

MULTI-OBJECTIVE PERMUTATION AND NON-PERMUTATION FLOW SHOP SCHEDULING PROBLEMS WITH NO-WAIT: A SYSTEMATIC LITERATURE REVIEW

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Abstract. Flow shop scheduling is a type of scheduling where sequence follows for each job on a set of machines for processing. In practice, jobs in flow shops can arrive at irregular times, and the no-wait constraint allows the changes in the job order to flexibly manage such irregularity. The flexible flow shop scheduling problems with no-wait have mainly addressed for flow optimization on the shop floor in manufacturing, processing, and allied industries. The scope of this paper is to identify the literature available on permutation and non-permutation flow shop scheduling with no-wait constraint. This paper organizes scheduling problems based on performance measures of variability and shop environments. The extended summary of two/three-machine and m -machine problems has been compiled, including their objectives, algorithms, parametric considerations, and their findings. A systematic appearance of both conceptual and analytical results summarizes various advances of the no-wait constraint. The paper includes independently investigated problems and suggestions for future research directions.

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1. INTRODUCTION

The multi-objective flow shop scheduling problem is the type of production scheduling problems. The production schedule is an arrangement of controlling, optimizing, and work loading in the manufacturing process. In some, the jobs processed in a series of operations in the same sequence, *i.e.*, following the same route in some manufacturing and assembly facilities. This environment is referred to as a flow shop and is a critical element of scheduling problems. Its significance and practical implementation to the industry sector have attracted researchers to study it from distinct angles. The methodological restraints qualify the raw processing order for every job in a flow shop. It is essential to develop robust and dynamic algorithms to improve production efficiency and enhance the optimization of manufacturing resources to enhance the competitive strength.

The decision support system (DSS) for multi-objective project management and scheduling has presented under the selection of advanced manufacturing technologies [3]. An approach is proposed to solve multi-criteria decision problems with mathematical programming models [34]. Gunasekaran *et al.* [47] realized the importance

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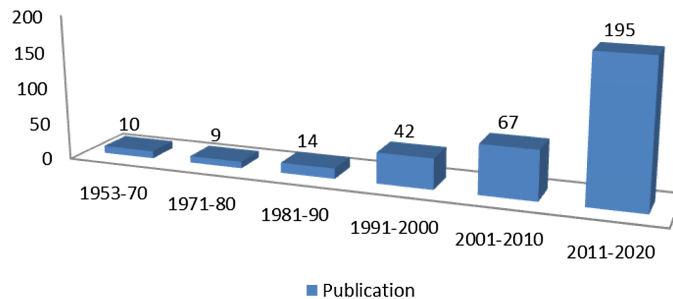


FIGURE 1. Number of papers published in ten-year periods (Source: Sec. quantitative analysis of literature).

of flexible manufacturing systems in increasing productivity and quality. Strategic management of sustainable manufacturing operations has featured a comprehensive survey of sustainability efforts [33]. It has highlighted the successful techniques used by different companies for flexible practices. A mixed-integer linear programming model is framed to show alternative critical activities and relationships [37].

The no-wait constraint processing of two successive operations of a job without any interruptions is the origin of occurring in scheduling. The research concern in scheduling with the no-wait constraint has begun in the 1970s. Several research papers have appeared since the mid-1990. Therefore, the current review paper provides a review of the scheduling research with the no-wait constraint from the mid-1950s to the present. Most of the literature on dealing FSP has focused on single-criteria scheduling. However, many objectives are taken in several real-life dynamic situations. The traditional approaches to solve single-criteria FSP and to challenge small-sized scheduling problems are widely available. However, despite the relative success of exact and approximation algorithm models, they are still incompetent in concentrating medium-and-large scale problems and are too complicated for real-world problems. In past decades, the architecture of multi-objective problems and programming skills to tackle FSP with multiple objectives has increased (Fig. 1). The current work aims to provide researchers with an updated analysis of the theoretical and practical topics of MFSP and future study trends.

This paper reviews over 300 articles with the no-wait constraint on scheduling permutation and non-permutation issues. It also addresses issues based on available shop environments, associated performance measures and other variables. Some prospective study issues suggested that separately addressed problems studied and less addressed problems identified.

2. THE PERMUTATION AND NON-PERMUTATION FLEXIBLE FLOW SHOP SCHEDULING PROBLEMS

The permutation flow shop (PFS) is one where each job processes in the same order. Therefore, once the job sequence on the first machine is fixed in a permutation flow shop, it will be the same in the rest of the stages. This problem is expressed as $Fm|prmu|C_{max}$ [150]. The flow shop scheduling problem with makespan can be denoted as $F3|C_{max}, F$ as introduced by [78], and $Fm||C_{max}, F$, as suggested by [27, 145]. There are some requirements of PFS: preemption is not allowed; all jobs are independent and are available for processing at time zero; the machines are available continuously; the setup times of jobs on machines are sequence-independent and included in the processing times [86, 113]. The no-wait performance measures of PFS and NPFS problems are categorized into three groups: completion time measures (C_{max}, F); due date measures (L, T); measures based on inventory and utilization costs [35, 38, 89].

