Logic-Based Evaluation Of Production Scheduling Rules Using Interpolative Boolean Algebra

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Abstract

This paper proposes a logic-based approach based on Interpolative Boolean Algebra (IBA) for multi-criteria evaluation of different priority and dispatching rules for production scheduling. Scheduling is crucial in optimizing operational activities, enabling efficient resource allocation within specific time constraints. While standard approaches to multi-criteria evaluation often use the weighted sum or weighted product method, they cannot capture logical and statistical relationships from the data. To address these limitations, we propose logical aggregation (LA) based on IBA, ensuring transparency and explainability in data aggregation. This paper evaluates the performance of six well-known priority and dispatching rules on 30 common benchmark instances of the job shop problem based on four scheduling criteria functions as input attributes. Analysis shows that the Critical Ratio rule performs the best, with Earliest Due Date also being a solid recommendation. This is a valuable insight for production managers unable to perform time-consuming simulations when facing tight deadlines.

Keywords: Scheduling, Job shop, Interpolative Boolean algebra, Logical aggregation, Logic-based decision making

1. Introduction

Scheduling in production and services refers to the allocation of resources, whether financial, material, human or other, to handlers, in a specific sequence and according to time constraints [21]. This complex process serves to optimize operational activities as much as possible, considering one or more objectives [19], i.e. minimizing completion time, flowtime, tardiness, work in process, the number of jobs that are late, etc. Scheduling consists of two phases, loading and sequencing. During the loading phase, jobs are assigned to the required resources (i.e. machines), and in the sequencing phase, a precise order of jobs for each machine is specified based on the assignation during the loading phase [7]. The result of this process is a production plan that specifies the start and finish times of each operation for each job and the resources used [2], [6].

Scheduling as an activity has been greatly influenced by rapid development of information and communication technology, especially computational intelligence (CI). Therefore, numerous activities that were an ahead-of-time activities in the past can now be performed in near real time [19]. Although scheduling can be performed to optimize production within multiple production plants manufacturing the same types of products, centralized scheduling, i.e. the process of scheduling within a single location, is still the most popular in the literature [10] and will be a focus point in this paper.

More precisely, this paper addresses the job shop scheduling problem by evaluating priority and dispatching rules using logic-based aggregation methods. Indeed, the most of existing work in this area is focused on the multi-attribute evaluation using traditional methods, such as the weighed sum or the weighed product [7], to evaluate production schedules based on several criteria functions simultaneously. However, these approaches fail to model the fact that different schedules may demonstrate favorable outcomes in some cases, albeit encountering certain limitations. Also, aggregation functions based on weighted sum or product are not able to incorporate logical and statistical relations in data, as well as possible input compensations. Therefore, there is a considerable space for introducing novel aggregation techniques in this context.

The aim of this paper is to employ logical aggregation (LA) based on interpolative Boolean algebra (IBA) to evaluate the performance of six different commonly used priority and dispatching rules [26] for production scheduling. The need for estimating the best rule in the general case is of critical importance in cases when managers need to choose among multiple criteria that are in conflict and when time-consuming optimizations and simulations are not possible. Ranking priority and dispatching rules using the proposed method allows managers to make faster decisions when time is of the essence, since it provides more information about the performance of different rules in relation to different objectives, i.e. criteria functions. IBA represents a framework for dealing with [0,1] values with respect of all Boolean axioms and theorems [23]. Further, LA based on IBA stands out for its explainability and transparency when aggregating data, and therefore seems to be a suitable method for solving this problem. To perform the rule evaluation, a simulation of 30 different instances of the job shop scheduling problem [7], is conducted. After the data analysis, the LA model is defined by a domain expert and further evaluated. Finally, the model is applied and priority and dispatching rules are ranked accordingly.

