The Comparison of Selected Priority Rules in Flexible Manufacturing System

M. Iringova, P. Vazan, J. Kotianova, and D. Jurovata

***Abstract*—The paper presents the results of the project. The project was oriented to investigate the influence of the selected priority rules of technological operations on chosen production goals. The authors have built the simulation model of production system for solution of this problem. This paper presents the dynamic scheduling process of operations on the selected model of production system. The effect of each priority rule has been studied for different production goals in different stressful situations. The synthesis and the evaluation of results were performed by using mathematical and statistical methods. The standard-variable method has been chosen by authors for evaluations of gained results.**

***Index Terms*—scheduling; production goals; priority rules; discrete-even simulation; simulation experiments**

I. Introduction

THE scheduling is one of the key problems of organizational activity of each manufacturing company. Customers require more and more variability of choice, more changes in the nick of time, short lead times and quick reaction to their orders. The production endeavors to reconcile the requirements of the production plan with the resources and constraints based on the real dispositions.

Let us consider a flexible manufacturing system that consists of a set of machines on which a set of jobs are processed. Each job consists of a set of operations. There are so called hard and soft constraints defined within the manufacturing systems. Hard constraints are related to the specific production process and machines characteristics (e.g. there are technological processes, order of operations, operating and processing times on machines and a variety of machines limitations and characteristics). Soft constraints are e.g. deadlines, working process limitations (holidays, weekend days, etc.) [1].

The production equipments, the set of production activities (which are divided into the sequence of individual operations) and their relationships limit the scheduling task. The finding of the best sequence of tasks is the solution of this problem for defined workstations. Sufficient production capacity cannot be effectively use without supporting high-quality scheduling tools. Existing systems for production scheduling have the possibility to simulate potential alternatives for future system behavior. These systems offer the choice in the right time. Computer simulation is one of the most suitable tools for evaluation alternative designs, analysis and improvement of management procedures in production systems. It is possible to examine complex systems easily. It could be difficult to realize it in practice because the process is too long and too expensive.

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II. Goals of Scheduling

The goal of scheduling process is to provide detailed chronological organization of production activities or production operations. It is necessary to realize these activities on production equipment within the plan time interval.

The goals of scheduling:

--To minimize work in progress production.
--To minimize average flow time of production.
--To minimize costs of production.
--To maximize utilization of production resources.
--To maximize number of finished products.
--To minimize the slack of production orders due date.

The scheduling is implemented in a period of time which is usually one week, one day or one shift. This horizon can be subdivided into smaller time periods.

It is necessary to cumulate capacity requirements of individual workplaces for the considered time period at the beginning of scheduling operations.

III. Approaches to the Scheduling Problem Solution

There are lots of possibilities how to solve the scheduling. There are various techniques and methods which include the conventional methods such as methods of network analysis, methods of the theory of succession, the mathematical approaches, / linear, nonlinear, dynamic programming /, heuristic approaches / priority rules, beam search, local search / or new methods. There are techniques of artificial intelligence, techniques of knowledge systems, neural networks or techniques of modeling and simulation.

The operation scheduling in production systems deals with a problem of finding a sequence of jobs for each of available machines, while keeping so called hard and soft constraints and optimization criteria. The problem, when all jobs have to be processed on the machines in the same order, is called flow-shop scheduling. A more complex problem, when there are different machine orders for different jobs, is

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called job-shop scheduling (JSP) [1].

This article solved flexible job-shop problem (FJSP). The flexible job shop problem is an extension of the classical job shop scheduling problem which allows an operation to be processed by any machine from a given set. The problem is to assign each operation to a machine and to order the operations on the machines, such that the maximal completion time of all operations is minimized.

A. Problem description and formulation

Similar to the classical JSP, solving the FJSP requires the optimal assignment of each operation of each job to a machine with known starting and completion times.

However, the task is more challenging than the classical one because it requires a proper selection of a machine from a set of machines to process each operation of each job. Furthermore, if a job is allowed to recirculate, this will significantly increase the complexity of the system [7]. The FJSP with recirculation is formulated as follows:

--Let $J = \{J_i\}_{1\leq i\leq n}$, indexed i, be a set of n jobs to be scheduled.

--Each job J_i consists of a predetermined sequence of operations $G_i = \{O_{i,j}\}_{1\leq j\leq O(i)}$ where $O_{i,j}$ denotes operation j of J_i and $O(i)$ is the total number of operations of job J_i.