The non-permutation flow shop scheduling problem (NPFS) is a simplification of the conventional permutation flow shop scheduling problem that permits job order changes on different machines. NPFS offers in industrial

TABLE 1. Permutation and non-permutation with no-wait objective function(s).

Problem	Problem type	Status
F	Single-objective function	
F	Performance measure	
$F2/F3/f1, f2$	Two/three machine problem with bi-objective	
$F2/F3/f1, f2, \dots, fk$	Two/three machine problem with multi-objective	Permutation/
$Fm/f1, f2$	m -machine problem with bi-objective	non-
$Fm/f1, f2, \dots, fk$	m -machine problem with multi-objective	permutation/
$F2/F3/w1, w2$	Two/three machine problem with weighted-objective	both
$Fm/w1, w2$	m -machine problem with weighted-objective	
$Fp/p1, p2$	m -machine problem with pareto-optimal objective	
Fm/Z_{cost}	m -machine problem with cost-objective function	
$Fm/\varepsilon, \forall, \theta, \Phi$	m -machine problem with constraint-bound approach	

model applications even though its complexity. The flow shop arrangements are usual in production configurations where machine stages $m = (1, 2, \dots, m)$ process job sets $n = (1, 2, \dots, n)$. Each job follows a machine sequence in the specific order, *i.e.*, (m_1, m_2, \dots, m_n) [143]. If the job order is uniform for m -machines, then the schedule is known as a permutation. The problem is expressed as $F2||C_{max}, F$ [109] and $Fm||prmu||C_{max}$ [144]. Otherwise, if the processing order can vary in m -machine stages, and the permutation criterion is flexible, then the problem is called a non-permutation flow shop scheduling problem. The problem is represented as $F2|block|C_{max}$ [148]. There are some requirements of NPFS besides specifications: all the jobs and machines should be available at the start; a job can be processed by one machine at one time; the experimental data should be deterministic and known in prior [112].

The configuration of PFS and NPFS approaches are similar; the third item is the most significant potential difference between them, *i.e.*, no-wait constraint. In some instances, PFS and NPFS problems also consider the intermediate buffers with infinite capacity and being so smoothly compatible in the flow shop. On the other hand, both approaches cannot find an optimal solution in the absence of intermediate buffers [121]. Besides the three key specifications and requirements described above in the standard form of PFS and NPFS, this explanation does not cover the whole spectrum of PFS and NPFS problems but helps as a framework for them. All the various PFS and NPFS measures can be validated by adding no-wait constraints.

The permutation and non-permutation techniques developed recently are used to handle MFSP. Their comprehensive surveys with the no-wait constraint, future developments, and challenges are relatively very limited. Johnson [53] studied two and three-stage industrial systems, which included setup times with the no-wait constraint. There have been a few case studies about multi-criterion scheduling available in the technical literature by [46, 98, 99, 112, 113, 156]. Ahmadizar and Farahani [2], Han *et al.* [51], Minella *et al.* [86], Rabadi [118], Pessoa and Andrade [111], Shahvari and Logendran [132], and Tadayon and Salmasi [152] reviews do not discuss future directions and challenges thoroughly. Several other approaches emerged after these papers were published. Most of the flow shop scheduling literature is restricted to a specific case, the permutation and non-permutation with no-wait. The literature on this issue is emerged in the last decade, suggesting that the subject is an active research field. In this paper, we will focus on permutation and non-permutation no-wait flow shop groups with makespan objective minimization. *Different methods have used to solve permutation, and non-permutation no-wait scheduling problems are abbreviated (attached in supplementary file). The summary of problems and approaches for permutation and non-permutation with the no-wait constraint are representing the two/three-machine, m-machine objective functions (Tab. 1), HF scheduling problem, permutation problem, SDST problem, the results on C_{max} for F2/F3, block problem and no-idle problem (Tab. 2).*

TABLE 2. Summary of problems and approaches for permutation and non-permutation with no-wait.