The rest of the paper is organized as follows. In Section 2, we analyze scheduling and the job-shop problem as well as priority and dispatching rules in detail. Section 3 introduces the essentials of the LA approach and IBA. Further, in Section 4, the problem to be solved is presented. The proposed model based on LA is presented in Section 5, while the experimental results and discussion are given in Section 6. The last section summarizes the main results and gives concluding remarks.

2. Scheduling and the priority and dispatching rules

Scheduling is a challenging task due to a large number of possible solutions, which leads to a combinatorial explosion [2]. For this reason, the use of heuristics to obtain near-optimal solutions is an idea that has been explored in scientific literature since the 1950s [4]. Since then, many different heuristic and metaheuristic approaches, along with constraint programming [8], simulation and CI approaches have been used to solve the scheduling problem and its variants. Some of the most prominent ones include the Johnson rule, simulated annealing, genetic algorithms, tabu search, ant colony optimization, Petri nets, neural networks and fuzzy logic [10].

One of the earliest heuristic approaches to the scheduling problem was the use of priority and dispatching rules to decide which product should be sequenced first when multiple jobs are available and require the same resource [4], often referred to as a conflict in scheduling.

Still relevant due to the complexity of the production environment, ease of understanding, minimal computational power requirements and acceptable performance [7], priority and dispatching rules are still used today when multiple scheduling decisions must be made instantaneously [9], and are particularly useful when new jobs arrive at the company during the execution of an existing schedule [26].

The choice of the priority or dispatching rule used has a major impact on the production goals, leading to improved performance in production [7]. Because of this, starting as early as the 1980's [11] many attempts were made to evaluate their performance based on different optimization functions. In the 1990's, the need for multi-attribute evaluation was recognized [4], which is still emphasized in recent literature [27].

3. Logical aggregation based on interpolative Boolean algebra

Interpolative Boolean algebra (IBA) was introduced as a [0,1]-valued realization of a finite Boolean algebra [23] that preserves all Boolean axioms and theorems. IBA is a two-leveled algebra, consisting of the symbolic and the value level [24].

The structure of a logical expression $\varphi(a_1,\dots,a_n)$ is the main focus on the symbolic level, and attributes $a_1,\dots,a_n$ are considered independently of their values. In order to stay in Boolean frame, logical expression is mapped into generalized Boolean polynomial (GBP) $\varphi^{\otimes}(a_1,\dots,a_n)$ according to the principle of structural functionality and IBA transformation rules:

$$\varphi(a_1,...,a_1) \to \varphi^{\otimes}(a_1,...,a_1) \tag{1}$$

GBP $\varphi^{\otimes}(a_1,\dots,a_n)$ is a polynomial that supports standard +, standard – and generalized product (GP) $\otimes$ as operators. IBA transformation rules to GBP for both complex elements (i.e. logical expression) and primary elements (i.e. attributes) are following [23]:

$$(\varphi \wedge \gamma)^{\otimes} = \varphi^{\otimes} \otimes \gamma^{\otimes} \tag{2}$$

$$(\varphi \vee \gamma)^{\otimes} = \varphi^{\otimes} + \gamma^{\otimes} - (\varphi \wedge \gamma)^{\otimes} \tag{3}$$

$$(\neg\varphi)^{\otimes} = 1 - \varphi^{\otimes} \tag{4}$$

$$(a_i \wedge a_j)^{\otimes} = \begin{cases} a_i \otimes a_j, & i \neq j \\ a_i, & i = j \end{cases}, \tag{5}$$

$$(a_i \vee a_j)^{\otimes} = a_i + a_j - (a_i \wedge a_j)^{\otimes} \tag{6}$$

$$(\neg a_i)^{\otimes} = 1 - a_i \tag{7}$$

Particularly noteworthy is the first IBA transformation rule for attributes (see Eq. 5), which guarantees idempotence in the IBA framework [17], i.e. the conjunction of two identical attributes is in fact that attribute. On the other hand, the conjunction of different attributes is equal to the value of the expression for the selected t-norm. In this way, the structure of the expression is placed before the values.