--Let $M = \{M_k\}_{1\leq k\leq m}$, indexed k, be a set of m machines.

--Each machine can process only one operation at a time.

--Each operation $O_{i,j}$ can be processed without interruption on one of a set of machines $F(O_{i,j}) \subseteq M$.

--Therefore, we denote by $O_{i,j,k}$ to be operation j of J_i that is processed on machine M_k and $p_{i,j,k}$ be its processing time on machine M_k.

--Recirculation occurs when a job can visit a machine more than once. Formally, this implies $\exists i, j_1, j_2$: $F(O_{i,j1}) \cap F(O_{i,j2}) \neq \varnothing$

--Let C_i and d_i be the completion time and the due date of the job J_i, respectively. The tardiness of this job is calculated by the following formula:

$$T_i = \max\{0, C_i - d_i\} \quad (1)$$

--The objective function T of this problem is to find a schedule that minimizes the sum of tardiness of all jobs (total tardiness problem):

$$T = \sum_{i=1}^{n} T_i = \sum_{i=1}^{n} \max(0, C_i - d_i) \quad (2)$$

If $F(O_{i,j})$ is the set of machines that operation $O_{i,j}$ can be processed on, then the FJSP is further classified into two sub-problems as follows:

--Total FJSP (T-FJSP): each operation can be processed on any one machine of set M: $F(Oi.j) = M$.

--Partial FJSP (P-FJSP): each operation can be processed on one machine of subset of M: $F(O_{i,j}) \subseteq M$.

Total tardiness is one of the major objectives in production scheduling. A job that is late may penalize the company's reputation and reduce customer satisfaction. Hence, keeping the due dates of jobs under control is one of the most important tasks faced by companies [6].

In this paper, we shall assume that:

--All machines are available at time 0.

--Each job has its own release date and due date.

--The order of operations for each job is predefined and cannot be modified.

The heuristic approach of scheduling problem solution was used in this project. Generally the scheduling is implemented in two phases:

--Loading.

--Sequencing.

B. Loading

It is necessary to cumulate capacity requirements of individual workstations for the considered time period at the beginning of scheduling operations. The basic idea of workstations capacity utilization is obtained by this way. The loading of operations allows obtaining the sequence of operations on the workstations because the cycle times are known.

Basic approaches to the implementation of loading:

--Forward loading.

--Backward loading.

The forward loading determines only approximate due date of each product. The processing begins at the actual time in first possible terms and products are assigned to workstations towards the future.

The capacity requirements are cumulated in the considered periods of time on the workstations. It can be considered within a limited or unlimited capacity of the workstation. If unlimited capacity is considered then there will be the danger of the delivery date of the product. It means no fulfilling of the time limit of scheduling.

The backward loading presents scheduling products on the workstation from the due date of the production system to backwards, i.e. to the actual date [2].

The loading begins at the latest possible dates. This ensures the minimization of the elaboration and short flow times of production. Possible overrun capacity limit is solved by removing of the operations to another workstation or removing of the starting time of some products towards the present (or also increasing the total available capacity). Overrun of the due date of product is not typical for this approach [3].

Our algorithms use the principle of forward scheduling as well as scheduling of products on the workstations on the basis of the principle of backward scheduling [3].

C. Sequencing

The basic question in sequencing is to determine the order in which the operation of the planned products will be processed. To solve the problem of sequencing there are many different algorithms, which using must consider an analyst himself [3].

At this phase, the precise order of the jobs is determined in the storage of job for workstation (given from the phase loading). Each operation on the product has earliest possible time processing, from which they are based. In the timetable, there are selected operations that can be processed. It starts from time zero (start of production). If only one operation has its earliest possible processing time less than or equal to the current schedule time of product the beginning of execution of the operation is attributed to the current schedule time.

If there are more operations with earliest possible processing time less than or equal to the current schedule time then their order should be provided. The priority rules represent quick and relatively easy way. It is selected the operation that best fulfils the rules. Start of the processing operation will be equal to the current schedule time.

The current schedule time is added to the length of operation which we have selected and then a new operation is searched for the new schedule time.

IV. The Definition of Evaluation Criteria for Case Study

The effect of defined priority rules of scheduling process has been studied by simulation experiments for the production operation in created simulation model. The results of process have been compared on the basis of evaluation criteria.

The following parameters have been selected from the set of potential criteria:

--The number of manufactured products.

--Average flow time.

