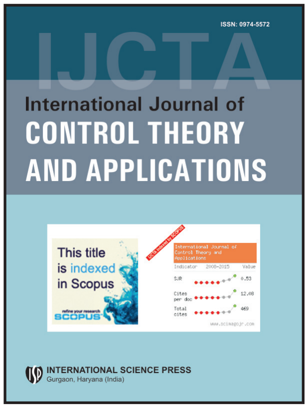

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Integration of Dispatching Algorithm and AHP-TOPSIS Method for Flexible Job-Shop Scheduling Problem: A Case Study from the Apparel Industry

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Abstract: Flexible Job-Shop Scheduling (FJSS) is a relevant decision in numerous industries due to its influence on firm performance and competitiveness. For an appropriate scheduling, FJSS algorithms prioritize operations according to unicriterion rules. Yet, as in different fields, since there are several criteria to be considered in apparel sector, selecting a multicriteria approach has become a difficult decision for scheduling operations in Flexible Job-Shop (FJS) systems. For this purpose, this paper presents a novel method that integrates Dispatching algorithm with Analytic Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). AHP and TOPSIS are combined to provide a closeness coefficient which incorporates different criteria that are critical in FJS systems. An empirical study from apparel industry is presented to prove the validity of the proposed method.

Keywords: Flexible Job-Shop Scheduling, Dispatching Algorithm, Analytic Hierarchy Process (AHP), TOPSIS, Apparel Industry.

1. INTRODUCTION

Colombia is a developing country that is trying to gain competitiveness through the impulse of different sectors, such as furniture, oil, agriculture among others. One of the important sectors that the government is giving aids, is the textile and apparel sector. Keeping in mind that the country has signed many free trade agreements with different countries, it has become attractive to several apparel companies to move their operations to Colombia. Therefore this sector has gained a major relevance for the Colombian economy, considering that it generated more than 153000 jobs in 2012 [1] and it contributes with a 1,2% of national gross domestic product [2].

The emerge of new actors in the sector and the possibility to access to new markets have changed the behavior of the costumers, increasing the demand for more customized goods, short delivery times, and due date compliance [3], [4], [30]. These challenges have forced the companies to implement different strategies to overcome these situations.

In the particular case of the production scheduling, apparel industry usually operates under flexible job shop conditions. In this job shop scenario there are group of machines in each work station. Taking into account that companies need to be more flexible, this kind of shop has gained importance because companies need to produce more customized goods, and this requires smaller batches, and machines capable to performed different operations. Therefore this kind of arrangement can be found more often in the industry [3], [5], [26]. Thus, job shop scheduling is a relevant field of investigation with the objective of minimizing the makespan, tardiness or mean flow time of parts [2]. The fact that a large number of small to medium companies operate at flexible job shops environment gives importance to the search for an efficient method to solve FJSS. Optimizing FJSS helps companies to increase its production efficiency; reduce cost and improve product quality [6].The difficulty of addressing flexible job shop scheduling (FJSS) lies on the fact that it is a well-known and complex Non-Polynomial (NP) hard combinational optimization problem [3],[4]. The decisions to be made in a FJSS include the selection among optional machines on which to perform an operation or the selection among flexible process plan of a part-type [6].

Due to the complexity of FJSS, different solution techniques such as various meta-heuristics approaches, and heuristic approaches have been developed [3] in order to optimize objectives like makespan, tardiness, tardy jobs, among others. Some classical optimization techniques like branch and bound, dynamic programming, and integer programming, can provide optimal or near optimal solutions[7]. The problem is difficult to solve for these classical techniques even for small size versions of the FJSS. In recent years, different metheuristics have been developed and applied extensively, in order to tackle the FJSS. For example ant colony algorithms [8]–[10], tabu search method [11]–[13], neural network algorithms [14]–[17], and simulated annealing method [18]–[20]. Genetic algorithms have proven to be most effective of these metaheuriscts in finding good quality solution with good computing times [7], [16], [21], [22], [25]. In order to upgrade the performance of these metaheuristics, researchers have recently work on hybrid version of them in order to improve their performance related with the quality of the solution and the computing time [23].

