Systematic Review Bi-Criteria Objective Scheduling in Flexible Flow-Shop Production

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Abstract:- Research on scheduling has been an ongoing endeavor for quite some time, increasingly adapting to advancements in industry practices. One particularly intriguing area of study is the development of bi-criteria objectives in scheduling. This research emphasizes that scheduling considerations should transcend the producer's viewpoint to also encompass customer interests. However, investigations into bi-criteria objectives remain relatively scarce. This study undertakes a systematic literature review focused on scheduling within flexible flow-shop systems. The methodological steps include planning, selection, extraction, and execution of relevant data. Data sources are drawn from Scopus, covering the period from 1986 to 2022, with the support of the Vosviewer tool. The study aims to elucidate past research on bi-criteria objectives in flexible flow-shop systems. From the studies conducted between 2016 and 2022, a notable research gap has been identified—specifically, the potential for applying a Group Scheduling model with bi-criteria objectives that incorporates Sequence Dependent Setup Times (SDST) in the context of non-identical parallel machines, presenting promising avenues for future research.

Keywords:- *Scheduling, Bi-Criteria Objective, Systematic Literature Review.*

I. INTRODUCTION

Scheduling activities involve allocating available resources or machines to perform a set of tasks within a specific timeframe. The primary goal of scheduling is to ensure that consumer demands are met promptly, thereby minimizing delays. [1]. In scheduling, both allocation decisions and sequencing decisions are made. In job sequencing, numerous methods have been developed by previous research, tailored to different types of production flow. Research on flexible flow shop scheduling with multiple criteria has seen significant growth recently [2]. The challenges in flexible flow shop scheduling differ from those in basic group scheduling. Tyagi et al [3], stated Flexible flow shop is a generalization of the classical and basic flow shop, characterized by a parallel processing environment.

In production scheduling, minimizing makespan is often prioritized for efficiency from the company's perspective. However, this focus can lead to delays from the customer's viewpoint, resulting in dissatisfaction [4]. Recently, multi-objective research in scheduling has gained traction [5]. The goal now is to achieve production efficiency while ensuring customer satisfaction through timely delivery. As a result, a multi-objective approach with two main goals is implemented. Scheduling with bi-criteria objectives involves optimizing a linear combination of total weighted completion time and weighted tardiness [6]. The total weighted completion time aims to minimize production costs by reducing time, energy, and labor, while weighted tardiness focuses on minimizing delays to maintain customer satisfaction. However, attempting to minimize both objectives can create conflicts, as a solution cannot always fully satisfy both aims [4].

Research on flexible flow shop scheduling with multiple criteria has recently increased [2]. The challenges encountered in flexible flow shop scheduling differ significantly from those in traditional group scheduling. In practice, flexible flow shops often deal with sequence-dependent setup times (SDST), where tasks such as machine cleaning or changes of materials/tools become critical in the scheduling process. [4] emphasize the importance of considering setup times in flexible flow shops with bi-criteria objectives. Bozogirad et al [7] studied bi-criteria scheduling in hybrid flow shops, while Shahravi and Logendran (2016) developed a bi-criteria scheduling design that assigns weights to each objective function, reflecting the prioritization of specific jobs. Tian et al. [8] applied a Pareto approach to hybrid flow shop scheduling, incorporating sequence-dependent setup times into their model.

Given the growth of research on flexible flow shop scheduling with bi-criteria objectives, this study will review various studies on this topic up to 2021. It is anticipated that this research will serve as a catalyst for future investigations in production scheduling using bi-criteria objectives, further advancing the field.

II. LITERATURE REVIEW

This chapter contains the theoretical foundation or references that are briefly outlined and will later be used as the supporting basis for addressing the problem to be researched.

A. Scheduling

Scheduling activities involve assigning available machines or resources to complete a set of tasks within a specific timeframe. This process includes managing various components, commonly referred to as "jobs." Each job represents a fundamental unit of work, often called an "operation." Every operation requires resource allocation for a specified duration, known as the processing time. These resources can include machines, waiting periods, and transportation, all of which are essential for ensuring that tasks are completed efficiently and on time.