--Number of work in progress in system.

--The costs per one produced piece.

--Utilization of machines in percentage.

The experiments performed on a given simulation model can be divided into two main categories:

--Experiments with the uniform input interval elements in the system; IAT - the same for all parts.

--Experiments with altered input interval elements; IAT - different for each component in various combinations.

Every simulation experiment simulates 480 minutes of work shift. At the beginning of the simulation process there has been set a warm-up period, where the system got into its typical operation. The results achieved during this period are not included in the resulting statistics, so they do not influence the results of simulation experiments.

The setting of machines, parts, buffers and a defined technique of production has been constant during the simulation experiments in the model. The Inter Arrival Time of parts and the priority rule have been the input parameters into the simulation model. These parameters have been changed for every experiment. The flexible manufacturing system has been simulated in three states. The first state represents relative empty state (input interval was 6 minutes). The second state represents normal utilization of workstation (input interval 4 minutes). The last state characterizes overloaded system (input interval 5 minutes).

V. The Selection of Priority Rules for Experimental Comparison

The priority system presents a defined logic for loading priorities of production orders. Heuristic priority rules are used most frequently.

Priority rules affect the level of achievement of goal criteria, i.e. observing the due date, the flow time of production, the level and uniformity of capacity load, the amount of work in progress supply.

The following rules were selected from many existing priority scheduling rules:

1) EDD (Earliest Due Date) – the preferred operation of product with the closest due date.
2) FIFO (First In - First Out) – the preferred operation according to incoming order or first in - first out.
3) LIFO (Last in First Out) - preferred operation of part with the longest waiting time; respectively last in - first out.
4) LPT (Longest Processing Time) – preferred operation of part with the longest cycle time.
5) LOPR (Least Operations Remaining) – preferred operation of part with the smallest number of still unrealized operations.
6) MOPR (Most Operations Remaining) – the preferred operation of part with the largest number still unrealized operations.
7) MWKR (Most Work Remaining) – preferred operation of part of the latest deadline.
8) SIRO (Service In Random Order) – a random selection of operation.
9) SLACK – preferred time operation of part with the lowest time reserve.
10) SPT (Shortest Processing Time) – preferred operation of part with the shortest cycle time [4].

VI. Implementation of Priority Rules

A. *Implementation of priority rules for phase Loading*

Selection of algorithm for next operation is realized on the output from all the machines. The next operation for specific part will be processed according to filling of storages in front of machines that can realize next operation. Then it will be processed according to price of operation. The next workstation is selected by this way and the selection is marked in variable destination. Subsequently the parts are transported by continuous queuing conveyor with sensors to the required workstation.

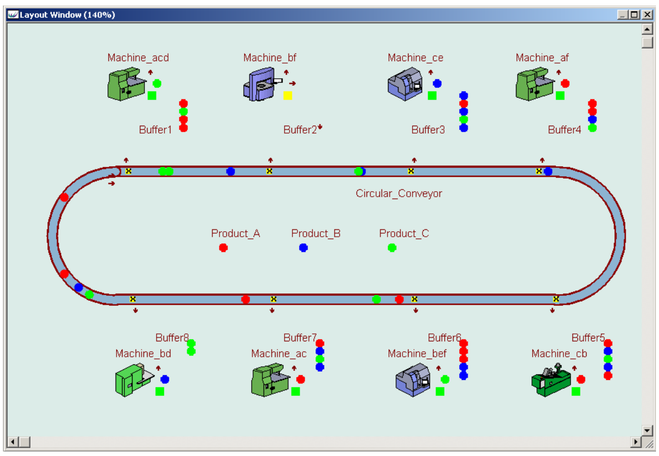

Fig. 1. Simulation model.

B. *Implementation of priority rules for phase Sequencing*

Sequencing determines the order in which operations will be implemented. Algorithms for each of the priority rules set the order of selection from storage for each product contained in the storage. They define the exact position of the element in the storage. Product selection algorithm based on the priority rules is realized on the input and output in all eight storages. All algorithms are solved uniformly and an element is always released from the storage if it has the attribute value enable = 1. Then specific algorithms deal with the way of defining attribute enable according to the selected priority rules.

VII. The Realization of Simulation Experiments

Simulation experiments have been subsequently realized on the proposed plan of experiments to assess the impact of specific priority rules for selected production goals. 90 simulation experiments have been chosen. The simulation experiments have been divided into 9 groups according to the plan in the Table 1. Every group constitutes 10 simulation experiments. It means that every simulation experiment has been realized for one priority rule.

