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Minimizing total earliness/tardiness penalties for common due date with general job-dependent learning effect

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ABSTRACT

In the literature, Earliness/Tardiness (E/T) problem was known as weighted absolute deviation problem. Both tardiness and earliness are very important performance criteria for scheduling problems. While total tardiness criterion provides adaptation for due date (ignoring results of early performed jobs), it deals with only cost of tardiness. However this phenomenon has been started to change with Just in Time (JIT) production concept. On JIT production, earliness is as important as tardiness. The phenomenon of the learning effect has been extensively studied in many different areas of operational research. However, there have been a few studies in the general context of production scheduling such as flow-shop scheduling. In this paper, we considered the minimization of the total earliness/tardiness penalties from a common due date under general job-dependent learning effects problem on a two-machine flow-shop scheduling environment. Furthermore, an interface at the Microsoft Excel was projected with Decision Support System Approach for Small and Medium Size Enterprises (SME). This interface could be easily used by SMEs, which have similar scheduling problems. This interface can also be improved/transformed for SMEs' different scheduling problems.

İş Bağımlı Öğrenme Etkili Çizelgelemede Ortak Teslim Tarihinden Toplam Erken/Geç Tamamlanma Cezalarının En Küçüklenmesi

Anahtar Kelimeler
Çizelgeleme, Akış Tipi, Erken/Geç Tamamlanma, Öğrenme Etkisi, Tamsayılı Programlama, Arayüz

ÖZET

Erken/Geç (E/G) tamamlanma problemi, önceleri literatürde ağırlıklandırılmış mutlak sapma problemi olarak bilinmekteydi. Hem erken hem de geç tamamlanma zamanı çizelgeleme problemlerinde önemli ölçütlerdir. Toplam gecikme ölçütü teslim tarihlerine uyuma ilişkin göstergeleri sağlarken (erken tamamlanan işlere ilişkin sonuçları göz ardı ederek), sadece geç tamamlanan işlerin cezaları ile ilgilenir. Ancak bu eğilim tam zamanında üretim (TZÜ) konusuna olan artan ilgi ile birlikte değişmeye başlamıştır. TZÜ'de erken tamamlanma geç tamamlanma kadar önemlidir. Öğrenme etkisi kavramı yöneylem araştırmasının birçok farklı alanında çalışılmıştır. Ancak üretim çizelgeleme ile ilgili sınırlı sayıda çalışma vardır. Bu çalışmada iki makine akış tipi çizelgeleme ortamında iş bağımlı öğrenme etkili ortak teslim tarihinden toplam erken/geç tamamlanma cezalarının en küçüklenmesi problemi ele alınmıştır. Ayrıca, KOBİ'ler için Karar Destek Sistemi (KDS) yaklaşımıyla Microsoft Excel®'de bir arayüz tasarlanmıştır. Bu arayüz KOBİ'lerde benzer çizelgeleme problemleri için kolaylıkla kullanılabilir. Bu arayüz ayrıca farklı çizelgeleme problemine sahip KOBİ'ler için geliştirilebilir ve dönüştürülebilir.

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1. Introduction

Today, many industries are widely used in the flow shop production. Therefore, the flow-shop scheduling problem has been carefully considered over. In flow shop scheduling there are m machines and n jobs, such that every job has to be processed on the machines in the fixed order 1…m. In the permutation flow-shop problem, it is also required that each machine processes the set of all jobs in the same order. Most of the flow-shop scheduling problems are known to be NP-hard [1-2].

In many realistic scheduling setting, the production facility (a machine, a worker) improves continuously with time. As a result, the processing time of a given job is shorter if it is scheduled later, rather than earlier in the sequence. This phenomenon is known as the "learning effect" in the literature [3]. The impact of learning on productivity in manufacturing was first observed by Wright [4] in the aircraft industry and was subsequently discovered in many industries in both manufacturing and service sectors. However, the effect of learning has not been investigated in the context of scheduling problems until recently.