B. Objective Scheduling

Scheduling activities involve allocating available machines or resources to complete a set of tasks within a specific timeframe. This process requires managing various components, commonly referred to as "jobs." Each job represents a fundamental unit of work, often called an "operation." Each operation necessitates resource allocation over a defined period, known as the processing time. Resources can include machines, waiting periods, and transportation, all of which are essential for ensuring that tasks are completed efficiently and within the desired timeframe.

C. Notation in Scheduling

Notation which common in scheduling based on Baker & Trietsch [1] are:

- Processing Time is the time required to complete the operation or process of job iii. This time includes preparation and setup for the process..
- Due Date is the deadline by which job iii must be completed. If the job is completed after this time, it is considered "tardy."
- Completion Time: The duration from the start of the first job (t=0) until the completion of job i.
- Lateness is defined as the difference between the actual completion time of a task and its due date, indicating whether a task finishes earlier or later than planned. When Li=Ci−di<0L_i = C_i - d_i < 0Li=Ci−di<0, the task is completed before its due date, known as an early job. When Li=Ci−di>0L_i = C_i - d_i > 0Li=Ci−di>0, the task surpasses its due date, resulting in a tardy job. Li represents the lateness value, Ci denotes the time when the task is completed and di is the predetermined due date for the task.

D. Flexible Flow-Shop Scheduling

The flexible flow shop consists of multiple machines arranged in series across several stages, where each stage contains a number of identical machines organized in parallel. Each job will pass through Stage 1, then Stage 2, and continue until completion. At each stage, a job will be processed by one of the identical machines [9].

In a flexible flow shop, the production process involves a series of jobs going through several production stages, with all jobs following the same sequence. At least at one of the stages, multiple machines are available. This situation requires making two critical decisions. On one hand, jobs must be assigned to machines at each stage, and on the other hand, the sequence of the jobs assigned to the machines must be organized [10].

This system allows for greater flexibility and efficiency in production, enabling companies to better adapt to varying demands and optimize their manufacturing processes. The inherent design of the flexible flow shop can lead to improved productivity and reduced lead times, ultimately benefiting both the organization and its customers.

E. Bi-Criteria Objective Scheduling

Bi-criteria objectives in production scheduling take into account the benefits not only for the producers but also for the customers, all while striving to find the optimal scheduling solution [11]. Generally, bi-criteria scheduling can be categorized into three classes [12]:

- One criterion is considered the primary objective to be optimized, while the other is treated as a constraint. This approach focuses on achieving a specific target while adhering to limitations set by the secondary criterion.
- Both criteria are regarded as equally important. In this case, the goal is to find an efficient schedule that balances both criteria without prioritizing one over the other, ensuring that neither side is neglected.
- The criteria are weighted differently, and the objective function is defined as the sum of the weighted functions. This method allows for a more nuanced approach where each criterion's importance is reflected in its weight, enabling a tailored scheduling solution that aligns with specific business goals and customer expectations.

F. Sequence Dependant Setup Time

In many real-world problems, setup time is influenced by the type of job that has just been completed as well as the type of job that will be processed next [1]. Before a job can commence, necessary preparations such as machine setting, cleaning, and machine changeovers must be conducted. This setup time is a critical factor in production scheduling and can easily consume more than 20% of the available machine capacity if not managed effectively [9].

Efficient management of setup times is essential for optimizing production processes, as it directly impacts overall productivity and resource utilization. Therefore, integrating setup time considerations into scheduling algorithms is crucial for enhancing operational efficiency and minimizing downtime. By doing so, organizations can ensure smoother transitions between jobs and improve their overall throughput.

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III. METODHOLOGY

The research method employed in this study is quantitative research. The data source utilized is secondary data obtained from the Scopus website. The research process consists of a series of activities organized in a sequential and systematic manner. The stages of this research are as follows:

A. Planning

This stage serves as the initial phase of the research. In the planning phase, the identification of research objectives is carried out. Additionally, the procedures to be discussed include how the tasks are managed and the approaches related to social innovation in the public sector during the search process.