The obtained values from one group of simulation experiments have been presented in graphs separately for every target parameter.

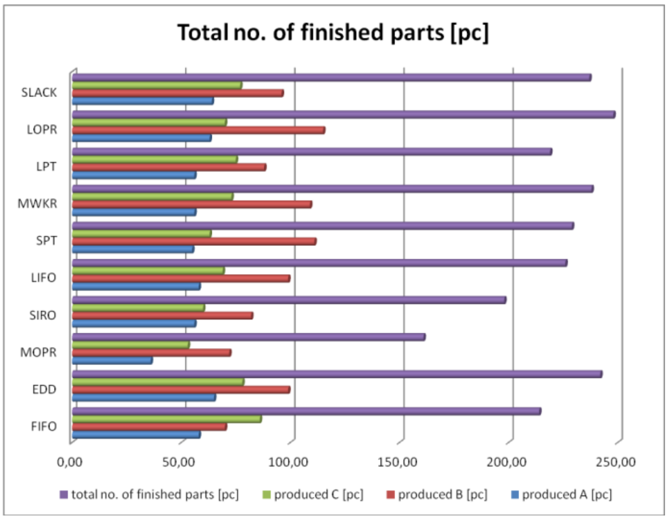

Fig. 2. Number of finished parts EXP 8 [6-4-5].

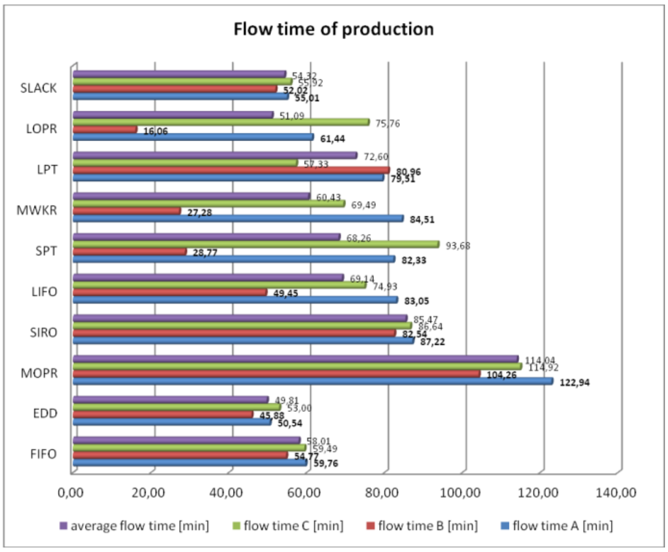

Fig. 3. Flow time of production EXP 8 6-4-5].

A. *Synthesis of results of experiments series EXP8[6-4-5]*

The synthesis of the results from experiment EXP 8 [6-4-5] is showed in Fig. 2-5 for illustration of the process. The obtained results have been processed in the same way for all realized experiments. The simulation experiment has been realized under the following input conditions:

--Input interval of part A was 6 min, 4 min for part B and for part C was 5 min.

--Time of simulation was 480 min.

--The lot size of each part was 1 piece.

--The priority rules were selected step by step FIFO, EDD, SIRO, MOPR, LIFO, SPT, MWKR, LPT, LOPR, SLACK.

The priority rule LOPR has been evaluated as the best rule. Fig. 2 documents maximum of finished parts for LOPR. Fig. 3 shows the results of the flow time parameter for every priority rules in EXP [6-4-5]. The minimum of flow time has reached for EDD priority rule.

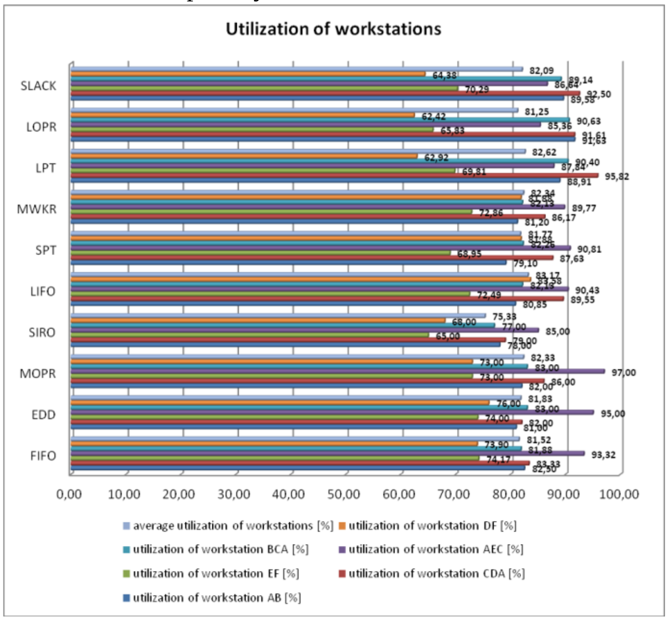

Fig. 4. Utilization of workstations EXP 8 [6-4-5].

