=1]. The SFC from scenario 2 is accepted as basic. For scenario 1 (N=7) the missing lines 4, 5 and 9 from Fig.1 are reflected by assigning $Line_{k1}$ = 0 for k=4,5,9 in the SFC.

The fuzzy model rule base of 17 rules in Fig.4 describes the relationships in Fig.1 for the basic SFC.

The SFC has been tested to prove that correctly directs cylinders to the proper lines. The difference between the two scenarios is felt for cylinders of type 2 and greater. Therefore in Fig.5 the SFC modelling surfaces for cylinders of type 3 are selected to illustrate the decision taken on proper line.



Line 4 (scenario 2) Line 5(scenario 2) and Line 6 Line 7

Line 8 Lines 1, 2, 3, 10 and 9 (scenario 2)

Fig.5 Model input-output surfaces for hydraulic cylinders of type 3

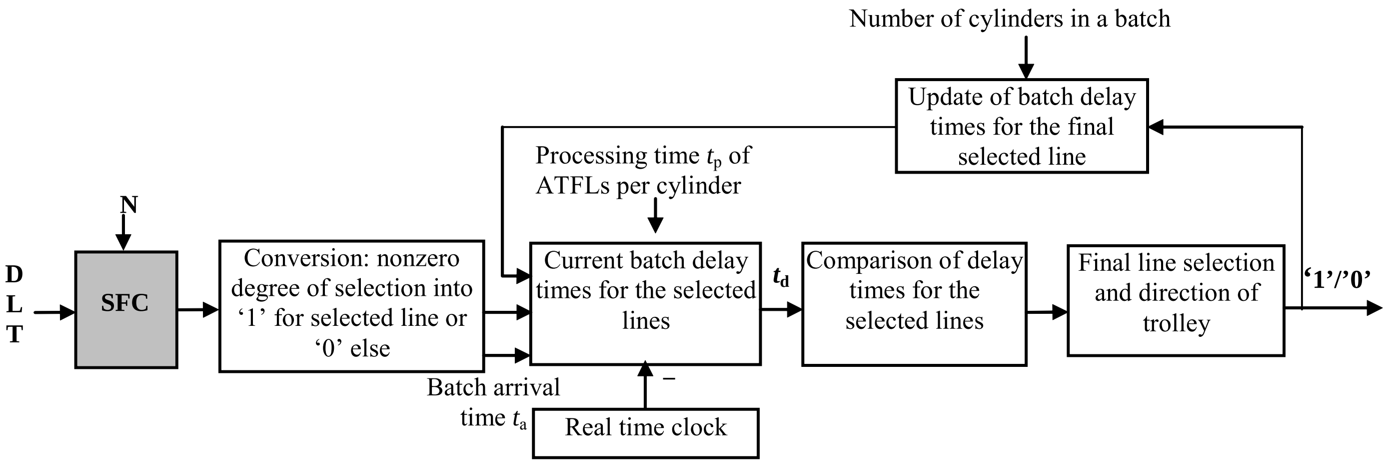


Fig.6 Implementation model of including SFC into existing ERP system

IV. Development of Implementation Model

An implementation model of the improved ERP system with the SFC is developed and shown in Fig.6. The existing ERP system is based on identification, parameterization and coding of hydraulic cylinders and their elements, systematized in a database that accompanies the movement of the cylinders throughout their processing. This code informs the operator where in the factory a given element is at a specified moment and which process is running. The SFC uses part of the generated codes, which includes a logic parameter from the functional part of the classification system in Fig.1 - cylinder type of action and type of cylinder, and digital parameters in decimal code related to the structural part in Fig.1 – piston stroke length and cylinder diameter. The current batch of cylinders reaches the SFC in trolleys when its description and documentation appear via the computer network on the computer of this working place. The fuzzy classification gets access to the necessary input information - **D**, **L**, and **T**, also the number of outputs (type of scenario) *N* and the number of cylinders in the batch. The alternative lines, suggested by the SFC, are compared by the delay times of the batches already in the queue before the current batch. Each ATFL has an individual processing time per cylinder. The corresponding delay time for a particular ATFL is computed by multiplying the individual processing time by the number of cylinders in the queue, and is currently reduced by a real-time clock. The final selection of ATFL for the current batch is based on ensuring minimal delay time for it. After final ATFL selection the current delay time for this line is updated with the delay of the cylinders in the batch. The trolley with the batch is directed to the selected line where the operator receives the description (input code) of the processing to be performed to the cylinders of the batch. After finishing the operator inputs a report to the ERP system of the work done. All ATFLs operate automatically, driven by the information from the database.