B. Selection

In the Selection stage, the database used is Scopus. Scopus is utilized to facilitate a comprehensive multidisciplinary review. By using this database, research on social innovation in the public sector conducted across various disciplines can be obtained.

C. Extraction

In the extraction stage, Vosviewer is used to delve into the content of the articles gathered from the selection stage. During this phase, articles that discuss the same topic and are relevant will be selected.

D. Execution

In the execution stage, articles that discuss the same main topic will be read, compared, and discussed to examine the relationships or connections between the contents of the research.

IV. RESULT AND DISCUSSION

This chapter discusses the core of the research through the stages of selection, extraction, and execution of the articles that have been collected.

A. Planning

In this case, a bibliometric analysis will first be conducted on the theme of scheduling with a flowshop type and using heuristic methods. Scopus is used as the primary tool for document retrieval. To examine the relationships among the documents, analysis will be carried out using the VOSviewer tool. The selected keywords are: "(TITLE-ABS-KEY (scheduling AND flexible AND flowshop)) AND (heuristic)," yielding 169 documents with the same keywords.

Among the 169 studies, 12 were conducted in 2021. Prior to this, research on this theme has been published since 1986. Figure 1 shows the graph of the number of documents published on the theme of flexible flowshop and heuristic methods.

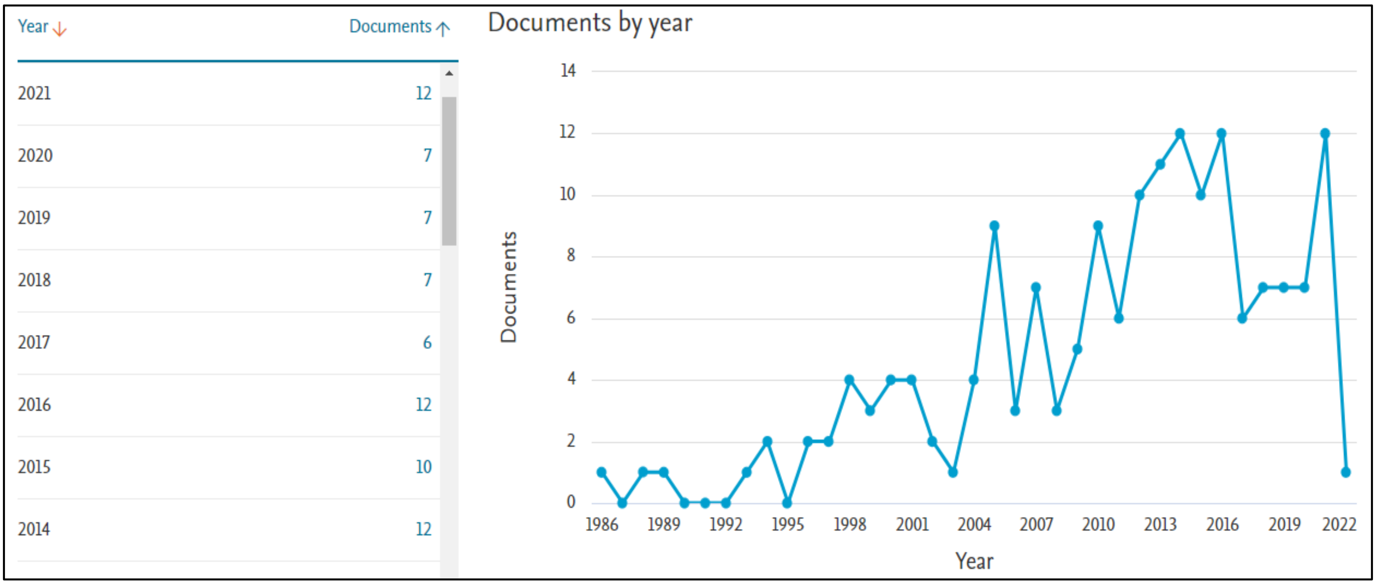

Fig. 1. Published Paper with Theme Flexible Flow-Shop & Heuristic Methods

In Figure 1, the number of publications on flexible flow shop optimization using heuristic methods was relatively low before the 21st century. However, in 2005, there was a significant increase, with the number of publications rising from 4 to 9. Following this surge, the publication count fluctuated each year but generally trended upward. The highest number of publications occurred in 2014, 2016, and 2021, with each of those years featuring 12 publications.