In addition, we could not find any study in which a dispatching rule and a multicriteria decision methodology are combined in order to generate an appropriate schedule. As it was mentioned before heuristcs and dispatching rules are valid ways in order to find fast and good solutions for the FJSS. In this sense the dispatching rule described by Calleja and Pastor [24] tackles the problem considering different criteria in a cardinal way, i.e. it prioritizes the jobs in the feasible set of available jobs for each machine according to a rule, if there is a tie continues to a second rule and so on until it ends the process and finds the final schedule for all machines. But this way to find an improved schedule does not consider all the criteria or rules as a whole in one index. And it also does not consider also how the indicators of each job in each of those criteria, deviates from the target value.

TOPSIS is a multi-criteria decision analysis method, that is based on the concept that the chosen alternative should have the shortest geometric distance from the positive ideal solution and the longest geometric distance from the negative ideal solution[27]. All the aforementioned characteristics of TOPSIS make it useful to rank different criteria, and scores like the ones handled in the dispatching algorithm. TOPSIS makes possible to consider at the same time criteria as throughput, tardiness, among others and the particular values obtained in those criteria, with the inclusion of a particular job in sequence. This helps managers to make better decisions related to the schedule, taking into account that in the process all the scores and criteria are considered simultaneously.

In the approach proposed in this paper, the schedule prioritization rule is generated by the incorporation of AHP-TOPSIS in the dispatching algorithm.

2. MATHEMATICAL MODEL

A. Dispatching Algorithm

1. Problem Description

The Flexible Job-shop Problem can be formulated as follows: Let $J = \{J_1, J_2, \ldots, J_n\}$ be a set of n jobs, which can be performed by m machines $M = \{M_1, M_2, \ldots, M_m\}$. Each job $J_i (1 \leq i \leq n)$ has a specific sequence of n_i operations P_{ij} ($j = 1, 2, \ldots, n_i$). Each operation P_{ij} has to be performed on a machine selected from a given set of available machines. The assignment of the operation P_{ij} to the machine $M_k (1 \leq k \leq m)$ involves the occupation of the last machine at a time set as t_{ijk}. R_{ki} has been defined as availability time of operation (j, i). In addition, fp_k has been denoted as the earlier time to start a new operation on the machine k (if no queue, infinite value is assigned). In this paper, the objective is to minimize average tardiness of jobs and obtain the lowest tardiness scores but considering throughput, monthly demand, client type and quantity variables simultaneously. Moreover, some assumptions are considered:

- Each machine can perform one operation at a time.
- Setup times and transfer batches are considered.
- There are not preemptions.
- Priorities are assigned to the jobs according to the closeness coefficient calculated by AHP -TOPSIS
- All jobs are released at time 0 and all machines are available at this time.
- Breakdowns are not considered.

2. Steps of Dispatching Algorithm

- **Start:** The initial operations of the jobs must be placed in the subset of ELEGIBLE OPERATIONS E_i with their respective $r_{1,\, i}$ values. Then, for each machine k, estimate fp_k value. Finally, calculate $fp_{\min}$ and indicate its respective machine
- **Machine Selection:** If $fp_{\min} = \infty$, all operations have been scheduled. Otherwise, choose a machine according to $fp_{\min}$. If there is a set of machines with $fp_{\min}$, choose the operation with the highest closeness coefficient by using AHP-TOPSIS [28]
- **Operation Selection:** If there is only one elegible operation, this must be scheduled. Otherwise, use the closeness coefficient for operation selection.
- **Update:** Schedule the selected operation (j, i) setting its initial and final time (refer to Eq. 1-2)

$$t_{\text{start}}(j, t) = rp_{j,\, i,\, k} \tag{1}$$

$$t_{\text{final}}(j, i) = t_{\text{start}}(j, i) = \mathrm{D}p_{j,\, i,\, k} \tag{2}$$

Where D represents the number of ordered units and $p_{j,\, i,\, k}$ is the unit processing time of operation j of the job i in the machine k. Place the eligible operation in the subset of schedule operations with its start and final times. If it is not the final operation of job i, move its next operation from N_i (Unavailable operations) to E_j subset.