On the value level, the values of attributes are introduced and the appropriate operator for GP is chosen. Although the generalized product can be any t-norm that gives a value greater than the Łukasiewicz t-norm and less than the minimum [24], there are clear guidelines for using different norms according to attributes nature and/or correlations. If the attributes are of the same nature, describe the same phenomenon, or are strongly positively correlated, the minimum should be used as the GP for their aggregation. For attributes of different nature or uncorrelated variables, the algebraic product should be used as the GP [15]. Łukasiewicz t-norm should be applied for negatively correlated variables.

Logical aggregation, a logic-based aggregation method, stands as the predominantly utilized method grounded in IBA. LA consists of two steps: the data normalization; and the aggregation of the normalized values into one globally representative value [24]. It is a general, transparent procedure that takes into account the logical and statistical relationships of the aggregated attributes [17].

In previous years, LA was primarily used for dealing with multi-attribute decision-making problems, e.g. for aggregating different quality attributes into a single global quality indicator [24]. Further, LA is used in the supplier selection process [14], consensus modeling to assess the degree of agreement between experts on a given topic [22], portfolio selection [25], credit scoring [12], etc.

4. The problem set-up

In this paper, the evaluation of different priority and dispatching rules is performed in regard to the classical job shop problem, which can be described as follows [4, 21, 26]: n jobs have to be processed on m machines; Each job consists of several operations which have known durations, referred to as a deterministic processing time t; Each job is processed on each machine exactly once according to the predefined production sequence; Preemption of the jobs is not allowed; Each machine can process at most one job at a time, and each job can be processed at most by one machine at a time; The objective is to schedule all operations, considering all constraints in a manner that minimizes a certain objective function F.

Although this problem is most commonly observed as the optimization problem solved using heuristics and metaheuristics, in this paper we aim to employ the simulation method along with logic-based decision making to determine the best scheduling rule. More precisely, we employed LA function to evaluate the performance of six different priority and dispatching rules given in Table 1.

Table 1. Explanation of different priority and dispatching rules

Rule	Mark	Explanation
Critical Ratio	CR	Time remaining to due date divided by total operation time remaining
Earliest Due Date	EDD	Operation of a product with an earliest due date is performed first
First Come First Serve	FCFS	Operation of the product that was defined in the system first is performed first
Longest Processing Time	LPT	Operation with the longest processing time is performed first
Shortest Processing Time	SPT	Operation with the shortest processing time is performed first
Minimum Slack	MS	Difference between the latest possible finish time and the earliest possible finish time in relation to the due date

The evaluation is performed on 30 well-known benchmark scheduling problems extended with due dates using a modification of the method proposed by Blackstone et al. [5]. The problems vary in size in terms of number of machines and products, e.g. 10 machines and 10 products; 15 machines and 15 products; 5 machines and 15 products, which covers a majority of the most common benchmark problem setups in literature.

The quality of the schedule is evaluated on the basis of various attributes defined by practitioners and academics. In this paper we chose four different most widespread criteria functions as input attributes: Total completion time of all jobs ($Cmax$), Maximum tardiness ($Tmax$), Number of late jobs (ΣUj) and Total Just-in-Time (ΣJIT). A detailed description of the inputs is given in Table 2.

Table 2. Explanation of the input attributes

Function	Mark	Explanation
C_{max}	c	Completion time of the last operation on the last job being processed, i.e. the completion time of all jobs.
T_{max}	t	Maximum tardiness. Maximum negative difference between the due date and the completion time of a job.
ΣU_j	u	Number of late jobs.
ΣJIT	j	Just-in-Time. The sum of total tardiness (ΣT_j) and total earliness (ΣE_j).

5. Methodology

The proposed IBA-based approach for this problem consists of six steps showcased in Figure 1.