B. Selection

The data that has been collected was compiled into a .csv format and further analyzed using Vosviewer software. In Vosviewer, the downloaded data in .csv format was inputted and the occurrence of each literature item was analyzed. In this topic, there are 1,088 keywords that emerged, with keywords synonymous with scheduling, flexible flow shop, and heuristic being the dominant occurrences, as they serve as key terms in the searches. Additionally, there are many other terms related to this theme. Table I presents the co-occurrence of the selected journals.

Table 1 Keyword Occurences

Keyword	**Occurrence**	***Total Link Strength***
Scheduling	125	1648
Flexible flowshop	60	840
Heuristic methods	39	590
Optimization	37	576
Genetic algorithms	31	558
Scheduling algorithms	28	520
Makespan	29	372
Integer programming	22	339
Problem solving	24	319
Sequence dependent setup time	19	297
Genetic algorithm	16	290
Computational complexity	16	244
Hybrid flowshop	14	235

In addition to the three keywords used in the search, other keywords with the highest occurrences include optimization, with 37 occurrences and a total link strength of 576; genetic algorithms, with 31 occurrences and a total link strength of 558; and scheduling algorithms, with 28 occurrences and a total link strength of 520. Keywords with bi-criteria or multiple criteria objectives are not even among the top thirteen occurrences, indicating that studies are still uncommon.

C. Extraction

The common parallel flow in manufacturing industries leads to the scheduling problem of flexible flow shops [2]. Although this phenomenon has been recognized for a long time, the first research publication was conducted by Li in 1997. The first solution using heuristic methods was presented by Logendran in 2005 [13]. Since then, there has been a surge in publications on this topic, with the number increasing from 4 to 9. Although the number of publications has fluctuated, it has generally grown each year. The highest number of publications occurred in 2014, 2016, and 2021, each year featuring 12 publications. This trend indicates significant advancements in production scheduling research within flexible flow shops using heuristic methods.

In contrast, only 16 articles have been published from 2016 to 2022 on the topic of flexible flow shops with bi-criteria objectives. Research on multi-criteria objectives has emerged from the need for companies to consider not only operational efficiency but also customer satisfaction [4]. The company's objectives primarily focus on minimizing makespan or total completion time [12] [14] [15] [16] [17]. Meanwhile, customer satisfaction focuses on minimizing tardiness. Several studies utilize objectives such as maximum lateness [12], total tardiness [17],mean tardiness [18], and weighted tardiness [6] [7]. Other studies explore different objectives, such as the Agreement Index [16]and customer importance levels [19]

Multi-criteria objectives indicate that the scheduling problem involves more than one goal, necessitating a model with two objectives. Pargar [4]mexamines a scenario with the dual goals of minimizing maximum completion time and tardiness, defining the objective function as min $\alpha Cmax + \beta \sum Tj$, where α and β are weighting coefficients with $\alpha > 0$ and $\alpha + \beta = 1$. In another study, Shahvari & Logendran [20] aim to minimize weighted completion time and weighted tardiness, defining their objective function

$min\ Z = \propto \sum_{i=1}^{g} \sum_{s=1}^{n_i} \sum_{j=1}^{n_i} w_{ij} X_{isj}^{st_{ij(mij)}} + \beta \sum_{i=1}^{g} \sum_{j=1}^{n_i} w_{ij} TD_{ij}$, which $i = 1,2\ldots,g$, $j = 1,2\ldots n_i$ and $s = 1,2 \ldots g_i$ is group, job and batches indicator's. X_{isj} are *completion time* from *job j* in the batch s^{th} in Group i. meanwhile T_{ij} is the *tardiness* of *job* in group i and is defined as max $(0, X_{isj} – d_{ij})$, where d_{ij} is the *due date* of *job* j in group i.

