Fuzzy Logic Based Approach to Optimal Hydraulic Cylinders Assembly

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Abstract: The established tendency towards demassovization of production and its orientation to the customers' unique needs puts forward the demand for cost reduction by employing highly productive reconfigurable equipment and software to enable optimization. This paper presents a comparison of scenarios built on the application of the fuzzy logic approach in the 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 for two scenarios 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 scenarios is assessed by simulation using a complex criterion that accounts for lines idle time and cylinders delay time.

Key-Words: Enterprise Resource Planning (ERP), Fuzzy Classifier, Hydraulic cylinders assembly, Optimal workload, Scenarios comparison, Simulation

1 Introduction and State-of-the-Art

This paper deals with a real problem in a Bulgarian factory "Hydraulic Cylinders and Systems" (HES) in the town of Yambol. 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 development of a local ERP system with 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 [8-10]. 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 compare the performances of two developed scenario for optimal balancing of the assembly-testing flow lines (ATFLs) workload on the basis of a designed fuzzy logic classifier. 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
- study by means of simulation investigations of 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.

2 Classification Scheme of Hydraulic Cylinders

Analyzing the production in the factory the general classification scheme from Fig.1 is suggested [13-15]. It reflects the annual factory production list and the equipment available for assembly and testing of a certain group of hydraulic cylinders (the production cell set up). The current ERP system considers 7 lines 1 and 2 united, 4 and 5 missing, the cylinders for them are directed to lines 7 and 6 respectively, and line 9 temporally stopped. The classification scheme unites 2 scenarios – scenario 1 is close to the current ERP system on 7 lines, and scenario 2, based on 10 lines – the extra-added lines [14] have to overcome the shortcomings of the first scenario [15]. In a similar way the classification can be modified to reflect other suggested scenarios.

3 Fuzzy Logic Classifier

A general fuzzy logic model of type Sugeno is developed as a generalization of the fuzzy model, proposed in [14], based on the classification scheme from Fig.1 and using MATLAB^{TM} facilities [16], called Sugeno fuzzy classifier (SFC). 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 assembly-testing flow lines, where $N = 10$ in scenario 2 and $N = 7$ in scenario 1. 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.2. There in correspondence with Fig.1 by D1-D6 are denoted the terms for the cylinder 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, $Line_k = [Line_{k1}]$, where $Line_{k1} = 1$. The SFC from scenario 2 with N=10 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.3 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.

4 Simulation Investigations

The simulation investigations are carried out in MATLAB^{TM} – Simulink environment [16]. A Simulink model used to imitate a real time operation is the developed in [14] modified 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 HES. 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