The priority rule LIFO has reached the best value for the workstation utilization as shown in Fig. 4.

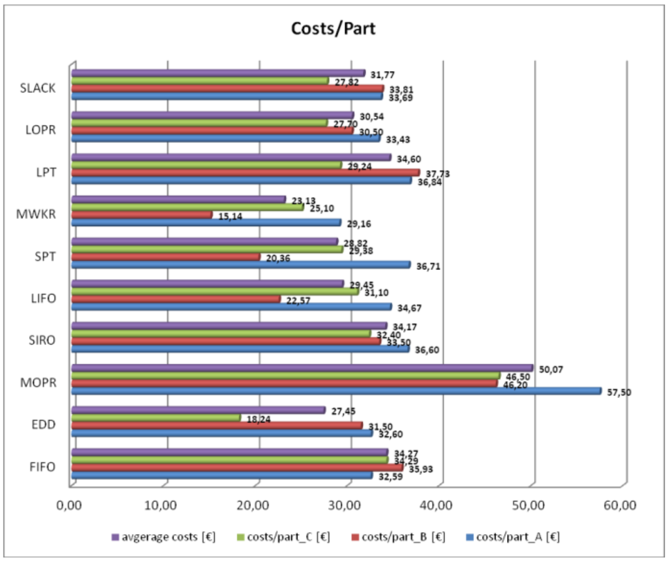

Fig. 5. Costs per production of one part EXP 8 [6-4-5].

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Fig. 5 presents the results of priority rules for costs per part parameter. The minimum value of costs per parts was optioned when the priority rule MWKR was used in scheduling process.

B. The total results of all experiments

The summary Table 1 was created on the results of the experiments. There are recorded the results for the individual goals. The table gives no information about the success of priority rules in given parameters.