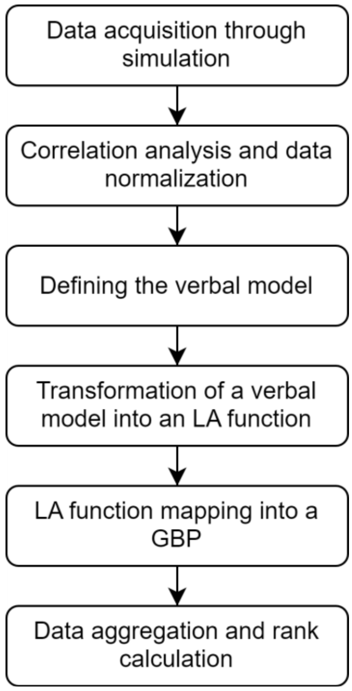

Fig. 1. The process diagram of the methodology steps

In the **data acquisition through simulation** step, 30 different well-known benchmark problems [1, 3, 13] were used and the simulation was performed using the LEKIN scheduling software [20]. The simulation output crystallizes into a dataset, containing values of criteria functions as input attributes, and different priority and dispatching rules for each problem as instances.

In the **correlation analysis and data normalization** step, the obtained values of the criteria functions are tested for correlation to ease the choice for the GP operator in the IBA framework. After the correlation analysis, we applied a standard min-max normalization in order to scale data to [0,1] interval. The values for minimum and maximum are calculated with the respect to the particular problem.

The verbal model is defined based on the expert knowledge regarding real-world situations in production plants. For instance, a production manager might want the machines to be available as soon as possible to meet its production targets while minimizing the maximum penalties for job lateness. However, management might also decide to accept a longer production schedule if it means that fewer jobs are late and the end times of these jobs are close to their due dates, ensuring cost minimization through lower holding costs and lower lateness penalties. More formally, if Total completion time of all jobs is not long, we are interested only in Maximum tardiness. On the other hand, if Total completion time of all jobs is long, it may be compensated with a small Number of late jobs and Total Just-in-Time.

This verbal model is **transformed into a LA function** as:

$$LA = (\neg c \wedge \neg t) \vee (c \wedge \neg u \wedge \neg j) \tag{8}$$

According to the IBA transformation rules [24] along with expression simplification, **LA function is mapped into a GBP**. Considering that in the IBA framework $a^{\otimes} a = a$ according to (Eq. 5), and consequently $a^{\otimes}(1-a) = 0$ (law of excluded middle), the transformation is conducted as follows:

$$LA = (1-c) \otimes (1-t) \vee (c \otimes (1-u) \otimes (1-j)) \tag{9}$$

$$LA = (1-c) \otimes (1-t) + c \otimes (1-u) \otimes (1-j) - (1-c) \otimes (1-t) \otimes c \otimes (1-u) \otimes (1-c) \tag{10}$$

$$LA = 1 - c - t + c \otimes t + c - c \otimes u - c \otimes j + c \otimes u \otimes j \tag{11}$$

$$LA = 1 - t + c \otimes t - c \otimes u - c \otimes j + c \otimes u \otimes j \tag{12}$$

The LA model described above represents the basis for all further evaluation of different priority and dispatching rules, i.e. **the data aggregation and rank calculation**. All statistical analysis is performed using the IBM SPSS software and R programming language, while the IBA expression transformation is conducted using jFuzzyIBATranslator [16].

6. Results and discussion

The next step in this study is correlation analysis of input attributes to justify the choice of operator for GP in LA model. Based on the Kolmogorov-Smirnov test, it is concluded that the values for all criteria functions are not normally distributed ($p<0.001$). For this reason, Spearman's correlation coefficient is used to calculate correlations between the evaluated attributes. The results are shown in Table 3.