The learning theory assumes a mass production environment where identical products are processed consecutively. Hence the processing times of the single operations would be identical if not influenced by learning. Mosheiov and Sidney [5] introduced a more general form of position-based learning effects [3]:

$P_{[j]}=P_{[1]}*j^{ai}$ (it is processing time of the job i which is scheduled on j^{th} position)

$P_{[j]}$: the required processing time for the j^{th} unit

$P_{[1]}$: the required processing time for the first unit

a_i: job-dependent learning index $a_i=\log(LR_i)/\log(2)$]
LR_i: learning rate for jobs [$LR_i=2^{ai}$] (The lower the learning rate the higher the effects from learning.)

Biskup [6] was the first to investigate the learning effect in a scheduling setting. Biskup [6] studied single-machine problems and considered the objective of (i) minimizing completion time, and (ii) minimizing the weighted sum of completion time deviations from a common due date and the sum of job completion times.

Mosheiov and Sidney [5] showed that some scheduling problems such as the makespan, total completion time and due date assignment can all be solved in $O(n^3)$ time by formulating them as assignment problems. They furthermore considered unrelated parallel machines flow-time minimization problem, for a given number of machines m, the problem can be solved by solving as many assignment problems as allocations of jobs to machines exist, see also Mosheiov [7].

Mosheiov and Sidney [8] considered the single machine problem of minimizing the number of tardy jobs (U_i) when a common due date for all jobs is available. They were able to formulate this problem as a different version of the classical assignment problem with a total running time of $O(n^3 \log n)$. Lin [9] recently confirmed that single machine problem of minimizing the number of tardy jobs (U_i) under common learning effect and the same problem under job dependent learning effect are NP-hard in the strong sense.

Eren and Güner [10] analyzed a scheduling problem under job-dependent learning effect in a two-machine flow-shop to minimize makespan. They showed that Johnson algorithm can not guarantee the best results in the situation with job-dependent learning effect. They also proposed a mixed integer programming model for this problem. Eren and Güner [11] also considered the bi-criterion two-machine flow-shop problem with a learning effect to minimize a weighted sum of total completion time and makespan. They formulated an integer programming model, a heuristic algorithm and a tabu search based heuristic algorithm.

The just-in-time (JIT) philosophy involves producing goods only when necessary. Owing to the wide adoption of JIT scheduling environment, scheduling problems for meeting the due date requirements have been investigated extensively, including those with general earliness/tardiness penalties about a common due date. For such problems, the due date and the penalties are negotiated in advance when a customer purchases a bundle of goods. Many practical and industrial applications have such requirements. Another application can be found in manufacturing systems where all parts must be ready by a pre-determined date for final assembly and with pre-determined penalty functions. Meeting due dates is a common objective for many manufacturing processes. Tardy jobs may generate contractual penalties and loss of credibility, causing damages to the company's image and loss of clients. Early jobs were discouraged since the advent of just-in-time approaches due to the costs generated by those jobs, such as tied-up capital and inventory costs. Therefore, an ideal schedule is one in which all jobs finish exactly on their assigned due date [12-13].

Baker and Scudder [14] presented the first survey on earliness/tardiness scheduling problems. It is well known that the earliness tardiness problem is NP-complete [15-16]. In the ET literature, the types of penalty cost functions used in the objective function such as linear, nonlinear, uniform penalties, and penalty differences among jobs. Penalty differences between earliness and tardiness are important assumption. They can be classified on four basic forms as job dependent, unequal, equal and penalty cost with job dependent proportional weight. In determining penalty functions, different penalty functions are more appropriate in that earliness and tardiness may be undesirable at the same proportion [17].

Sakuraba et al. [18] studied the minimization of the mean absolute deviation from a common due date in a two-machine flow-shop scheduling problem and they developed mathematical model to solve the problem. They also developed heuristic methods with sequencing rules. The results of those heuristics were compared by Sarper [19], using problems with up to 500 jobs.

This paper analyzes the minimization of the total earliness/tardiness penalties from a common due date under learning effects on a two-machine flow-shop scheduling environment. Some of the related to E/T problem with learning effect in the literature: Biskup [6]; Mosheiov [20]; Mosheiov and Sidney [5]; Biskup and Simons [21]; Kuo and Yang [22]; Toksari and Güner [23,24]; Isler et al. [25,26]. Nowadays, computer and computer-aided information systems has gained importance. Decision Support Systems (DSS) are a specific class of computerized information system that supports business and organizational decision-making activities. A properly designed DSS is an interactive software-based system intended to help decision makers compile useful information from raw data, documents, personal knowledge, and/or business models to identify and solve problems and make decisions [27].

