MULTI-OBJECTIVE UNRELATED PARALLEL MACHINES SCHEDULING WITH SEQUENCE-DEPENDENT SETUP TIMES AND PRECEDENCE CONSTRAINTS

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Abstract This paper presents a novel, multi-objective model of a parallel machines scheduling problem that minimizes the number of tardy jobs and total completion time of all jobs. In this model, machines are considered as unrelated parallel units with different speeds. In addition, there is some precedence, relating the jobs with non-identical due dates and their ready times. Sequence-dependent setup times embedded in the proposed model may vary in different machines based on their characteristics. This paper proposes a two-level mixed-integer programming for the given problem. By solving the presented model, the associated promising results show the effectiveness of this model for small and medium-sized problems, respectively.

Keywords Unrelated Parallel Machine Scheduling, Multi-Objective Model, Sequence-Dependent Setup Times, Precedence Constraints

چکیده در این مقاله، یک مدل ریاضی چند هدفه جدید برای مساله زمان بندی ماشین‌های موازی ارائه می‌شود به نحوی که تعدّاد کارهای دارای دیرکرد و مجموع مدت زمان تکمیل کارها کمینه گردد. در این مدل ماشین‌های نامرتبط دارای سرعت‌های متفاوت در نظر گرفته می‌شوند. همچنین کارها در لحظه شروع زمان بندی، از لحاظ زمان‌های دسترسی و موعد تحویل دارای شرایط یکسانی نبوده و بین برخی از کارها محدودیت‌های تقدمی در پردازش ماشین‌ها وجود دارد. در این مساله، زمان‌های آماده‌سازی قبل از پردازش کارها در نظر گرفته شده است که این زمان‌ها به توالی کارها و همچنین نوع ماشینی که بر روی آن قرار می‌گیرند، وابسته می‌باشند. در این مقاله یک برنامه‌ریزی عدد صحیح مختلط دو سطحی برای مساله مورد نظر ارائه می‌گردد. با حل این مدل، نتایج حّل حاکی از کارایی مدل پیشنهادی برای مسائل با اندازه‌های کوچک و متوسط می‌باشد.

1. INTRODUCTION

A classical parallel machine problem can be stated as a set of independent jobs to be processed on a number of available identical parallel machines. Each machine can process only one job at a specific time, and each job can be processed only on one machine. Each job is ready at the beginning of the scheduling horizon and has a distinct processing time and due date [1].

It is assumed that machines are identical, all jobs with common due dates are available at the beginning of scheduling. Also, the majority of scheduling studies assumes that setup times are negligible or are included in processing times of the job. While, this assumption simplifies the analysis and/or reflects certain applications; it adversely affects the solution quality for many applications which require the explicit treatment of setup and cause the model not to be effective in real environments.

In several cases due to the difference between technologies in utilized machines, the machines work with different speeds, therefore processing times for the jobs that must be scheduled on these machines are not the same. In addition, maybe all jobs are not available at the beginning of scheduling and they arrive in a dynamic manner also each job may be considered to have its own due date.

In a manufacturing environment, setup times consist of all activities done on material in order to prepare machines and situations in a process phase. Production problems related to setup times are divided in two important Sections 1 Sequence-dependent setup times; and 2 Sequence-independent setup times. For instance, at a production facility where paint is manufactured, a setup time is incurred for cleaning the machine whenever a color change is required. The thoroughness required in cleaning the machine depends on both the color being removed and the color for which it is being prepared. Similarly, in the plastic industry, items of different colors are typically assigned to different extrusion machines. When a color change is required, a certain amount of time is taken until the extruded plastic reaches the desired color. Such problems are also common in a glass manufacturing industry as well, in which molten glass is held in huge vats before the actual glass blowing process. The vats have to be changed for different colors and properties of the glass. This changeover process incurs major setup times. Similarly, in a soft beverage industry, the manufacturing lines have to go through major setups while changing over from filling glass bottles to soda cans. Other similar examples can be found in chemical and paper manufacturing industries [2].