3. Transfer batch

Considering k' as the machine associated to the next operation of job i, Q is the transfer batch size and t_q is the time to move a transfer lot size Q, release date $r_{j+1,i}$ can be calculated as described in Table 1:

Table 1
Release dates with transfer batches

Relation between k and k′	*Relation between $p_{(j,i,k)}$ and $p_{(j+1,i,k)}$*	$r_{(j+1,i,k)}$
$k = k'$	All possible relations between $p_{j,i,k}$ and $p_{j+1,i,k}$	$t_{final(j,i)}$
$k \neq k'$	$p_{(j+1,i,k')} \geq p_{(j,i,k)}$	$t_{start(j,i)} + (t_q + Q_{p(j,i,k)})/60$
	$p_{(j+1,i,k')} < p_{(j,i,k)}$	$t_{final(j,i)} - Dp_{(j,i,k)} + (t_q + Q_{p(j,i,k)})/60$

Update f_k values of the machine k'. If the machine k' has not already used $f_k = 0$. If any operation in machine k has been scheduled, then, $f_k = t_{final}\,(j, i)$ i.e., the machine j will have an availability time f_k that is equal to final time of the last programmed operation in the machine k. Then, calculate $rp_{j,i,k}$ by using Eq. 3:

$$rp_{j,i,k} = \text{máx}(r_{j,i}, f_k) \tag{3}$$

Calculate $fp+_{min}$ by applying Eq. 4:

$$fp_{min} = \min(rp_{j+1,i}) \tag{4}$$

3. A CASE STUDY FROM APPAREL INDUSTRY

The proposed method was validated in a production system of a company from Apparel Industry. This manufactures three product families (Bedspreads, Ponchos and Muleras) that represent a variety of 13 products. Its layout can be observed in Figure 1. Each product has a different sequence of steps. In some of the 6 subprocesses, operations can be processed by any resource from the given set. In addition, different performance ratios can be found for a specific operation (refer to Table 1). This is due to differences in technology and the age of machines.

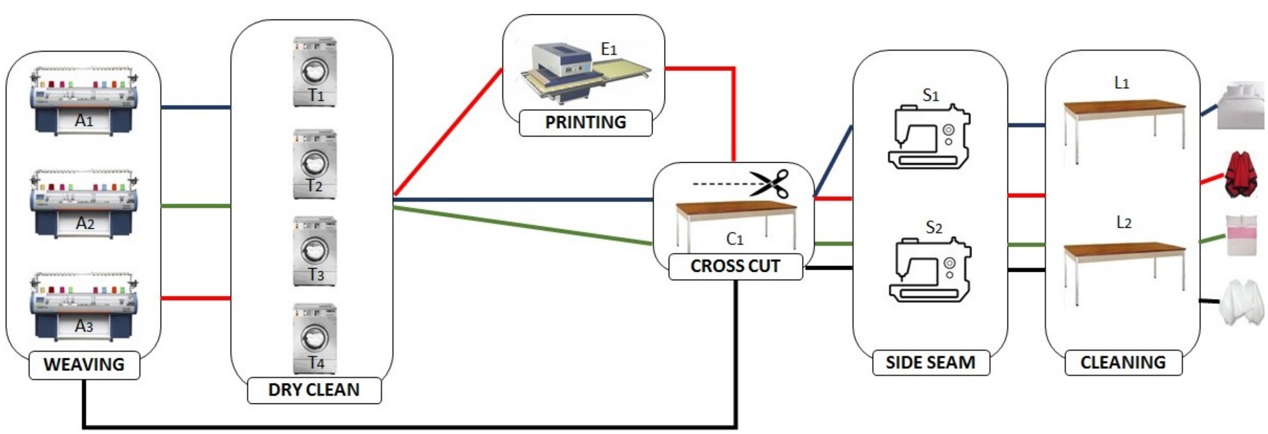

Figure 1: Layout of the textile-confection plant

According to the aforementioned description, this production line can be categorized as a Flexible Job-Shop system. The processing times of each product are described in Table 2. In this, the black cells indicate that the work station is not part of the specified processing order of the product. The throughput and monthly demand variables are illustrated in Table 3. The jobs of each product type are also enlisted in Table 3. The delivery dates are indicated in brackets (day – month). The primary aim of this technique is to provide a scheduling with the minimum average tardiness without discarding throughput, demand, customer type and quantity variables