V. Assessment of Performance of Scenarios by Simulations

Simulation are carried out in MATLABTM – Simulink environment [16] employing adapted from [14] Simulink model to imitate real time operation with the new general for the two scenarios SFC. The final decision from all given by the SFC alternative lines is made for the line that ensures the least cylinders' delay time. The input data for the simulation are provided by factory. In [14] has been proven for scenario 2 that the use of the SFC leads to an improvement on average by 30% in the uniform loading of the lines due to the greater flexibility in distribution of the cylinders among the assembly lines.

The aim of the present investigations is to use the general SFC in the suggested two scenarios to find by means of comparison an optimal solution to the problem for even distribution of cylinders among assembly lines ensuring reduced costs, estimated by the number of lines, the cylinders' delay time and the lines' idle time. The Simulink model assumes [14]: 1) a continuous flow of cylinders every minute to the SFC; 2) the one or more cylinders with identical parameters D, L, T make an inseparable batch, the cylinders of a batch are processed one after another by the same line with a single adjustment; 3) each line adjustment takes 5 minutes and is included as a part of the batch processing time; 4) the fuzzy classification may result in several alternatives, from which only one final line is selected – the one that ensures a minimal cylinder delay time; 5) from several lines with equal minimal cylinder delay times, the first (the line with the lower number) is chosen; 6) the loading of the ATFL follows the scenarios, suggested in Fig.1, and is objectively and automatically determined.

Input data to the Simulink model are the based on the observations in factory parameters of the processed cylinders [D, L, T] of a sample of the n=197 batches, containing m=2935 cylinders, the sizes of the batches (number of cylinders m_j, $j=1\div n$ in each batch), the processing and the arrival time of each batch. The analysis of the character of the sample with respect to the type of cylinders produced at the factory shows 68% double-acting piston cylinders, 26% single-acting telescopic, 6% single-acting piston and plunger and 0.1% double-acting telescopic. Output data is the matrix of the selection pattern, pattern distribution of the total number of the processed cylinders, the delay time for batches and the idle time for lines, and the processing time along lines and batches. The simulation results are statistically processed to enable analysis and assessment of scenarios efficiency according to the following accepted criterion:

$$I = \frac{1}{N.m}\left(\sum_{j=1}^{n} t_{dj}.m_j + \sum_{k=1}^{N} t_{idk}\right), \quad (1)$$

where t_{dj} is delay time for the cylinders in the j^{th} batch and t_{idk} is the idle time of k^{th} line. A comparison of the loading of the lines in the factory system and in the two simulated fuzzy systems with 10 and with 7 lines is shown in Fig. 7. The processing time of lines and the cylinders (batches) delay time (total, average, and maximal) in the fuzzy systems are presented in Fig.8 and Fig. 9.

The simulation results, obtained for the two scenarios, allow the following assessment analysis.