In almost all real industrial environments, precedence constraints are very important for sequencing and jobs scheduling. In most real situations, some cases occurred in which the beginning of a job is required, to complete another job, while the preceding job which is not a completed job, cannot be started.

Scheduling all jobs on parallel machines, with all the above-mentioned constraints, decreases the solution space; however, it does not mean that the optimal solution will be achieved easily for this given problem. But rather accessibility to the optimal solution has been hard by adding constraints to the model.

During the last decades, many researchers investigated multi-criteria parallel machines scheduling problems with two or more criteria that appear simultaneously or hierarchy in the objective function. Minimizing the number of tardy jobs is one of the objectives that researchers paid less attention to. However in many situations, we are confronted with conditions that delay in delivering orders, could cause costumers to cancel their orders. Therefore, in these situations we want to have a scheduling problem that minimizes the number of tardy jobs.

On the other hand, minimization of the total completion time of all jobs is ever applied in scheduling problems, by a number of researchers using many different methods to minimize this criterion. Decreasing the completion times is effective in decreasing the amount of job delay from its due dates which causes the reduction in the number of tardy jobs. Also, decreasing the completion times causes decrease in the number of total works-in-process (WIP) inventories, and minimizes irregularities and inordinate crowd due to uncompleted jobs in a shop floor. Therefore, decreasing the completion times is one of the most significant criteria for manufacturing and service organizations.

The extended parallel machine can be formulated as a generalized parallel machine problem and therefore it belongs to a class of NP-hard problems. Thus in this paper, a genetic algorithm (GA) is proposed to solve the extended model, for the real-sized instances.

The rest of this paper is organized as follows: a brief overview of the extended model and related literature is presented in Section 2. The new multi-objective model of a unrelated parallel machines scheduling problem is formulated in Section 3. The related computational results are reported in Section 4 and finally Section 5 covers the conclusion.

2. LITERATURE REVIEW

Most studies preformed on machine scheduling do not consider sequence-dependent setup times between jobs. We can find a survey on this problem in [3,4]. Different methods for solving this problem exist. Some researchers reach the optimal or the near-optimal solution by using the mathematical programming models [2,5,6], meta-heuristics, such as genetic algorithm, and heuristic method based on list scheduling [7-9].

Monma, et al [10] considered the complex computing of scheduling parallel machine with sequence dependent set up cost. Balakrishnam, et al [11] considered this problem to minimize the total earliest and tardiness cost in just in time production environments and solves them with genetic algorithm and mixed integer programming,. Blidgue, et al [1] solved this problem considering minimization of total tardiness by tabu search and then compared with Serifoglu's problem and earned a better result than GA with TS. Other researches with different objectives were presented by Vinegar, et al [12] and Flower, et al [13]. Tavakkoli-Moghaddam, et al [14] presented a new integer-linear programming (ILP) model for an identical parallel-machine scheduling problem with family setup times that minimizes the total weighted flow time (TWFT). They proposed genetic algorithms to solve this model for the given problem. Tavakkoli-Moghaddam, et al [15] presented a new mathematical model for a multi-criteria parallel machine scheduling problem, minimizing the total earliness and tardiness penalties as well as machine costs. Machines are defined as unrelated parallel machines with different speeds. They proposed genetic algorithms to solve such a NP-hard problem. Javadin, et al [16] presented a mathematical model for a uniform parallel machine scheduling problem minimizing total costs of earliness/tardiness penalties. In this model, there are a few triangular fuzzy parameters, such as processing times, due dates, and unit cost of earliness/tardiness penalties. They proposed a novel interactive approach by the use of a strategy of minimizing the most possible value of the imprecise total costs, maximizing the possibility of obtaining lower total costs, and minimizing the risk of obtaining higher total costs simultaneously.