Table 3. Correlations between input attributes

Spearman's rho correlation coefficient				
	Cmax	*Tmax*	*ΣUj*	*ΣJIT*
Cmax	1.000	0.059	-0.167*	0.239**
Tmax	0.059	1.000	0.228**	0.685**
ΣUj	-0.167*	0.228**	1.000	0.108
ΣJIT	0.239**	0.685**	0.108	1.000

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Bearing in mind that in the IBA frame correlation coefficient may be interpreted as a similarity of inputs' nature, there is a single strong correlation that suggests a solid relationship between criteria *Tmax* and *ΣJIT*. In all other cases correlations emerge with diminished intensity, occasionally resulting in statistical insignificance. Therefore, the GP operator between all inputs should be standard product, with an exception of input *Tmax* and *ΣJIT* where minimum should be used. Given that, the final form of LA model is following:

$$LA = 1 - t + c \cdot t - c \cdot u - c \cdot j + c \cdot u \cdot j \tag{13}$$

According to the obtained LA model, rankings of all priority and dispatching rules are calculated for each of the 30 job shop problems. The descriptive statistics of rules' rankings are shown in Table 4.

Table 4. Descriptive statistics of priority and dispatching rules rankings

Rule	Mean rank	Std. dev. of ranks	Best rank (min)	Worst rank (max)	percentile 75th	percentile 50th	percentile 25th
CR	3.53	1.634	1	6	2.00	4.00	5.00
EDD	3.13	1.697	1	6	2.00	3.00	5.00
FCFS	3.47	1.432	1	6	2.00	4.00	4.00
LPT	4.77	1.135	2	6	4.00	5.00	6.00
MS	1.97	1.273	1	6	1.00	1.00	3.00
SPT	4.03	1.650	1	6	2.75	4.00	6.00

Based on the descriptive statistics, the MS rule clearly stands out as the best in general case, as it is the only rule that has a mean rank of less than 2. Also, in more than 50% of the observed scheduling problem it is ranked as the best alternative. On the other hand, the LPT rule is the only rule with a mean rank close to 5, and the only rule that hasn't been ranked first in any of the tested instances, making it the worst performing rule. According to Table 3, other observed rules (CR, EDD, FCFS and SPT) have shown similar performance on chosen dataset.

To gain further insight into the performance of these priority and dispatching rules, the frequencies of the rankings based on LA model for all evaluated rules are presented in Table 5.

Table 5. Frequencies of rankings of priority and dispatching rules

CR			EDD		
Rank	Frequency	Percent	Rank	Frequency	Percent
1	4	13.3	1	6	20.0
2	7	23.3	2	7	23.3
3	2	6.7	3	6	20.0
4	5	16.7	4	2	6.7
5	10	33.3	5	6	20,0
6	2	6.7	6	3	10,0
FCFS			LPT		
Rank	Frequency	Percent	Rank	Frequency	Percent
1	3	10.0	1	0	0
2	5	16.7	2	1	3.3
3	6	20.0	3	3	10.0
4	10	33.3	4	8	26.7
5	3	10.0	5	8	26.7
6	3	10.0	6	10	33.3
MS			SPT		
Rank	Frequency	Percent	Rank	Frequency	Percent
1	16	53.3	1	1	3.3
2	4	13.3	2	6	20.0
3	7	23.3	3	6	20.0
4	2	6.7	4	4	13.3
5	0	0.0	5	4	13.3
6	1	3.3	6	9	30.0

To test whether there are statistically significant differences between the rankings of different priority and dispatching rules, the Friedman test is used. This non-parametric test is used to test for differences in ordinal data when it is not possible to use ANOVA, e.g. when the normality assumption is violated. The results of the Friedman test show that there are statistically significant differences in the ranking of the different priority and dispatching rules ($p<0.001$).

A post-hoc analysis to test among which specific priority and dispatching rules the differences in rankings exist is performed via the Nemenyi test [18], the results of which are shown in Table 6.