TABLE I
THE TOTAL RESULTS OF EXPERIMENTS

EXP	Total no. of finished parts [pc]		Average flow time [min]		Utilization of workstations [%]		Costs / Pc [€]	
EXP 1 [4-4-4]	1. 252	6. 212	1. 76.32	6. 106.41	1. 86.20	6. 83.76	1. 25.01	6. 38.00
	2. 246	7. 209	2. 81.95	7. 107.38	2. 84.83	7. 83.48	2. 31.93	7. 39.07
	3. 245	8. 187	3. 82.66	8. 116.42	3. 84.69	8. 83.00	3. 33.83	8. 43.24
	4. 217	9. 167	4. 96.41	9. 125.93	4. 84.50	9. 82.60	4. 34.10	9. 59.30
	5. 216	10. 53	5. 104.14	10. 198.74	5. 84.35	10. 77.33	5. 37.38	10. 150.00
EXP 2 [5-5-5]	1. 246	6. 221	1. 45.20	6. 62.24	1. 83.49	6. 82.56	1. 26.62	6. 33.10
	2. 239	7. 220	2. 50.15	7. 65.81	2. 83.22	7. 81.39	2. 31.02	7. 33.17
	3. 236	8. 208	3. 53.23	8. 73.60	3. 83.00	8. 79.85	3. 31.19	8. 34.23
	4. 235	9. 203	4. 53.82	9. 83.51	4. 82.93	9. 79.77	4. 32.34	9. 36.43
	5. 222	10. 185	5. 60.71	10. 91.50	5. 82.67	10. 75.33	5. 32.98	10. 42.83
EXP 3 [6-6-6]	1. 233	6. 222	1. 20.03	6. 28.91	1. 79.02	6. 76.83	1. 25.02	6. 31.00
	2. 230	7. 222	2. 20.47	7. 29.73	2. 79.00	7. 76.65	2. 27.61	7. 31.20
	3. 230	8. 219	3. 21.52	8. 31.04	3. 78.76	8. 76.18	3. 30.40	8. 31.51
	4. 227	9. 218	4. 25.04	9. 34.88	4. 77.60	9. 76.00	4. 30.42	9. 31.97
	5. 223	10. 218	5. 25.16	10. 39.40	5. 77.06	10. 76.83	5. 30.98	10. 32.15
EXP 4 [4-5-6]	1. 255	6. 218	1. 42.87	6. 70.32	1. 83.33	6. 79.03	1. 27.36	6. 34.07
	2. 242	7. 210	2. 55.33	7. 74.20	2. 83.17	7. 78.63	2. 29.95	7. 34.44
	3. 236	8. 206	3. 56.74	8. 79.78	3. 82.18	8. 77.76	3. 30.53	8. 34.73
	4. 234	9. 95	4. 57.98	9. 88.19	4. 81.06	9. 77.60	4. 31.06	9. 37.41
	5. 219	10. 93	5. 69.62	10. 91.65	5. 80.95	10. 76.67	5. 31.66	10. 41.30
EXP 5 [4-6-5]	1. 248	6. 209	1. 49.55	6. 76.72	1. 83.67	6. 78.69	1. 28.77	6. 33.87
	2. 232	7. 207	2. 56.92	7. 77.15	2. 82.67	7. 78.02	2. 29.93	7. 36.09
	3. 232	8. 204	3. 57.39	8. 85.92	3. 82.50	8. 77.25	3. 30.24	8. 37.72
	4. 229	9. 174	4. 59.23	9. 104.98	4. 81.56	9. 77.13	4. 31.55	9. 43.88
	5. 211	10. 169	5. 74.17	10. 109.25	5. 79.33	10. 76.33	5. 32.28	10. 47.27
EXP 6 [5-4-6]	1. 251	6. 226	1. 47.91	6. 68.09	1. 83.71	6. 81.59	1. 23.94	6. 31.47
	2. 251	7. 223	2. 48.35	7. 68.64	2. 83.33	7. 81.26	2. 29.85	7. 31.73
	3. 247	8. 219	3. 50.30	8. 74.08	3. 82.32	8. 81.25	3. 29.97	8. 34.12
	4. 241	9. 211	4. 55.75	9. 74.41	4. 81.99	9. 81.14	4. 30.50	9. 34.43
	5. 240	10. 195	5. 58.27	10. 85.05	5. 81.67	10. 77.00	5. 30.57	10. 41.43
EXP 7 [5-6-4]	1. 239	6. 215	1. 52.83	6. 74.60	1. 84.41	6. 82.36	1. 26.63	6. 34.18
	2. 231	7. 205	2. 57.18	7. 75.60	2. 84.24	7. 79.54	2. 30.63	7. 35.45
	3. 229	8. 194	3. 59.62	8. 93.05	3. 83.67	8. 78.47	3. 30.63	8. 35.83
	4. 217	9. 166	4. 67.95	9. 116.15	4. 83.00	9. 78.05	4. 33.41	9. 45.33
	5. 216	10. 135	5. 70.13	10. 132.78	5. 82.42	10. 75.83	5. 33.84	10. 58.50
EXP 8 [6-4-5]	1. 248	6. 226	1. 49.81	6. 68.26	1. 83.17	6. 81.83	1. 23.13	6. 31.77
	2. 242	7. 219	2. 51.09	7. 69.14	2. 82.62	7. 81.77	2. 27.45	7. 34.17
	3. 238	8. 214	3. 54.32	8. 72.60	3. 82.34	8. 81.52	3. 28.82	8. 34.27
	4. 237	9. 198	4. 58.01	9. 85.47	4. 82.33	9. 81.25	4. 29.45	9. 34.60
	5. 229	10. 161	5. 60.43	10. 114.04	5. 82.09	10. 75.33	5. 30.54	10. 50.07
EXP 9 [6-5-4]	1. 237	6. 220	1. 55.67	6. 72.40	1. 83.96	6. 82.17	1. 25.86	6. 32.18
	2. 236	7. 218	2. 55.71	7. 74.38	2. 83.39	7. 81.15	2. 30.89	7. 32.29
	3. 234	8. 190	3. 61.86	8. 94.64	3. 83.00	8. 80.23	3. 30.90	8. 34.70
	4. 229	9. 184	4. 70.88	9. 102.46	4. 82.77	9. 80.20	4. 31.18	9. 40.11
	5. 222	10. 143	5. 71.98	10. 123.31	5. 82.62	10. 75.67	5. 32.11	10. 54.60

VIII. FINAL RESULTS

It was necessary to use any of the multi-objective evaluation methods for evaluation of influence of priority rules. These methods are based on the comparison of many indicators. The four production goals are selected in this case.