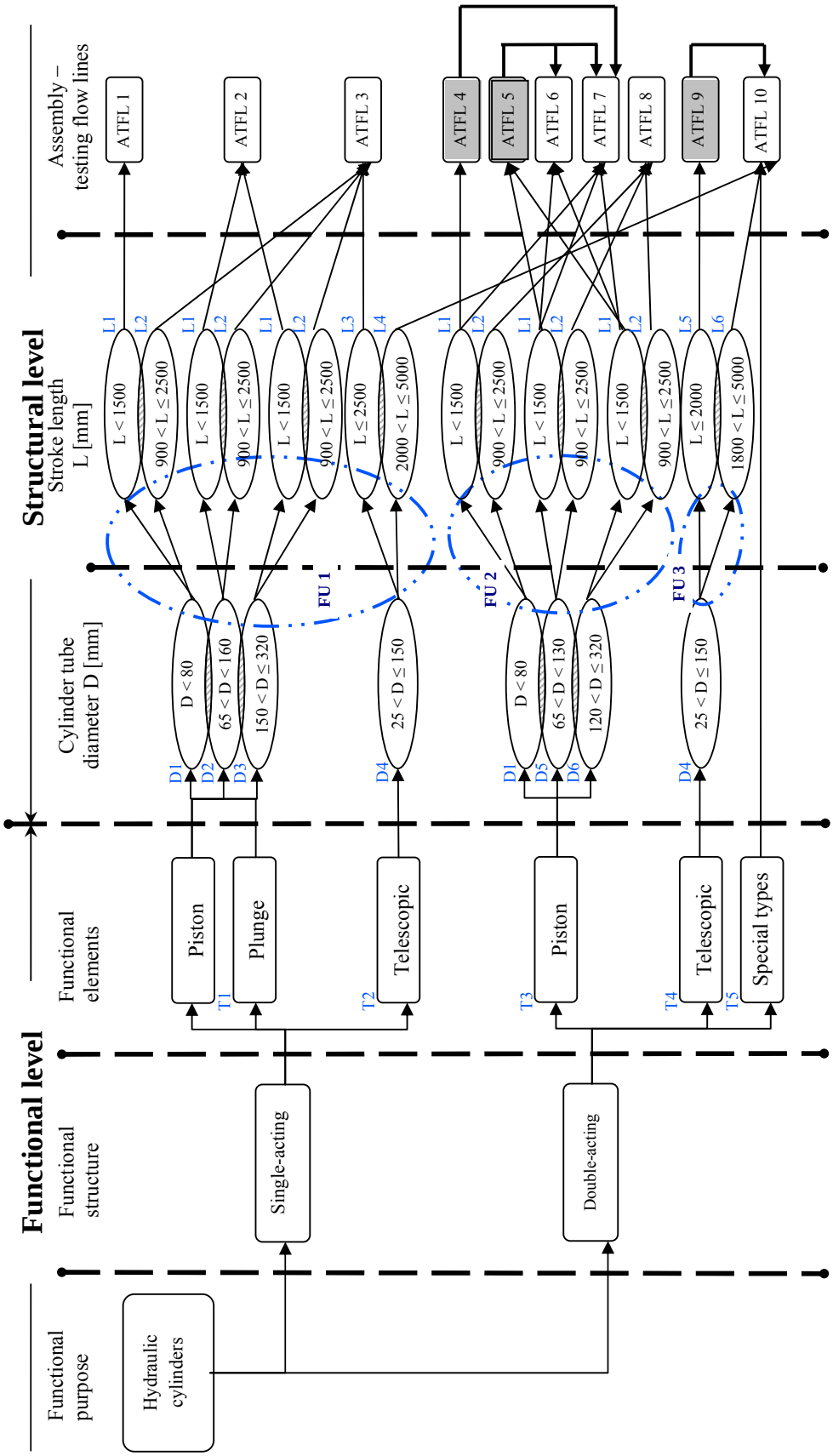

Fig.1 Hydraulic cylinders classification and proposed options for assembly and testing

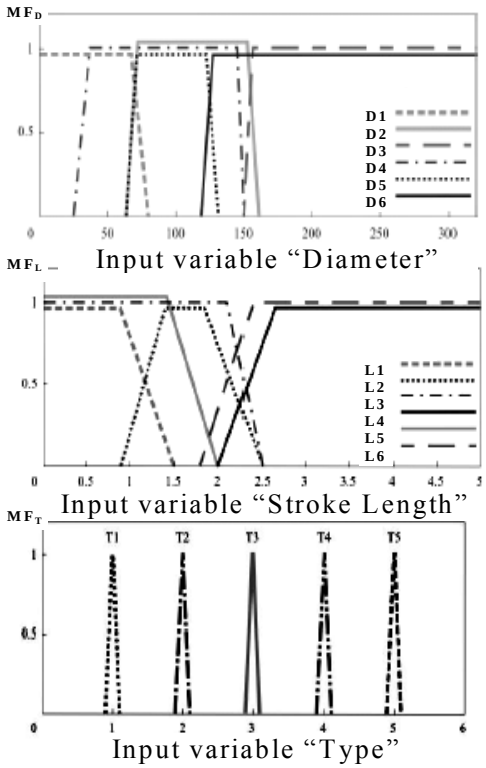

Fig.2 Membership functions for the inputs terms

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 parameters of the 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÷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 HES

	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.3 Model fuzzy rule base

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:

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

where t_{dj} is delay time for the cylinders in the jth batch and t_{idk} is the idle time of kth line.

A comparison of the loading of the lines in the HES system and in the two simulated fuzzy systems with 10 and with 7 lines is shown in Fig. 4. The processing time of lines and the cylinders (batches) delay time (total, average, and maximal) in the fuzzy systems is presented in Fig.5 and Fig. 6.