Studies in the literature for the solution of scheduling problems of SMEs are set up mathematical models and these models are solved with the help of computer software. In this study, an interface at the Microsoft Excel was projected with Decision Support System Approach for SMEs. This interface could be used easily SMEs which have similar scheduling problems. This interface has also a characteristic that can be developed/transformed for SMEs' different scheduling problems.

The rest of the study is organized as follows. In Section 2, the problem and the proposed integer programming model are described. The interface is presented in the Section 3. The experimental results are given in the Section 4. Finally, conclusions and evaluations of the study and suggests some directions for future researches are provided.

2. Problem Description

The problem is the minimization of the total earliness/tardiness penalties from a common due date under learning effects on a two-machine flow-shop scheduling environment. The normal processing times for job i on machine k are denoted as P_{ik} (i=1,…,n; k=1,2). Furthermore, we assume that both machines have the same learning effect. The processing time of a given job is shorter if it is scheduled later, rather than earlier in the sequence. If the job i on machine k scheduled in position *j* in a sequence, then its actual processing time is defined as $P_{ijk}=P_{ik}*j^{ai}$ [3,5]. The objective is the minimization of the total earliness/tardiness penalties from a common due date. The problem is denoted $n/2/P_{ij}=P_i*j^{ai},d_i=d/\sum(\alpha_i E_j+\beta_i T_j)$.

Assumptions for this problem are:

-Setup time is known, and it is included in the processing time,

-Machine preemption is not allowed, each operation, once started, must be completed before another operation starts on the same machine,

-Machines are stable and available throughout the scheduling period,

-A machine can process one job at a time.

The parameters and variables in the model are described below and then the proposed model is given.

Parameters

n: Number of sequencing jobs

d: Common due date ($d=[\sum_{i=1}^{n}(P_{i1}+P_{i2})]*h$, i=1,2,…n; h: Restrictive factor for due date.)

P_{ik}: The normal processing times for job i on machine k

α_i: Job-dependent earliness penalty

β_i: Job-dependent tardiness penalty

LR_i: Job-dependent learning rate (for example; LR=0.8 for %80 learning curve)

a_i: Job-dependent learning index [$a_i=\log(LR_i)/\log(2)$]

Variables

x_{ij}: If job i is assigned to position j, x_{ij} is 1 else x_{ij} is 0

C_{j1}: Completion time of a job in position j on the first machine

C_{j2}: Completion time of a job in position j on the second machine

E_j: Earliness of a job in position j

T_j: Tardiness of a job in position j

I_{jk}: Idle time of between position j and j+1 on machine k

$W_{j,2}$: Waiting time of a job in position j between two machines

Model

Objective Function:

$$\min\sum_{j=1}^{n}\sum_{i=1}^{n}x_{i,j}(\alpha_i E_j+\beta_i T_j) \quad \textbf{(1)}$$

Constraints:

$$C_{j,2}=d-E_j+T_j \quad j=1, 2, \ldots, n \quad \textbf{(2)}$$

$$C_{1,1}=\sum_{i=1}^{n}(P_{i,1}*x_{i,j})+I_{1,1} \text{ and } C_{1,2}=C_{1,1}+\sum_{i=1}^{n}(P_{i,2}*x_{i,j})+I_{1,2} \quad j=1,2,\ldots,n \quad \textbf{(3)}$$

$$C_{j,1}=C_{j-1,1}+I_{j,1}+\sum_{i=1}^{n}(P_{i,1}*x_{i,j}*j^{a_i}) \quad j=1,2,\ldots,n \quad \textbf{(4)}$$

$$C_{j,2}=\max\{C_{j-1,2},C_{j,1}\}+I_{j,2}+\sum_{i=1}^{n}(P_{i,2}*x_{i,j}*j^{a_i}) \quad j=1,2,\ldots,n \quad \textbf{(5)}$$