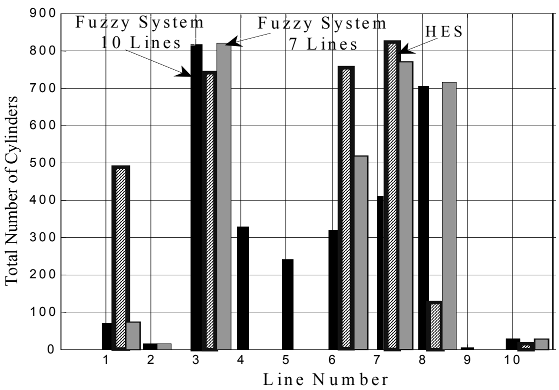


Fig.7 Processed cylinders by each line

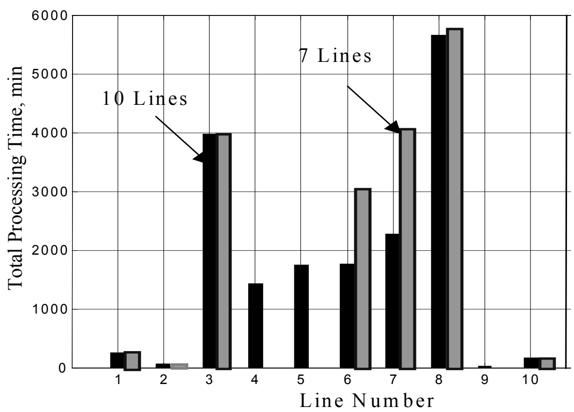


Fig.8 Processing time of each line

1. Lines 3 and 8 process the greatest number of cylinders, which is almost equal for the two scenarios.

The justification of the two selected scenarios is the following. In the real system in the factory the heaviest loaded lines are 7, followed by 6 and 3, and line 2 is united with 1 while line 9 has not been used. Therefore, in scenario 2 are introduced lines 4 and 5.

However, lines 9, 2 and 10 process very small loading in scenario 2. Therefore in scenario 1 line 9 is united and substituted by line 10. Lines 2 and 9 are not loaded enough as seen in Fig.6 but this is due to the character of cylinders in the sample used. The fuzzy systems ensure more uniform distribution of cylinders over the lines, which is objective and automatic. In scenario 1 lines 6 and 7 have a greater load compensating the missing lines 4 and 5.

2. Lines 8 and 3, have the longest processing time, while lines 9 (scenario 2), 2 and 10 have the shortest. Here again the difference between the two scenarios is in the increased processing time of lines 6 and 7.

3. Cylinders' total and maximal delay times are long for line 8, followed by 3. In scenario 1 for line 8 it is reduced a little at the expense of a drastically increase total and maximal delay times of lines 6 and 7.

4. The average delay time for cylinders and idle time for lines is minimized, except for line 9 idle time in scenario 2, in scenario 1 line 9 is missing.

5. The lines idle time is more evenly distributed over the lines than the cylinders delay time, which is concentrated on lines 8 and 3 in scenario 2 and on 7, 8 and 6 in scenario 1.

6. The heavy loading of line 8 is predetermined by the flow of cylinders with given parameters since line 8 has processed 31 batches of cylinders with no alternative line and only 1 batch with alternative lines. This means that the industrial demand for cylinders to be assembled and tested by line 8 is great and adding a new line can reduce the cylinders delay time.

In Table 1 are systemized the general performance measures of the two scenarios investigated. The total processing time for all the lines is $Tt_{pr}L$=17376 min (5.92 min per cylinder).

The SFC improves the flexibility with reduction of cases without alternative with 9%. The decisions taken using the SFC are different from those taken in the factory for 41% of the total number of cylinders. Besides, cylinders average delay time is smaller and the cylinder distribution over ATFLs is more even.

Table 1. General performance measures of scenarios

Performance measures	Scenario 1 7 lines	Scenario 2 10 lines
Total batches delay time Tt_dL for all lines	192000 min 9.3 min per cylinder & line	114150 min 3.9 min per cylinder & line
Total line idle time for all lines	10107 min 5.3% of Tt_dL 58.2% of $Tt_{pr}L$	13175 min 11.5% of Tt_dL 75.8% of $Tt_{pr}L$

VI. CONCLUSION

The main contribution of the investigation could be concluded to the following.

1. A general classification scheme for linking hydraulic cylinders to assembly-testing flow lines is suggested, accounting for assembled elements functional and structural specifics and the overlapping of lines facilities, which introduces flexibility and new options. It reflects two possible scenarios, considered in the lines workload optimisation problem.

2. A general for several scenarios Sugeno fuzzy classifier is developed to ensure objective and automatic flexible loading of the assembly-testing flow lines enabling reduction of both cylinders delay time and lines idle time.

3. Simulink investigations allow comparison of scenarios and selection of the optimal according to an accepted criterion to be included in the factory ERP system.