4 Scenarios Assessment and Conclusion

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

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 HES system the heaviest

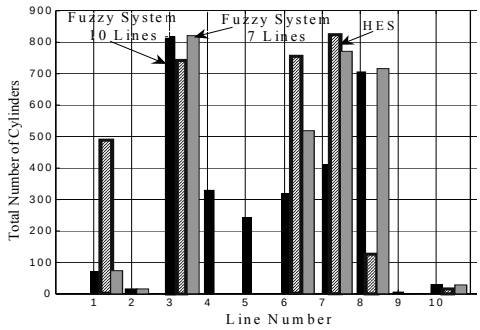

Fig.4 Processed cylinders by each line

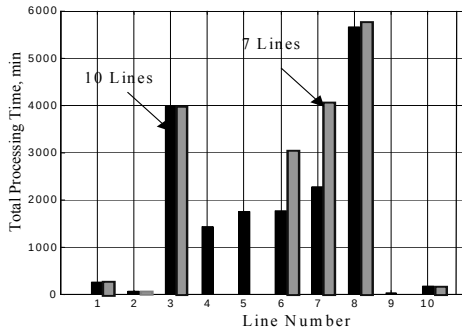

Fig.5 Processing time of each line

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 are introduced 2 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.5 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 6,7.

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.

The total processing time for all the lines is 17376 min (5.92 min per cylinder). The total cylinders (batches) delay time for all lines is 114150 min for scenario 2 / 192000 min for scenario 1 (3.89 respectively 9.3 min per cylinder per line). The total line idle time for all lines is 13175 min for scenario 2 / 10107 min for scenario 1 -11.5% and 5.3% respectively of total cylinders (batches) delay time for all lines and also about 75.8% and 58.2%.

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 HES for 41% of the total number of cylinders. Besides, cylinders average delay time is smaller and the cylinder distribution over ATFLs is more even.

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 HES ERP.

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.

The results of the work are in process of implementation in the HES factory.

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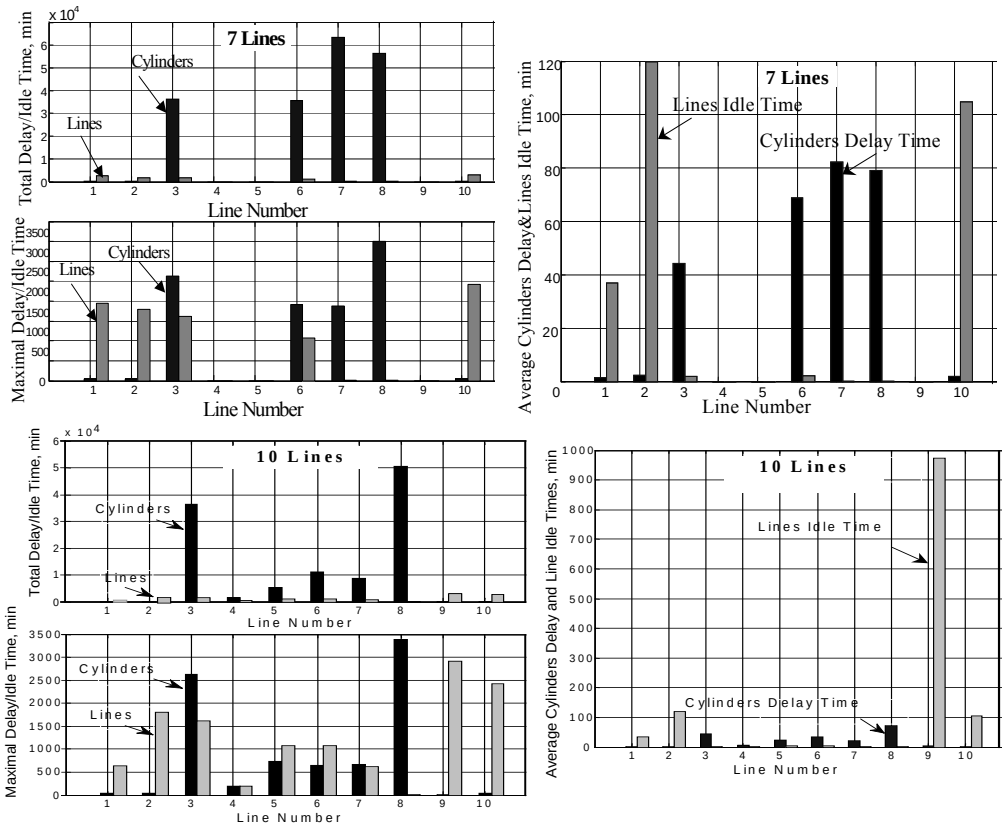

Fig.6 Total, maximal and average batches' delay times and lines' idle times