Jolai, et al [17] considered a parallel machines scheduling problem with split jobs to minimize the total tardiness. They proposed a new approach to solve the given problem and proved a number of theorems regarding resource planning and job sequencing. Torabi, et al [18] considered an economic lot sizing and scheduling problem in flexible flow lines with unrelated parallel machines over a finite planning horizon. They developed a new mixed zero-one nonlinear mathematical program for this problem, and proposed an efficient constructive heuristic (SCD) consisting of two phases, called assigning and sequencing. Tavakkoli-Moghaddam, et al [19] presented a new mixed-integer goal programming (MIGP) model for a parallel machine scheduling problem with sequence-dependent setup times and release dates under the hypothesis of fuzzy processing time's knowledge. They considered a bi-objective model that minimizes the total weighted flow time and total weighted tardiness.

So far, Uzsoyet, et al [20] discussed minimizing the maximum lateness in the presence of precedence constraints and sequence dependency of jobs. Each job was considered to have its own due date. A neighborhood search algorithm obtained a local optimal solution, was presented along with a branch-and-bound algorithm to obtain optimal solutions. Hurink, et al [21] presented scheduling $P/S_{ij},Prec/C_{\max}$ as an NP-hard problem. In this paper, they dealt with the question whether it is possible to design an efficient list scheduling algorithm for this problem, which produces a dominant set of list schedules if it is applied to all sequences of jobs which are compatible with the given precedence (i.e. are linear extensions of the partial order induced by the precedence). A positive answer to this question could lead to a solution approach for the considered problem by using a set of all possible job sequences as solution space and the developed method to generate corresponding schedules. However, they shown that a positive answer to this question is very unlikely. Huo, et al [22] presented multi-objective parallel machines scheduling to minimize a number of tardy jobs and maximum weighted lateness. Prankish, et al [23] studied a comprehensive survey on bi-criteria parallel machines scheduling problems and presented several heuristic algorithms to solve them.

3. PROPOSED MODEL

In this paper, we define the parallel machine scheduling where some machines operate with different speed and all of them are available at the beginning of the scheduling. Jobs are not independent and there is some precedence relations between them and all jobs are not available at the beginning of the scheduling, each of them has its own due date. We know that setup times are depended on a job sequence and machine type. The objectives are to minimize a number of tardy jobs and total completion times. In this paper, we present an integer-goal programming for solving the problem.

3.1. Input Parameters

M Total number of machines

N Total number of jobs for processing

UB Maximum number of situations on each machine that jobs are placed on them is: $UB = N + M - 1$

P_{im} Processing time of job i on machine m (i = 1, 2,…,N; m=1, 2, …, M)

d_i Due date of job i

r_i Time at which job i is available for processing (i.e., ready time)

S_{ijm} Setup time to switch from job i to job j on machine m (j = 1, 2, ..., N)

L An arbitrary positive large number

3.2. Decision Variables

C_i Completion time of job i

U_i 1, if job i is tardy; 0, otherwise.

X_{ikm} 1, if job i is assigned on situation k at machine m; 0, otherwise (k = 1, 2,…,UB)

3.3. Mathematical Model for Phase 1

$$\min \sum_{i=1}^{N} U_i \tag{1}$$

s.t.

$$\sum_{m=1}^{M}\sum_{k=1}^{UB} X_{ikm} = 1 \quad , \forall i \tag{2}$$

$$\sum_{i=1}^{N} X_{ikm} \le 1 \quad , \quad \forall k, m \tag{3}$$

$$\sum_{i=1}^{N} X_{ikm} - \sum_{j=1}^{N} X_{j,k-1,m} \le 0 \qquad \forall m \quad , \quad k = 2,\ldots,UB \tag{4}$$

$$C_j - C_i + L(2 - X_{jkm} - X_{i(k-1)m}) \ge P_{jm} + S_{ijm} \qquad k = 2,\ldots,UB \quad , \forall i, j, m \quad (i \ne j) \tag{5}$$

$$C_i \ge r_i + \sum_{k=1}^{UB} P_{im} * X_{ikm} \quad , \quad \forall i, m \tag{6}$$