$$I_{j,1}+\sum_{i=1}^{n}[P_{i,1}*x_{i,j+1}*(j+1)^{a_i}]+W_{j+1,2}=W_{j,2}+\sum_{i=1}^{n}(P_{i,2}*x_{i,j}*j^{a_i})+I_{j,2} \quad j=1,2,\ldots,n \quad \textbf{(6)}$$

$$\sum_{i=1}^{n}x_{i,j}=1 \quad j=1,2,\ldots,n \quad \textbf{(7)}$$

$$\sum_{j=1}^{n} x_{i,j} = 1 \qquad j=1,2,\ldots,n \qquad \textbf{(8)}$$

$$I_{j,k} \geq 0 \qquad j=1, 2, \ldots, n;\ k=1, 2$$

$$W_{j,2} \geq 0 \qquad j=1,2,\ldots,n$$

$$E_j, T_j \geq 0 \qquad j=1,2,\ldots,n$$

$$x_{ij} \in \{0,1\} \qquad i=1, 2, \ldots, n;\ j=1, 2, \ldots, n$$

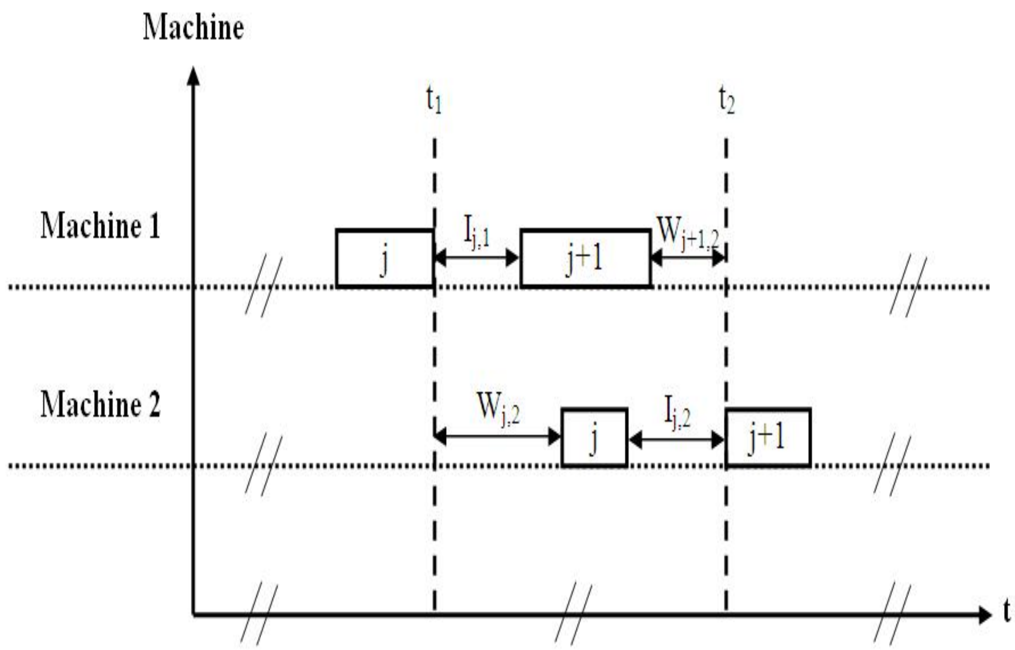

Figure 1. Graphic representation of the set of constraints (6) [18, 25-26].

The objective function (1) declares the minimization of the total earliness/tardiness penalties from a common due date. The constraint set (2) calculates earliness and tardiness. The constraint set (3) calculates the completion times of the job on the first position on the first and second machine; this constraint set is especially needed restricted version of problems. Constraint set (4) calculates the completion times of the jobs on the first machine.

Constraint set (5) calculates the completion times of the jobs on the second machine. Constraints of form (6) relate variables to physical constraints of the problem that may be better understood in Figure 1. This figure shows the relationship among idle and waiting times, which are represented by the difference between time t_1 (completion time of the j th job on machine 1) and t_2 (start time of the job in position j+1 on machine 2). Constraints of form (7) and (8) indicate that each position is occupied by only one job and each job occupies only one position, respectively. Other constraints are of non-negativity or define variables x_{ij} as binaries [18,25-26].