Meanwhile, for the scheduling constraints used to determine the optimal batch sequence, Shahvari & Logendran (2016) [20] modeled it as follows:

$$X_{isj}^{k} + M\left(A_{ptis}^{k}\right) + M\left(1 - Z_{ish}^{k}\right) + M\left(1 - Z_{pth}^{k}\right) + M\left(1 - \emptyset_{isj}^{k}\right) \geq C_{is}^{k} + S_{pih}^{k} + t_{ijh}^{k} i\ , p \in I^{k} (p \leq i\ dan\ jika\ p = i\ maka\ t \neq s); j\ \in J_{p}^{k}\ ; h \in v_{ij}^{k}; k = 1,2,\ldots,m;\ s = 1,2,\ldots,g_{i}^{k}; t = 1,2,\ldots,g_{p}^{k}; M : large\ number \quad (1)$$

$$X_{ptj}^{k} + M\left(A_{ptis}^{k}\right) + M\left(1 - Z_{ish}^{k}\right) + M\left(1 - Z_{pth}^{k}\right) + M\left(1 - \emptyset_{isj}^{k}\right) \geq C_{is}^{k} + S_{iph}^{k} + t_{pjh}^{k} i, p \in I^{k} (p \leq i\ dan\ jika\ p = i\ maka\ t \neq s); j\ \in J_{p}^{k}\ ; h \in v_{ij}^{k}; k = 1,2,\ldots,m; s = 1,2,\ldots,g_{i}^{k}; t = 1,2,\ldots,g_{p}^{k}; M : large\ number \quad (2)$$

$$X_{isj}^{k} + M\left(1 - \emptyset_{isj}^{k}\right) \geq \sum_{h \in v_{ij}^{k}} \left(a_{k}^{h} + s_{0ih}^{k} + t_{ijh}^{k}\right) Z_{ish}^{k}\ ; i\ \in I^{k}\ ; j \in J_{i}^{k}; s = 1,2,\ldots,g_{i}^{k}, k = 1,2,\ldots,m \quad (3)$$

$$X_{isj}^{k} + M\left(1 - \emptyset_{isj}^{st_{ij(1)}}\right) \geq r_{ij} + \sum_{h \in v_{ij}^{st_{ij(1)}}} t_{ijh}^{st_{ij(1)}}(Z_{ish}^{st_{ij(1)}})\,;\; i = 1, 2, \ldots, g;$$
$$j = 1, 2, \ldots, n_i; s = 1, 2, \ldots, g^{st_{ij(1)}} \quad (4)$$

$$X_{isj}^{k} - X_{isq}^{k} + M(Y_{isjq}^{k}) + M(1 - \emptyset_{isj}^{k}) + M(1 - \emptyset_{isq}^{k}) \geq \sum\nolimits_{h \in v_{ij}^{k} \cap v_{iq}^{k}} t_{ijh}^{k}(Z_{ish}^{k})$$
$$i \in I^{k}; j, q \in J_{i}^{k}\ (j < q); k = 1, 2, \ldots, m; s = 1, 2, \ldots, g_{i}^{k}; M{:}\ large\ Number \quad (5)$$

$$X_{isq}^{k} - X_{isj}^{k} + M(1 - Y_{isjq}^{k}) + M(1 - \emptyset_{isj}^{k}) + M(1 - \emptyset_{isq}^{k}) \geq \sum\nolimits_{h \in v_{ij}^{k} \cap v_{iq}^{k}} t_{ijh}^{k}(Z_{ish}^{k})$$
$$i \in I^{k}; j, q \in J_{i}^{k}\ (j < q); k = 1, 2, \ldots, m; s = 1, 2, \ldots, g_{i}^{k}; M{:}\ large\ Number \quad (6)$$

$$C_{is}^{k} \geq X_{isj}^{k};\ i \in I^{k}; j \in J_{i}^{k}; s = 1, 2, \ldots, g_{i}^{k}; k = 1, 2, \ldots, m \quad (7)$$