4. The optimal SFC based scenario allows to plan and to carry out in real time assembly and testing of every single hydraulic cylinder and group of cylinders as well and to reduce the ATFL configuration time.

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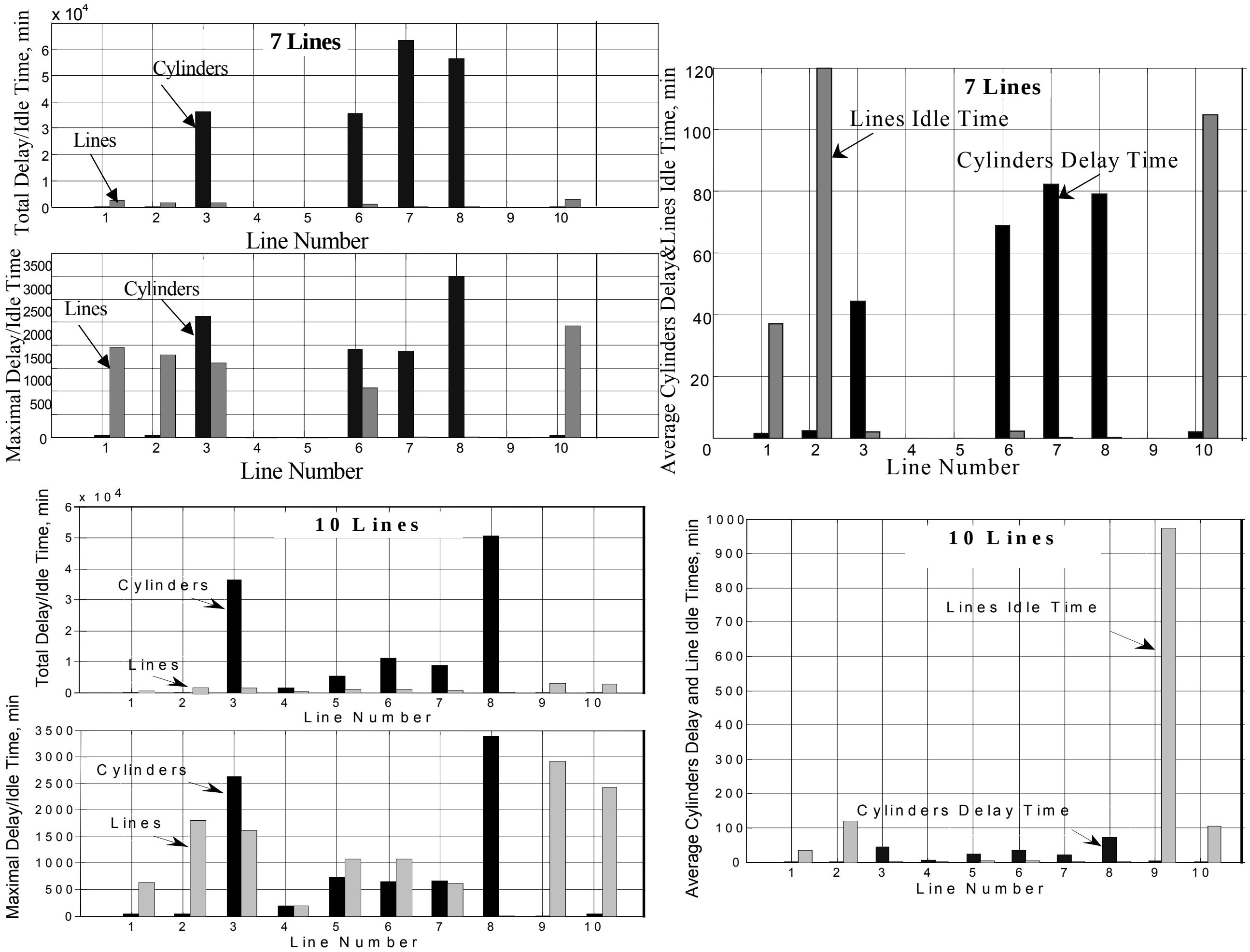

Fig.9 Total, maximal and average batches’ delay times and lines’ idle times