3. Interface

Projected in Microsoft Excel interface (on the Figure 2) to enter data and see the result for user is an environment which was created with the DSS approach. This interface includes the “Data, Models and Explanations” worksheets. The “Data” page is used as the main page for interface. The “Model” page contains mathematical models to the LINGO package program the code necessary to transfer [28-29]. This interface is projected to use easily different colors for different data. In this interface what kinds of colors for how to fill what types of data and how the interface will be introduced into service has been stated on the “Explanations” page. Required data for this interface are entered and the “SCHEDULING” button is pressed, with the related macro the LINGO package program automatically runs, solution of the problem is found using codes on the “Model” page and dataset on the “Data” page. Finally, which job will be done on which sequence on the “SEQUENCE” column, and global cost of this schedule on the “OBJECTIVE FUNCTION VALUE” can be seen [28-29]. Belonging to this interface, you can find more extensive information from Isler’s Doctor of Philosophy (PhD) Science Thesis [30].

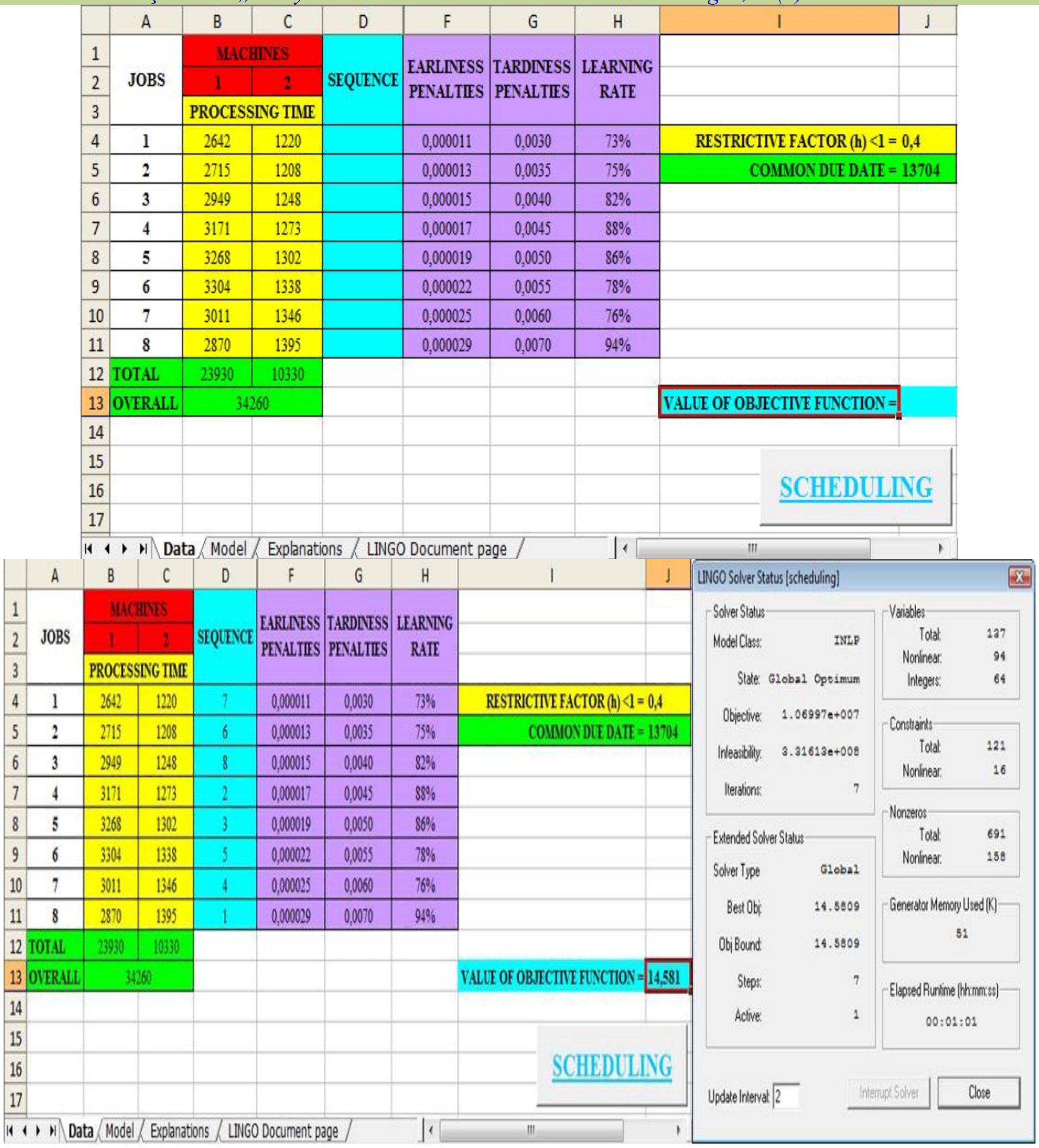

Figure 2. Interface

4. Sample application

Dataset from Isler et al. [26]'s study (on the Table 1) was used for sample application. In addition to this dataset, data of jobs' learning rate was determined and used for job-dependent learning effect.

Table 1. Jobs' processing times, earliness/tardiness penalties and learning rates for sample application

i	JOBS	P_{i1}	P_{i2}	α_i	β_i	LR_i (%)
1	PLUS A2	2642	1220	0,000011	0,0030	73
2	PLUS A3	2715	1208	0,000013	0,0035	75
3	PLUS A4	2949	1248	0,000015	0,0040	82