A. Multi-objective evaluation method

The most common multi-objective evaluation method includes [5], [2]:

--The simple method or weighed sum of order.

--The scoring method.

--The standard-variable method.

--The method of distance of the fictitious point.

The mathematical-statistical standard-variable method was used to evaluate the obtained results from methods mentioned above.

The principle of this method is the transfer of different values for the parameters of comparable shape - a standard variable.

Method implementation procedure:

--Calculation of arithmetic means xj and standard deviations Sxj for individual indicators.

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--Transformation of the original values of pointer.

To maximize the pointer:

$$u_{ij} = \frac{x_{ij} - x_{priemj}}{Sx_j} \tag{3}$$

To minimize the pointer:

$$u_{ij} = \frac{x_{priemj} - x_{ij}}{Sx_j} \tag{4}$$

--Calculation of integral pointer d_i - calculated as a weighted average of standardized values.

$$d_i = \frac{1}{m} \sum_{i=1}^{m} u_{ij} * p_j \tag{5}$$

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i = 1, 2, ..., n
p_j = weight of j-th pointer

--Determining the order of the rules according to the size of the average value of standardized values (the higher value the better ranking).

The sequence of success of each priority rule has been found in different experiments by using method of distance of the fictitious point. There have been accepted all production goals. Then the final sums of points have been obtained for all rules based on the evaluation of each sequence (10 points for 1st place and 1 point for 10th place). This way has created the definitive sequence of success of the priority rules (Table 2).

TABLE II
THE COMPLEX EVALUATION OF THE PRIORITY RULE FUNCTION

EXP	Order of rules in individual experiments									
	FIFO	EDD	MOPR	SIRO	LIFO	SPT	MWKR	LPT	LOPR	SLACK
1 [4-4-4]	5	9	1	2	6	7	10	3	8	4
2 [5-5-5]	8	9	1	2	5	6	10	4	7	3
3 [6-6-6]	6	7	9	1	2	3	8	4	10	5
4 [4-5-6]	9	10	2	3	4	6	8	1	7	5
5 [4-6-5]	8	10	2	3	4	5	9	1	7	6
6 [5-4-6]	10	8	2	1	3	5	9	4	7	6
7 [5-6-4]	5	9	1	3	7	6	10	2	8	4
8 [6-4-5]	4	9	1	2	6	5	10	3	8	7
9 [6-5-4]	6	9	1	2	7	5	10	3	8	4
Points	61	80	20	19	44	48	84	25	70	44
Resulting order	4	2	9	10	6-7	5	1	8	3	6-7

B. *Final evaluation*

The following conclusions have been deduced from the results of experiments that have been reported in the Table 1 and Table 2:

--FIFO priority rule can be defined as one of the most universal (all-purpose) priority rules which had a positive influence over the number of finished products.

--EDD priority rule became the second most successful rule, therefore it may be recommended when the main goal is to minimize flow time of production.

--MOPR priority rule can be evaluated as the second most unsuccessful. Its positive influence is reflected only in the maximizing of the machines utilization.

--SIRO priority rule is clearly evaluated as the most unsuccessful rule. This priority rule may be recommended when the main goal is to minimize the cost of production per 1 product.

--LIFO priority rule had a positive influence over the machines utilization.

--SPT priority rule may be recommended for usage when the main goal is to maximize the machines utilization.

--MWKR priority rule became the most successful rule and should be used when production priority is to minimize the cost of production per 1 product.

--LPT priority rule is the third most unsuccessful rule. Its positive influence is reflected only in the maximizing of the machines utilization.

--LOPR priority rule can be evaluated as the second most successful and its positive influence was reflected mainly in the maximizing of the number of finished products.

--SLACK priority rule can be used for the purpose of minimizing of flow time.

IX. CONCLUSION

The problems of process dynamic scheduling manufacturing operations have been solved in the presented project. The main aim of the project was to evaluate selected priority rules influence over defined production goals.

The following results were reached:

--The identification of basic scheduling problems in flexible manufacturing system.

--The analysis of application priority rules in scheduling process.

--The relevant data were obtained from simulation model of flexible manufacturing system. This data was used to evaluate priority rules influence over the production goals.

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