$$X_{isj}^{st_{ij(r)}} - X_{isj}^{st_{ij(r-1)}} \geq \sum\nolimits_{h \in v_{ij}^{st_{ij(1)}}} t_{ijh}^{st_{ij(r)}}(Z_{ish}^{st_{ij(r)}}) + (\emptyset_{ish}^{st_{ij(r)}} + Z\emptyset_{ish}^{st_{ij(r-1)}} - 2)M,$$
$$i = 1, 2, \ldots, g;\ j = 1, 2, \ldots, n_i; s = 1, 2, \ldots, n_i; s = 1, 2, \ldots, g^{st_{ij(r-1)}}; r = 2, 3, \ldots, m_{ij};\ M = large\ Number \quad (8)$$

In this model, Constraints 1 and 2 are used to determine the batch sequence, specifically limiting the completion time of each job within every batch of each group. Constraints 3 and 4 address machine availability: Constraint 3 ensures that a job cannot be processed if the assigned machine is unavailable, while Constraint 4 stipulates that job processing cannot commence until the job has been released. Additionally, Constraints 5 and 6 are implemented to establish the order of jobs within each batch. Constraints 7 and 8 are utilized to calculate the completion time for each batch in each group at every stage.

In this model, Shahvari and Logendran also consider setup time, which depends on the job previously performed. This phenomenon is known as Sequence-Dependent Setup Time (SDST). SDST typically arises in facilities producing various types of items [1]. Recently, SDST has gained prominence in research as a significant type of setup time [2]. Several studies have explored this topic with a bi-criteria objective, including works by Bozorfirad et al (2016) [7], Vaisi et al. (2016) [21], Aqil and Allali [15](2018), and Yu et al. (2020) [22].

D. Executionn

Based on previous research, several studies have been selected as the foundation for this investigation. The following studies serve as a basis for this research:

Pargar et al. [4]: In their study titled The Effect of Worker Learning on Scheduling Jobs in a Hybrid Flow Shop: A Bi-Objective Approach, the authors developed a scheduling model for a hybrid flow shop with two objectives: minimizing makespan for efficiency and minimizing total tardiness to prevent customer dissatisfaction. The study also took setup time into consideration.

Aqil, S. & Allali, K. [15]: In their research entitled Heuristics and Metaheuristics for the Bi-Criterion Optimization of the Flexible Flow Shop Scheduling Problem with Two Stages, the authors combined two criteria with specific weighting coefficients for each. The objectives were to minimize makespan and weighted average completion time. They employed methods including the Greedy Randomized Adaptive Search and the Local Search Iterative Algorithm. Results indicated that the Local Search Iterative Algorithm, in combination with the NEH heuristic algorithm, outperformed the Greedy Random Adaptive Search procedure.

Qin, Y. & Zhang, H [23]: Their study, titled Elite Particle Swarm Optimization Algorithm for Solving the Bi-Criteria No-Wait Flexible Flow Shop Problem, applied the Elite Particle Swarm Optimization Algorithm. The primary objectives were to minimize maximum completion time and maximum delay time. Findings suggested that this algorithm exhibited superior validity and accuracy compared to the standard PSO and ICA algorithms.