4	PLUS A5	3171	1273	0,000017	0,0045	88
5	PLUS A6	3268	1302	0,000019	0,0050	86
6	PLUS A7	3304	1338	0,000022	0,0055	78
7	PLUS A8	3011	1346	0,000025	0,0060	76
8	PLUS A9	2870	1395	0,000029	0,0070	94

Sequence of the integer programming model of considered problem was compared with sequence of the alternative methods that was described on Table 2 and random sequence as suitable way for literature. Results on the Table 3 was gotten using restrictive factor h=0.8, h=0.6, h=0.4, h=0.2 and h=0.1. Visual Basic 6.0 is used to determine E/T penalties of alternative sequences. Furthermore, the integer programming model is used to find the optimal solutions of the considered problem using Extended LINGO Relaese 8.0 software package. LINGO is widely used to solve for many problems in literature [23-26]. Sequences of Johnson's rule and LPT2 were same for considered problem because process times of second machine were less than process times of first machine. Table 3 shows that the mathematical modeling gives as expected the best results for the all values of restrictive factors (h). Johnson's rule [30] and LPT2 give considerably better results than other alternative methods and especially they are quite effective for h≤0.4.

Table 2. Alternative sequence methods and their descriptions

Rule	Description
LPT_1	LPT (longest processing time) using processing times on the first machine.
LPT_2	LPT using processing times on the second machine.
LPT_T	LPT using the sum of processing times on both machines.
SPT_1	SPT (shortest processing time) using processing times on the first machine.
SPT_2	SPT using processing times on the second machine.
SPT_T	SPT using the sum of processing times on both machines.
Johnson's Rule	Using Johnson's rule [31].