Table 6. p-values for differences between different priority and dispatching rules

	CR	EDD	FCFS	LPT	MS
EDD	0.947	-	-	-	-
FCFS	1.000	0.974	-	-	-
LPT	0.092	**0.006**	0.064	-	-
MS	**0.007**	0.100	**0.011**	**0.000**	-
SPT	0.987	0.630	0.969	0.362	**0.001**

Some valuable conclusions can be drawn from analysing the frequency distributions of rankings of evaluated priority and dispatching rules. First, the MS dispatching rule appears to be the best, ranking first in 53.3 percent of cases and in the top 3 in 90 percent of cases. Another rule that stands out is the EDD rule, which ranks first in 20 percent of cases and in the top 3 in 63.3 percent of cases. No other rule is in the top 3 in more than 50 percent of cases. The SPT and LPT priority rules, on the other hand, appear to perform the worst, as both are in last place in more than 30 percent of cases. The CR and FCFS rules seem to be somewhat in between, as they are most often ranked in the 2-5 range.

On one hand, the Friedman test has shown that there is a statistically significant difference in the ranking of the evaluated priority and dispatching rules. On the other hand, a post hoc analysis shows that there is a statistically significant difference between the MS rule and all others except the EDD rule. This is somewhat unexpected due to the large difference in mean ranks between the two rules, but makes sense given that these were the two best performing rules based on the frequency distribution. The only other statistically significant difference in ranks occurred between the EDD and LPT rule, with all other relationships being statistically insignificant.

This type of insight can be very valuable to shop floor managers when there is not enough time to perform multiple simulations to determine which rule is best for specific production needs. In such cases, a recommendation can be made for a dispatching or a priority rule that is most likely to lead to a good production schedule. In this instance, a recommendation can be made that the rule to be used should the MS rule, while the solid second choice is the EDD rule.

7. Conclusion

In this paper, six different priority and dispatching rules were evaluated based on 30 classical job shop benchmark problems, with the aim of proposing the best performing rule with respect to the specific multi-attribute objective of the production plant. For this purpose, a logical aggregation approach based on IBA was used, taking into account four different criteria functions commonly used to evaluate the quality of production schedules as input attributes. Based on the assessed ranks of priority and dispatching rules, faster generation of good production schedules is enabled. In this particular case, MS rule prove to be the most efficient one, while EDD rule was the clear second-best choice. The obtained results may facilitate scheduling problem, i.e. only a few priority and dispatching rules should be taken into account when dealing with an unfamiliar real-world scheduling problem.

One of the limitations of this study is the number of scheduling rules that are evaluated, since numerous different approaches in literature and practice that are not taken into account. A second limitation of this study is that all rules were evaluated based on the classic job shop problem representation extended by due dates. However, in manufacturing plants there are often other types of production flows, ranging from the possibility of having multiple machines of the same type. It is an open question whether the same rules would also perform well for these types of production setups. These issues will be examined in further research.

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References

1. Adams, J., Balas, E., Zawack, D.: The shifting bottleneck procedure for job shop scheduling. Manage Sci. 34 (3), 391–401 (1988)
2. Alvarez, E.: Multi-plant production scheduling in SMEs. Robot Comput Integr Manuf. 23 (6), 608–613 (2007)
3. Applegate, D., Cook, W.: A computational study of job-shop scheduling. School of Computer Science, Carnegie Mellon University (1990)
4. Belton, V., Elder, M.D.: Exploring a multicriteria approach to production scheduling. Journal of the Operational Research Society. 47 162–174 (1996)
5. Blackstone, J.H., Phillips, D.T., Hogg, G.L.: A state-of-the-art survey of dispatching rules for manufacturing job shop operations. The International Journal of Production Research. 20 (1), 27–45 (1982)