$$C_j - C_i \ge \sum_{m=1}^{M}\sum_{k=1}^{UB} P_{jm} X_{jkm} \quad , \quad i < j \tag{7}$$

$$(C_i - d_i) - LU_i \le 0 \quad , \quad \forall i \tag{8}$$

$$X_{ikm}, U_i \in \{0,1\} \quad , \quad C_i \ge 0 \tag{9}$$

Equation 1 minimizes the total number of tardy jobs. Constraint (2) ensures that each job is assigned to one of the existing positions on the machines. Constraint (3) guarantees that on each existing positions, at most one job can be assigned. Constraint (4) ensures that until one position on a machine is empty, jobs is not assigned to subsequent positions and jobs assigned to empty positions on each machines, respectively. Constraint set (5) ensures that the completion time of a real job in a sequence on a machine is at least equal to the sum of the completion time of the preceding job, the sequence-dependent set-up time, and the processing time of the present job. Constraint (6) measures the completion time for each job on each machine. Constraint (7) observes precedence relationships. Constraint (8) specifies the tardy jobs. Constraint (9) defines the type of decision variables.

3.4. Mathematical Model for Phase 2 After solving the proposed mathematical model for Phase 1, the optimal solution obtained for solving the minimization of the number of tardy jobs is added as a constraint to the second phase that is called minimization of the total completion time for all jobs. We assume that U is a solution that minimizes the number of tardy jobs.

$$\min \sum_{i=1}^{N} C_i \tag{10}$$

s.t.

Constraints 1 to 9,

$$\sum_{i=1}^{N} U_i = U \tag{11}$$

Equation 10 minimizes the total completion time of all jobs. Equation 11 guarantees that the number of tardy jobs obtained at the first phase remains at its optimal amount. The solution results at the second phase, is the final solution for minimization of the number of tardy jobs and the total completion times problem by priority of the number of tardy jobs.

4. COMPUTATIONAL RESULTS

To solve the proposed model, a number of test problems are randomly generated in small and medium sizes. To generate the model's data, such as processing times, set up times, ready time, and due dates, we use the methods presented by Balakrishnan, et al [11] and Radhakrishnan, et al [2].

To produce processing times and setup times, we use uniform distribution [1,20] and [1,7], respectively. Then the amount of the setup times is corrected based on inequality $S_{ijm} + S_{jkm} \geq S_{ikm}$. The random number generation for the due dates obtained by Equation 12 that is the extension of the work presented by Radhakrishnan, et al [2].

$$d_i = r_i + [(SUMP/2M)(1-F-RD/2), (SUMP/2M)(1-F+RD/2)] \tag{12}$$

$$SUMP = \sum_{m=1}^{M} \sum_{i=1}^{N} P_{im}$$

F = Coefficient delay set to 0.5

RD = Relative range of due date set to 0.1

To produce the precedence relations, we use an N-dimensional square matrix (Prec), in which its arrays consist of 0 and 1 generated at random. If Prec $(i, j) = 1$, it means that job i precedes job j. When prec(i, j) = prec$(j, i) = 1$, then we set one of them to zero randomly. Table 1 shows an example for a problem with 6 jobs and 2 machines, and 3 precedence constraints.

Considered precedence constraints are as follows: $4 < 2$, $1 < 5$ and $2 < 3$. The computational results of the given test problem are shown in Table 2. These results contain the completion time for all jobs (i.e., C_i), assigned situation to each job (i.e., X_{ikm}) and the objective values in Phases 1 and 2 of the proposed model.

For small-sized problems, we consider 27 different test problems and by using the proposed method, we produce 15 sample data for each of them. These problems are optimally solved by a branch-and-bound (B and B) method under the LINGO 8.0 software on a Personal Computer including two Intel® CoreTM2 T5600@1.83 GHz processors and 512 GB RAM. The principle criterion to evaluate the performance of the proposed model is the number of iterations. The average number of iterations and average of the solution time for two objectives of the proposed models are shown in Tables 3 and 4. In these tables, for each test problem this information is shown: the number of jobs and machines, precedence constraints, number of iterations until achieving the optimal solution and averages of the solution times.