Table 2
Processing times in each sub-process (min)

Product	*Weaving*			*Dyeing*				*Printing*	*Cutting*	*Whipstitching*		*Cleaning*	
Resource	*A1*	*A2*	*A3*	*T1*	*T2*	*T3*	*T4*	*E1*	*C1*	*S1*	*S2*	*L1*	*L2*
Single Bedspread	2,74	3,5	3,4	0,56	0,61	0,9	0,6		0,49	1	1	0,43	0,43
Single fringe Bedspread			2,75	0,67	0,73	1,08	0,72		0,49	1	1	0,43	0,43
Stamped Single Bedspread	2,74	3,5	3,4	0,56	0,61	0,9	0,6	0,94	0,49	1	1	0,43	0,43
Double Bedspread	4,23		3,84	1,1	1,19	1,77	1,18		0,49	1,33	1,33	0,54	0,54
Double fringe Bedspread			6,57	0,84	0,92	1,35	0,89		0,49	1,33	1,33	0,54	0,54
Stamped Double Bedspread	4,23		3,84	1,1	1,19	1,77	1,18	1,5	0,49	1,33	1,33	0,54	0,54
Special Single Bedspread			3,6	0,55	0,61	0,89	0,59		0,51	0,5	0,5	0,43	0,43
Special Single fringe Bedspread			2,7	0,67	0,73	1,07	0,71		0,51	0,5	0,5	0,43	0,43
Special Double Bedspread			5,4	0,67	0,73	1,07	0,71		0,51	0,5	0,5	0,43	0,43
Special Double fringe Bedspread			4,34	0,67	0,73	1,07	0,71		0,51	0,5	0,5	0,43	0,43
Poncho	0,74		0,86						0,12	0,87	0,87	1,4	1,4
Yellow Poncho		0,76	0,86						0,12	0,87	0,87	1,4	1,4
Mulera	4,28		4,98						0,04	0,87	0,87	4,37	4,37

Table 3
Throughput, monthly demand and registered orders of each product

Product	*Throughput ($/min)*	*Monthly demand (und/month)*	*Jobs*		
			Job 1	*Job 2*	*Job 3*
Single Bedspread (1)	$3458	3565	73 (26 – 07)	90 (19 – 07)	49 (12 – 07)
Single fringe Bedspread (2)	$3458	2156	36 (26 – 07)	18 (19 – 07)	
Stamped Single Bedspread (3)	$4611	1203	12 (26 – 07)	74 (19 – 07)	126 (12 – 07)
Double Bedspread (4)	$3358	510	78 (26 – 07)	24 (19 – 07)	
Double fringe Bedspread (5)	$2162	813	21 (26 – 07)	12 (19 – 07)	
Stamped Double Bedspread (6)	$4478	187	36 (26 – 07)	72 (12 – 07)	
Special Single Bedspread (7)	$3527	2042	2 (26 – 07)	25 (12 – 07)	156 (05 – 07)
Special Single fringe Bedspread (8)	$3527	305	16 (26 – 07)	82 (15 – 07)	
Special Double Bedspread (9)	$2650	2042	24 (26 – 07)		
Special Double fringe Bedspread (10)	$2130	309	21 (26 – 07)		
Poncho (11)	$3622	2512	3176 (30 – 06)	2551 (23 – 06)	
Yellow Poncho (12)	$4396	2512	1001 (27 – 07)	851 (24 – 07)	
Mulera (13)	$1511	2650	3451 (28 – 07)	3451 (12 – 07)	

To prioritize operations, an AHP-TOPSIS model was designed (refer to Figure 2). In this case, five criteria were established by the decision-makers from the company: ORDER DELAY, PRODUCT THROUGHPUT, MONTHLY DEMAND, ORDER QUANTITY and CUSTOMER TYPE. “ORDER DELAY” criterion represents the delay time of undelivered jobs which is a critical to satisfaction for customers. “PRODUCT THROUGHPUT” describes the maximum amount of a product that the company can produce and deliver to clients in a specific period of time. This is based on the production rate of bottleneck resource in the manufacturing system. “MONTHLY DEMAND” factor indicates how important is each product in the market. “ORDER QUANTITY” criterion is defined as the number of units that are demanded by clients in each order. Finally, “CUSTOMER TYPE” categorizes clients according to their purchase history.