Table 3. Results of sample application

Method	h	Sequence	Penalty (Objective function value)
Mathematical Model	**0.8**	**1-4-3-5-8-2-6-7**	**0.350137**
SPT_T		1-2-3-8-7-4-5-6	2.372442
LPT_T		6-5-4-7-8-3-2-1	2.406019
SPT_1		1-2-8-3-7-4-5-6	2.405303
LPT_1		6-5-4-7-3-8-2-1	2.387774
SPT_2		2-1-3-4-5-6-7-8	2.280776
Johnson's Rule-LPT_2		8-7-6-5-4-3-1-2	2.643063
Random		1-2-3-4-5-6-7-8	2.273155
Mathematical Model	**0.6**	**1-4-3-5-8-2-6-7**	**0.350137**
SPT_T		1-2-3-8-7-4-5-6	1.337790
LPT_T		6-5-4-7-8-3-2-1	1.371367
SPT_1		1-2-8-3-7-4-5-6	1.370651
LPT_1		6-5-4-7-3-8-2-1	1.353122
SPT_2		2-1-3-4-5-6-7-8	1.246124
Johnson's Rule-LPT_2		8-7-6-5-4-3-1-2	1.608410
Random		3-1-7-4-2-6-8-5	1.374301
Mathematical Model	**0.4**	**8-4-5-7-6-2-1-3**	**14.580860**
SPT_T		1-2-3-8-7-4-5-6	36.423078
LPT_T		6-5-4-7-8-3-2-1	28.164663
SPT_1		1-2-8-3-7-4-5-6	34.884888
LPT_1		6-5-4-7-3-8-2-1	37.151916
SPT_2		2-1-3-4-5-6-7-8	43.311793
Johnson's Rule-LPT_2		8-7-6-5-4-3-1-2	20.368388
Random		4-7-8-5-2-1-6-3	22.773053
Mathematical Model	**0.2**	**8-7-6-5-4-3-2-1**	**139.438900**
SPT_T		1-2-3-8-7-4-5-6	197.552374
LPT_T		6-5-4-7-8-3-2-1	189.891212
SPT_1		1-2-8-3-7-4-5-6	190.384374
LPT_1		6-5-4-7-3-8-2-1	193.441212
SPT_2		2-1-3-4-5-6-7-8	216.498075
Johnson's Rule-LPT_2		8-7-6-5-4-3-1-2	147.385298
Random		7-5-2-3-4-6-8-1	192.162124
Mathematical Model	**0.1**	**8-7-6-2-1-5-3-4**	**249.1772**
SPT_T		1-2-3-8-7-4-5-6	315.9660
LPT_T		6-5-4-7-8-3-2-1	311.4745
SPT_1		1-2-8-3-7-4-5-6	308.8280
LPT_1		6-5-4-7-3-8-2-1	315.0245
SPT_2		2-1-3-4-5-6-7-8	334.1410
Johnson's Rule-LPT_2		8-7-6-5-4-3-1-2	257.0595
Random		8-7-6-5-4-3-2-1	256.9175

5. Conclusions and evaluations

In this paper, we considered the minimization of the total earliness/tardiness penalties from a common due date under general job-dependent learning effects on a two-machine flow-shop scheduling environment. A mathematical model was developed for this problem and sample application was performed for SME at Isler et al. [26]'s study. Mathematical modeling gives as expected the best results for the all values of restrictive factors (h) at this application. Therefore, if jobs are taken to assembly line with sequence of integer programming model, sources of manufacturing are used best way.

Furthermore in this study, an interface at the Microsoft Excel was projected with Decision Support System Approach for SMEs. This interface could be used easily SMEs which have similar scheduling problems. This interface has also a characteristic that can be developed/transformed for SMEs' different scheduling problems.

As a result, practices that will be done to make solutions of SMEs' problems which related to their work easy will combine industrial applications with theoretical literature and will provide significant contributions to the development of SMEs.