It is worthy noting that increasing the number of jobs increase the number of iterations. Also, increasing the number of machines is effective in decreasing the number of iterations until receiving the optimal solution. Increasing the number of precedence constraints because of decreasing the solution space has the same effect in the number of iterations.

The analysis of variance (ANOVA) proves its correction by using the MINITAB software . The ANOVA results for the first level of the model are shown in Table 5. Further, Table 6 shows the associated ANOVA in confidence level of 0.95, all three factors: number of machines, number of jobs, and precedence constraints are effective on the number of iterations until achieving the optimal solution. The related results for the second level of the model show the same results. Moreover, the

TABLE 1. Sample Problem Data.

job	1	2	3	4	5	6
P_{i1}	3	16	9	3	6	12
P_{i2}	3	17	17	4	17	14
d_i	21	18	47	34	23	22
r_i	7	3	31	18	8	8

Number of Jobs = 6; Number of Machines = 2

Setup Times on Machine 1 (m = 1)

From/to	1	2	3	4	5	6
1	0	4	4	4	4	3
2	3	0	4	5	2	4
3	6	7	0	3	4	5
4	6	4	6	0	6	4
5	6	4	7	5	0	4
6	2	5	7	1	3	0

Setup Times on Machine 2 (m = 2)

From/to	1	2	3	4	5	6
1	0	6	4	5	4	5
2	2	0	6	2	4	3
3	4	3	0	2	5	2
4	5	5	5	0	3	6
5	5	6	4	5	0	6
6	3	4	٧	5	6	0

TABLE 2. Results for the Given Problems.

Job	C_i	$X_{ikm}=1$
1	10	X_{111}
2	48	X_{241}
3	57	X_{322}
4	28	X_{431}
5	20	X_{521}
6	22	X_{612}
$\sum U_i = 2$		$\sum C_i = 185$

mutual effect of the number of jobs and precedence constraints are effective on the number of iterations; thus increasing and decreasing of these two factors simultaneously, is effective in the number of iterations until achieving the final optimal solution.

TABLE 3. Test Results for the Primary Model with the Objective Function Of $\sum U_i$.

Job	Machine	No. of Precedence Constraints	Average Pivots	Average Solution Time (S.)
6	2	3	22831	18
		4	10162	11
		5	783	4
	3	3	13195	17
		4	4167	8
		5	120	2
	4	3	4571	6
		4	724	3
		5	68	1
8	2	3	185437	165
		4	146018	82
		5	20124	30
	3	3	110224	131
		4	51014	64
		5	14340	23
	4	3	49112	78
		4	10352	25
		5	590	9
10	2	3	1239105	2640
		4	890418	1312
		5	115116	459
	3	3	983212	1834
		4	351489	1088
		5	35282	315
	4	3	512307	1092
		4	103225	402
		5	6678	135

5. CONCLUSION

In this paper, a parallel machine scheduling was solved by zero-one linear programming with two-level and goal programming approach. In attention to parallel machine scheduling that the number of

TABLE 4. Test Results for the Secondary Model with the Objective Function of $\sum C_i$.

Job	Machine	No. of Precedence Constraints	Average Pivots	Average Solutiontime (S.)
6	2	3	433789	342
		4	213402	231
		5	15660	80
	3	3	263900	340
		4	75006	144
		5	2160	36
	4	3	100562	132
		4	14480	60
		5	1428	21
8	2	3	5563110	4950
		4	4234522	2378
		5	583596	870
	3	3	3086272	3668
		4	1530420	1920
		5	430200	690
	4	3	1522472	2418
		4	320912	775
		5	19470	297
10	2	3	61955250	93200
		4	45411318	56912
		5	5870916	19409
	3	3	48177388	79866
		4	16871472	42224
		5	1834664	11380
	4	3	25615350	44600
		4	5264475	17502
		5	333900	5750

machine operated with different speed and all of them are available at the beginning of the scheduling and jobs are not independent and precedence constraints at machines exists between the jobs and all the jobs are not available at the beginning of scheduling, and each of them have non common due date, our objectives contain minimizing the total job tardiness and total processing time which they are important characteristics that have not been considered yet. The inverse relationship between precedence constraint jobs and the number of iterations is one of the important results of this paper.