6. Buxey, G.: Production scheduling: Practice and theory. Eur J Oper Res. 39 (1), 17–31 (1989)
7. Červeňanská, Z., Važan, P., Juhás, M., Juhásová, B.: Multi-criteria optimization in operations scheduling applying selected priority rules. Applied Sciences. 11 (6), 2783 (2021)
8. Da Col, G., Teppan, E.C.: Industrial-size job shop scheduling with constraint programming. Operations Research Perspectives. 9 100249 (2022)
9. Herrmann, J.W.: A history of production scheduling. Handbook of production scheduling. 1–22 (2006)
10. Jiang, Z., Yuan, S., Ma, J., Wang, Q.: The evolution of production scheduling from Industry 3.0 through Industry 4.0. Int J Prod Res. 60 (11), 3534–3554 (2022)
11. Kiran, A.S., Smith, M.L.: Simulation studies in job shop scheduling—II: Performance of priority rules. Comput Ind Eng. 8 (2), 95–105 (1984)
12. Latinovic, M., Dragovic, I., Arsic, V.B., Petrovic, B.: A fuzzy inference system for credit scoring using Boolean consistent fuzzy logic. International Journal of Computational Intelligence Systems. 11 (1), 414–427 (2018)
13. Lawrence, S.: Resouce constrained project scheduling: An experimental investigation of heuristic scheduling techniques (Supplement). Graduate School of Industrial Administration, Carnegie-Mellon University. (1984)
14. Mandic, K., Delibasic, B.: Supplier selection using interpolative Boolean algebra and logic aggregation. In: Information Processing and Management of Uncertainty in Knowledge-Based Systems: 15th International Conference, IPMU 2014, Montpellier, France, July 15-19, 2014, Proceedings, Part II 15. pp. 1–9. Springer (2014)
15. Milošević, P., Petrović, B.: Interpolative Boolean Algebra for Generalizations of Intuitionistic Fuzzy Sets. In: 11th Conference of the European Society for Fuzzy Logic and Technology (EUSFLAT 2019). pp. 676–681. Atlantis Press (2019)
16. Milošević, P., Petrović, B., Radojević, D., Kovačević, D.: A software tool for uncertainty modeling using Interpolative Boolean algebra. Knowl Based Syst. 62 1–10 (2014)
17. Milošević, P., Poledica, A., Rakićević, A., Dobrić, V., Petrović, B., Radojević, D.: IBA-based framework for modeling similarity. International Journal of Computational Intelligence Systems. 11 (1), 206–218 (2018)
18. Nemenyi, P.B.: Distribution-free multiple comparisons. Princeton University (1963)
19. Parente, M., Figueira, G., Amorim, P., Marques, A.: Production scheduling in the context of Industry 4.0: review and trends. Int J Prod Res. 58 (17), 5401–5431 (2020)
20. Pinedo, M.: Planning and scheduling in manufacturing and services. Springer (2005)
21. Pinedo, M.L.: Scheduling. Springer (2012)
22. Poledica, A., Milosevic, P., Dragovic, I., Radojevic, D., Petrovic, B.: A consensus model in group decision making based on interpolative boolean algebra. In: 8th conference of the European Society for Fuzzy Logic and Technology (EUSFLAT-13). pp. 688–694. Atlantis Press (2013)
23. Radojević, D.: (0, 1)-valued logic: a natural generalization of Boolean logic. Yugoslav Journal of Operations Research. 10 (2), 185–216 (2000)
24. Radojevic, D.: Logical aggregation based on interpolative. Mathware & Soft Computing. 15 (1), 125–141 (2008)
25. Rakićević, A., Milošević, P., Poledica, A., Dragović, I., Petrović, B.: Interpolative Boolean approach for fuzzy portfolio selection. Applying fuzzy logic for the digital economy and society. 23–46 (2019)
26. Sels, V., Gheysen, N., Vanhoucke, M.: A comparison of priority rules for the job shop scheduling problem under different flow time-and tardiness-related objective functions. Int J Prod Res. 50 (15), 4255–4270 (2012)
27. Zahmani, M.H., Atmani, B., Bekrar, A., Aissani, N.: Multiple priority dispatching rules for the job shop scheduling problem. In: 2015 3rd International Conference on Control, Engineering & Information Technology (CEIT). pp. 1–6. IEEE (2015)