Table 2 Related Articles

Author(s)	Flow Production Type	Objective	Method	GS	SDST	Parallel Machine
Bozorgirad & Logendran (2016)	hybrid flow shop	Minimization of weighted completion time and weighted tardiness	Meta-heuristik : Tabu Search and Simulated Annealing dibandingkan dengan Genetic Algorithm	Yes	yes	Identical
Qin & Zhang (2016)	flexible flow shop	Minimization of maximum completion time and maximum delay time	Elite Particle Swarm Optimization Algorithm	yes	no	Identical
Shahvari & Logendran (2018)	hybrid flow shop	Minimization of weighted completion time and weighted tardiness	Meta-heuristik : two staged based hybrid algorithm	Yes	No	Identical
Pargar, dkk (2018)	flexible flow shop	Minimization of makespan and tardiness	Meta-heuristik : Pendekatan Pareto	No	Yes	Identical
Vaisi dkk (2018)	parallel flow shop	minimization of waktu siklus and biaya	weighted sum method and ∊-constraint method,	Yes	Yes	Identical
Aqil & Allali (2018)	flexible flow shop	Minimization of makespan and weighted average completion time	Greedy ranndomized adaptive search and local search iterative algorithm	No	Yes	Identical
Yang & Liu (2018)	blocking flow shop	minimization of fuzzy makespan and maksimasi rata-rata agreement index	multi-objective genetic algorithm	Yes	No	Identical
Wang dkk (2019)	hybrid flow shop	minimization of makespan and konsumsi energi	Ant colony Optimisation and Tabu Search	No	No	UnIdentical
Golneshini & Fazlollahtabar (2019)	hybrid flow shop	Minimization of linear kombinasi dari total completion time and maximum lateness	Meta-heuristic : Genetic Algorithm and Particle Swarm Optimization	No	No	Identical
Xue & Wang (2022)	flow shop	Minimization of total cost and Mean tardiness	Multi Objective Discrete Evolution (MDDE)	Yes	No	Identical

Shahvari & Logendran [24]: In their paper titled A Comparison of Two Stage-Based Hybrid Algorithms for a Batch Scheduling Problem in a Hybrid Flow Shop with Learning Effects, the authors compared two hybrid algorithms in a hybrid flow shop setting. The scheduling objectives were to minimize weighted completion time and weighted tardiness. The research operated under the assumption of group technology and did not account for Single-Duration Setup Time (SDST) or identical parallel machines.

Table 2 provides details of nine related research articles obtained from Scopus, using the keywords "scheduling," "flexible flow shop," "heuristic," and "bi-criteria," covering the period from 2016 to 2022.

V. GAP ANALYSIS

Studies have delved into the intricate realm of bi-criteria issues associated with flexible flow shop scheduling, proposing a wide array of algorithms designed to optimize various performance metrics. These algorithms typically aim to minimize pivotal factors such as makespan— the total length of time required to complete a set of jobs—and total completion time, striving to strike a delicate balance between competing objectives to enhance overall operational efficiency. However, a significant observation in the existing body of research is that it has largely concentrated on flexible flow shops operating under the simplifying assumption of identical parallel machines.

Several studies have also taken into account Sequence Dependent Setup Time (SDST) in the models or algorithms used. Incorporating the SDST assumption provides solutions that align more closely with real-world conditions, as it reflects the varying setup times required between tasks based on the specific order in which they are processed. This consideration enhances the practical applicability of scheduling models by addressing the additional time and resources needed for sequence-specific setup adjustments, thereby improving the overall efficiency and accuracy of scheduling solutions in realistic operational environments.

A particularly noteworthy contribution to the field comes from the work of Wang et al. (2019), who ventured into more complex scheduling landscapes by considering situations in which not all machines possess the capability to process every type of job. This innovative approach introduced a selective capability model that acknowledges the specialization of certain machines for specific tasks. By recognizing that different machines may exhibit varied processing abilities, this research illuminated the critical importance of customizing scheduling strategies to accommodate these distinctions. Their findings underscore a pivotal shift from a simplistic view of machine capabilities to a more nuanced understanding that better reflects the realities of modern production environments.

VI. CONCLUSION

Based on the research conducted, the conclusions that can be drawn from this study are as follows:

Research in flexible flow-shop production scheduling with bi-criteria objectives remains relatively underexplored, highlighting a significant opportunity for further advancements in this field.

Between 2016 and 2022, several methods have been utilized to tackle bi-criteria objective challenges in flexible flow-shop and hybrid flow-shop environments. However, there is a notable gap in the literature regarding the application of a Group Scheduling model that incorporates Sequence Dependent Setup Times (SDST) in the context of non-identical parallel machines. This presents a unique area for future investigation and development.

RECOMMENDATIONS

Based on the previous conclusions, the following recommendations can be made from this research:

Development research scheduling production model flow flexible flow-shop production with bi-criteria objective can still be developed further. In particular, the SDST model of production system with the assumption of fixed scheduling production, group scheduling and parallel machine production is not identical.

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