TABLE 5. General Linear Model: Ave. Pivot Versus Job; No. of Prec.

Factor	Type	Levels	Values		
Job	Fixed	3	6	8	10
Machine	Fixed	3	2	3	4
No. of Prec.	Fixed	3	3	4	5

TABLE 6. ANOVA for Pivot 2, using Adjusted SS for Tests.

Source	DF	Seq. SS	Adj. SS	Adj. MS	*F*	*P*
Job	2	1.15094E + 12	1.15094E + 12	5.75471E + 11	50.30	0.000
Machine	2	2.10279E + 11	2.10279E + 11	1.05139E + 11	9.19	0.008
No. Prec.	2	4.76514E + 11	4.76514E + 11	2.38257E + 11	20.83	0.001
Job*No. Prec.	4	6.49357E + 11	6.49357E + 11	1.62339E + 11	14.19	0.001
Job*Machine	4	2.43831E + 11	2.43831E + 11	60957861553	5.33	0.022
Machine*No. Prec	4	75854770452	75854770452	18963692613	1.66	0.251
Error	378	91526334595	91526334595	11440791824		
Total	396	2.89830E+12				

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7. REFERENCES

1. Blidgue, U., Kirac, F., Kurtulan, M. and Pekgun, P., "A Tabu Search Algorithm for Parallel Machine Total Tardiness Problem", ***Computers and Operation Research***, Vol. 31, No. 3, (2004), 397-414.
2. Radhakrishnan, S. and Ventura, J. A., "Simulated Annealing for Parallel Machine Scheduling with Earliness/Tardiness Penalties and Sequence-Dependent Setup Times", ***In. J. of Production Research***, Vol. 38, No. 10, (2000), 2233-2252.
3. Sivrikaya-Şerifoğlu, F. and Ulusoy, G., "Parallel Machine Scheduling with Earliness Tardiness Penalties", ***Computers and Operation Research***, Vol. 26, (1999), 773-787.
4. Sumichrast, R. T. and Frendewey, J. O., "Scheduling Parallel Processors with Setup Cost and Resource Limitations", ***Decision Science***, Vol. 19, (1988), 138-146.
5. Frederickson, G., Hecht, M. S. and Kim, C. E., "Approximation Algorithm for Some Routing Problems", ***SIAM Journal of Computing***, Vol. 7, (1978), 178-193.
6. Sumichrast, R. T., "Scheduling Parallel Processors to Minimize Setup Times", ***Computers and Operations Research***, Vol. 14, No. 4, (1987), 305-313.