References

1. Iyer S.K. and Saxena B., Improved genetic algorithm for the permutation flowshop scheduling problem, Computers&Operations Research, 31, 593-606, 2004.
2. Cheng M.B., Sun S.J. and Yu Y., A note on flow shop scheduling problems with a learning effect on no-idle dominant machines, Applied Mathematics and Computation, 184, 945-949, 2007.
3. Biskup D., A state-of-the-art review on scheduling with learning effects, European Journal of Operational Research, 188, 315-329, 2008.
4. Wright T.P., Factors affecting the cost of airplanes, Journal of The Aeronautical Sciences, 3, 122-128, 1936.
5. Mosheiov G. and Sidney J.B., Scheduling with general job-dependent learning curves, European Journal of Operational Research, 147, 665-670, 2003.
6. Biskup D., Single-machine scheduling with learning considerations, European Journal of Operational Research*,* 115, 173-178, 1999.
7. Mosheiov, G., Parallel machine scheduling with learning effect, Journal of The Operational Research Society, 52, 1165-1169, 2001a.
8. Mosheiov G. and Sidney J.B., Note on scheduling with general learning curves to minimize number of tardy jobs, Journal of The Operational Research Society, *56*, 110-112, 2005.
9. Lin S.W., Chou S.Y. and Ying K.C., A sequential exchange approach for minimizing earliness-tardiness penalties of single-machine scheduling with a common due date, European Journal of Operational Research, 177, 1294-1301, 2007.
10. Eren T. and Güner E., Flowshop scheduling with general job-dependent learning effect, K.H.O. Journal of Defense Sciencesi, (In Turkish), 2, 1-11, 2003.
11. Eren T. and Güner E., A bicriteria flowshop scheduling problem with a learning effect, Applied Mathematical Modelling, 32, 1719-1733, 2008.
12. Baker K.R., Elements of sequencing and scheduling, Dartmounth College, Hanover, 1997.
13. Hino C.S., Ronconi D.P. and Mendes A.B., Minimizing earliness and tardiness penalties in a single-machine problem with a common due date, European Journal of Operational Research, 160, 190-201, 2005.
14. Baker K.R. and Scudder G.D., Sequencing with earliness and tardiness penalties: A review, Operations Research, 38 (1), 22-36, 1990.
15. Hall N.G., Kubiak W. and Sethi S.P., Earliness–tardiness scheduling problem, II: Deviation of completion times about a restrictive common due date, Operations Research 39 (5), 847–856, 1991.
16. Hall N.G. and Posner M.E., Earliness–tardiness scheduling problem, I: Weighted deviation of completion times about a common due date, Operations Research 39 (5), 836–846, 1991.
17. Lauff V. and Werner F., Scheduling with Common Due Date, Earliness and Tardiness Penalties for Multimachine Problems: A Survey, Mathematical and Computer Modelling, 40 (5-6), 637-655, 2004.
18. Sakuraba C.S., Ronconi D.P. and Sourd F., Scheduling in a two-machine flowshop for the minimization of the mean absolute deviation from a common due date, Computers&Operations Research, 36 (1), 60-72, 2009.
19. Sarper H., Minimizing the sum of absolute deviations about a common due date for the two machine flow shop problem, Applied Mathematical Modelling, 19 (3), 153-161, 1995.
20. Mosheiov G., Scheduling problems with a learning effect, European Journal of Operational Research, 132, 687-693, 2001b.
21. Biskup D. and Simons, D., Common due date scheduling with autonomous and induced learning, European Journal of Operational Research, 159, 606–616, 2004.
22. Kuo W.H. and Yang D.L., Single machine scheduling with past-sequence-dependent setup times and learning effects, Information Processing Letters, 102, 22-26, 2007.
23. Toksari M.D. and Güner E., Parallel machine earliness/tardiness scheduling problem under the effects of position based learning and linear/nonlinear deterioration, Computers&Operations Research, 36 (8), 2394-2417, 2008.
24. Toksari M.D. and Güner E., The common due-date early/tardy scheduling problem on a parallel machine under the effects of time-dependent learning and linear and nonlinear deterioration, Expert Systems with Applications, 37, 92-112, 2010.
25. Isler M.C., Celik V. and Toklu B., The minimization of absolute deviation from common due date in two machine Flowshop scheduling with learning effect, (In Turkish), J. Fac. Eng. Arch. Gazi Univ., 24(2), 351-357, 2009.
26. Isler M.C., Toklu B., Celik V. and Ersoz S., Just in time scheduling problem with learning effect and application in a "SME", (In Turkish), Int. J. Eng. Research&Development, 1(2), 29-33, 2009.
27. Power D.J., Decision support systems: concepts and resources for managers, Greenwood Publishing Group Inc., USA, 2002.
28. Lingo User's Guide, Lindo Systems Inc., Chicago, IL, 1999.
29. Sakallı Ü.S. and Birgören B., A linear programming interface for production planning in casting industry, (In Turkish), YAEM2004, 154-156, 2004.
30. İşler M.C., Theoretical and Applied Investigation of Just in Time Flow-shop Scheduling Problem with a Learning Effect in Manufacturing Systems, PhD Science Thesis, Kırıkkale University, 2010.
31. Johnson SM., Optimal two and three stage production schedules with set-up times included, Naval Research Logistics Quarterly, 1(1), 61-68, 1954.