AHP comparisons were processed using Superdecisions® software. The criteria weights are shown in Figure 2. These are used as the input data for TOPSIS. To apply this MCDM technique, a performance indicator was also established for each factor (refer to Figure 2). For instance, *customer classification* was set to define CUSTOMER TYPE. In this case, three types of clients have been identified: "1" (Clients who have paid their invoices on a 30-day schedule), "2" (Clients whose payment schedules are extended from 30 days to 60 days) and "3" (Clients who have paid their invoices on a period longer than 60 days). The main output of TOPSIS method is the closeness coefficient. The operation whose coefficient is closer to 1, has the highest priority.

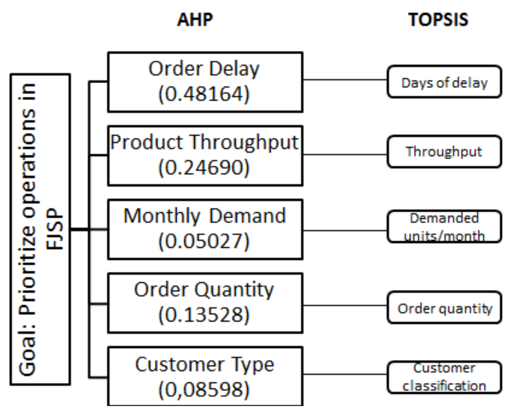

Figure 2: Hierarchy to prioritize operations in the Flexible Job-Shop System of this company

Table 4 illustrates the first seven scheduled operations by using the combination of Dispatching algorithm and AHP- TOPSIS method. According to the proposed approach, the first operation that must be programmed is O_{133} which corresponds to WEAVING, Job 3 and Special Single Bedspread. This operation got the highest closeness coefficient (0.8814). This table also shows the selected resources for each operation. For this case study, 27 jobs were considered (refer to Table 2) with Q = 40 units. The results demonstrated that average tardiness (AT) could be improved (5.46 days) compared to both Pareto-based grouping discrete harmony search algorithm (PGHDS) [28] and the integrated HHS/LNS approach [29] whose AT were 5.55 days and 5.52 days respectively.

Table 4
First seven operations scheduled by the proposed approach

Product	*Operation*	*Closeness Coefficient*	*Order Number*	*Candidate resources*	*Selected resource*	t_q *(h)*	*t – start (h)*	*t – end (h)*
Special Single Bedspread	Weaving	0,8814	3	A3	A3	0	0	9,36
Poncho	Weaving	0,7110	1	A1	A1	0	0	39,17
Stamped Single Bedspread	Weaving	0,3377	3	A2	A2	0	0	8,06
Single Bedspread	Weaving	0,3184	3	A2	A2	0	8,06	10,91
Stamped Single Bedspread	Dyeing	0,3377	3	T1	T1	0	9,30	10,47
Poncho	Weaving	0,6422	2	A3	A3	10	9,36	55,92
Stamped Single Bedspread	Printing	0,3377	3	E1	E1	0	10,01	11,98

4. CONCLUSIONS

Scheduling Flexible Job-Shop Systems under multi-criteria prioritization rules is a very important task to increase the competitiveness and firm performance of numerous industries. However, in literature there are not algorithms that consider different variables simultaneously to prioritize operations. To cover this gap, the present study proposed an integration of Dispatching Algorithm and AHP-TOPSIS. This specific issue is even more important when companies are faced with customer loyalty, process throughput and possible sanctions due to undelivered orders. In the present paper, setup times, transfer batches, job parameters and other assumptions were considered to schedule operations in a company from Apparel Industry. The result is an approach that supports FJSS under multi-criteria environments with basis on combined AHP-TOPSIS technique and its closeness coefficient. Of course, the proposed method is scalable and adaptable in any FJSS. Future studies aim to develop models that takes into account preemptions and breakdowns under multi-criteria prioritization.

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