7. Weng, M. X., Lu, J. and Ren, H., "Unrelated Parallel Machine Scheduling with Setup Consideration and a Total Weighted Completion Time Objective", ***Int. J. of Production Economics***, Vol. 70, No. 3, (2001), 215-226.
8. Ovacik, I. M. and Uzsoy, R., "Worst-Case Error Bounds for Parallel Machine Scheduling Problems with Bounded Sequence-Dependent Setup Times" ***Operations Research Letters***, Vol. 14, No. 5, (1993), 251-256.
9. Sameh, T. A. and Rajan, V. N., "Reduction of Total Weighted Tardiness on Uniform Machines with Sequence Dependent Setups", ***6th Industrial Engineering Research Conference Proceedings***, IIE, Norcross, GA, (1997), 181-185.
10. Monma, C. L. and Potts, C. N., "On the Complexity of Scheduling with Batch Setup Times", ***Operations Research***, Vol. 37, (1989), 798-804.
11. Balakrishnan, N., Kanet, J. J. and Sridharan, Sir V., "Early/Tardy Scheduling with Sequence Dependent Setup on Uniform Parallel Machines", ***Computers and Operation Research***, Vol. 26, (1999), 127-141.
12. Vignier, A., Sonntag, B. and Portmann, M. C., "Hybrid Method for a Parallel-Machine Scheduling Problem", ***IEEE Symposium on Emerging Technologies and Factory Automation, ETFA***, Vol. 1, (1999), 671-678.
13. Flower, J. W., Horng, S. M. and Cochran, J. K., "A Hybridized Genetic Algorithm to Solve Parallel Machine Scheduling Problem with Sequence Dependent Setups", ***Int. J. of Industrial Engineering***, Vol. 10, No. 3, (2003), 232-243.
14. Tavakkoli-Moghaddam, R. and Mehdizadeh, E., "A New ILP Model for Identical Parallel-Machines Scheduling with Family Setup Times Minimizing the Total Weighted Flow Time by a Genetic Algorithm", ***Int. J. of Engineering, Transaction A: Basic***, Vol. 20, No. 2, (2007), 183-194.
15. Tavakkoli-Moghaddam, R., Jolai, F., Khodadadeghan, Y. and Haghnevis, M., "A Mathematical Model of a Multi-Criteria Parallel Machine Scheduling Problem: A Genetic Algorithm", ***Int. J. of Engineering, Transactions A: Basic***, Vol. 19, No. 1, (2006), 79-86.
16. Javadian, N., Javadi, B., Tavakkoli-Moghaddam, R. and Safaei, N., "Possibility Linear Programming to Uniform Parallel Machines Scheduling with Sequence-Dependent Setup Times: Early/Tardy Penalties", ***Proceeding of the 36th Int. Conf. on Computers and Industrial Engineering***, Taipei, Taiwan, (June 20-23, 2006), 3488-3497.
17. Jolai, F., Tavakkoli-Moghaddam, R. and Azadian, F., "Parallel Machine Scheduling for Split Able Jobs with Sequence Dependent Setup Times", ***J. of Faculty of Engineering***, University of Tehran, Vol. 40, No .4, (2006), 495-506.
18. Torabi, S. A., Jenabi, M., Fatemi Ghomi, S. M. T., Jolai, F. and Tavakkoli-Moghaddam, R., "Finite Horizon ELSP in Flexible Flow Lines with Unrelated Parallel Machines", ***Proceeding of the 12th IFAC Symposium on Information Control problems in Manufacturing***, Saint Etienne, France, (May 15-19, 2006), Vol. 4, 137-142.
19. Tavakkoli-Moghaddam, R., Gharehgozli, A. H., Rabbani, M. and Zaerpour, N., "A Fuzzy Mixed-Integer Goal Programming Model for a parallel Machine Scheduling Problem", ***Proceeding of the 8th WSEAS Int. Conf. on Fuzzy Systems (FS '07)***, Vancouver, Canada, (June 19-21, 2007), 196-201.
20. Uzsoy, R., Vega, M., Lee, C. Y. and Leonard, P. A., "Production Algorithms for Semiconductor Test Facility", ***IEEE Transactions on Semiconductor Manufacturing***, Vol. 4, (1991), 270-280.
21. Hurink, J. and Knust, S., "List Scheduling in a Parallel Machine Environment with Precedence Constraints and Setup Times", ***Operations Research Letters***, Vol. 29, (2001), 231-239.
22. Huo, Y., Leung, J. Y. T. and Zhao, H., "Bi-Criteria Scheduling Problems: Number of Tardy Jobs and Maximum Weighted Tardiness", ***European Journal of Operational Research***, Vol. 177, No. 1, (2007), 116-134.
23. Prakash, D., "Bi-Criteria Scheduling Problems on Parallel Machines", M.Sc. Thesis, Department of Industrial and System Engineering, Virginia Polytechnic Institute and State University, U.S.A., (1997).