Problem type	Status (permutation)	Problem	Algorithm	Reference
Bi-objective $n/2/3/P/f$	✓	$F3 C_{\max}, F$	B&B	[78]
	✓	$F2 C_{\max}, F$	Heuristics, JA	[109]
	✓	$F2(PM) nwt C_{\max}$	GA	[160]
	✗	$F2 C_{\max}, Z_{\text{cost}}$	MILP	[175]
	✗	$F2 C_{\max}, T$	Priority scheduling approach	[58]
	✓	$F3 w_{i1}, w_{i2} C_{\max}$	B&B	[57]
	✗	$F3 he_{ijn}, j, \varepsilon C_{\max}$	NSGA-II, MOPSO, GA, and SPEA-II	[141]
	Bi-objective $n/m/P/f$	✗	$Fm L_{\max}, F$	MCDP
✓		$Fm prmu C_{\max}$	Various conditions	[150]
✓		$Fm C_{\max}, F$	TSH	[27]
✓		$Fm C_{\max}, F$	N&M heuristics	[95]
✓		$Fm C_{\max}, F$	MNEH, MSA	[79]
✗		$Fm C_{\max}, F$	ACS	[170]
✓		$Fm C_{\max}, F$	JA based heuristics	[38]
✓		$HF2 C_{\max}, T$	BOLS	[94]
✓		$Fm prmu C_{\max}$	EDA	[161]
✓		$Fm C_{\max}, F$	TS, SA	[18]
✗		$J C_{\max}, F$	GA	[127]
✓		$Fm prum C_{\max}$	BS-HH	[73]
✓		$Fm C_{\max}, F$	Polynomial algorithm	[24]
✓		$F2 (AG_{1,2}) C_{\max}, T_{\max}$	h-MOEA	[41]
Multi-objective $n/m/P/f$		✓	$Fm C_{\max}, F$	DTA
	✓	$Fm C_{\max}, F$	CDA	[22]
	✓	$Fm prmu C_{\max}$	B&B	[114]
	Both	$Fm SDST, block C_{\max}, T$	TSP-heuristics	[48]
	✓	$Fm SDST C_{\max}, F$	Heuristics	[50]
	✗	$Fm C_{\max}, L_{\max}$	Heuristics, LB	[125]
	✓	$Fm prmu C_{\max}, F$	SA, TS, heuristics	[147]
	✓	$Fm prmu T_{\max}, F$	LRT	[75]
	✓	$Fm s_{ijk}, prmu C_{\max}$	B&B	[84]
	Both	$Fm prmu, block C_{\max}$	TS, heuristics	[44]
	✓	$Fm T_{\max}, C_{\max}$	IA	[4]
	Both	$Fm SDST C_{\max}$	TS-heuristics	[172]
	✓	$Fm nwt, prmu C_{\max}$	HDPSO	[105]
	✓	$Fm prmu C_{\max}$	NEGA-VNS	[183]
	✓	$Fm C_{\max}, F, C_w$	MOACSA	[165]
	Both	$Fm prmu, block C_{\max}$	DLHS	[106]
	✗	$HFm(PM) C_{\max}, Z_{\text{cost}}$	GA, heuristics	[182]
	✓	$Fm nwt, prmu C_{\max}$	HDDE	[28]

TABLE 2. (Continued.)

Problem type	Status (permutation)	Problem	Algorithm	Reference
	✓	$HFm(PM) C_{\max}, F$	PSO	[69]
	✗	$Fm SDST Z_{\text{pih_cost}}, I_{\text{sum}}$	GA	[10]
	✓	$Fm SDST, prmu C_{\max}$	HGA	[88]
	✓	$Fm ST_{sd}, no-wait, r_j C_{\max}$	ECS	[96]
	✓	$Fm prmu, SDST C_{\max}$	MBO	[14]
	✓	$Fm prmu C_{\max}, F$	MONEH, MMOIG	[31]
	✓	$Fm prmu C_{\max}, \Psi$	BRILS	[39]
	✓	$Fm prmu C_{\max}$	GA, AIS	[15]
	✓	$HFm SDST, r_j, skip C_w, T_w$	TS, path-relinking	[131]
	✓	$Fm nwt C_{\max}, D$	HDTPL	[133]
	✓	$Fm prmu C_{\max}$	NS-SGDE	[133]
	✓	$Fm nwt C_{\max}, F$	ACO-SA	[122]
	✓	$F nwt, d_j C_{\max}$	Enumeration algorithm	[128]
	✓	$Fm nwt C_{\max}, I_{\text{sum}}$	AIT heuristic, ISA	[168]
	✗	$HFm lsm C_{\max}$	Heuristics	[62]
	✗	$Fm Z_{\text{cost}}, W_{\text{ave}}$	I-ICA	[120]
	✓	$Fm prmu C_{\max}, T_{\max}, F$	CMA	[29]
	✓	$Fm nwt, d_j C_{\max}$	Enumeration algorithm	[129]
	✓	$FFm SDST C, T_{\max}, W_w$	I-HGA	[76]
	Both	$Fm prmu, block C_{\max}, F$	MBGA, NSGA-II	[102]
	✗	$Fm SDST F_{\text{ave}}, T$	CDRs, GP	[56]
	✓	$Fm prmu, no-idle C_{\max}$	MANEH, GVNS-SA	[136]
	✓	$Fm prmu C_{\max}$	SS, DT	[43]
	✓	$Fm prmu, no-idle \sum T$	I(fj, d) – ICH	[97]
	✓	$Fm prmu C_{\max}, \Theta$	IGA	[101]
	✓	$F prmu, SDST C_{\max}, F$	EMBO, STH heuristic	[142]
	✗	$FHm(PM) skip C_{\max}$	Heuristics, dispatching rules	[32]
	✓	$Fm prmu, d_o, ak C_{\max} T_{\max}$	IGA	[77]
	✓	$HFm ST_{sd}, r_j, M_j, skip \sum w_j, T_j$	TS/PR, PSO/LSA	[132]
	✓	$Fm no-wait C_{\max}$	DWWO	[177]
	✓	$Fm r_j, perm \sum F(C_j)$	ILS, IGS, BRKGA, VND	[111]
	✗	$Fm PIC, JTT C_{\max}, Z_{\text{cost}}$	HDMGWO	[117]
	✓	$Fm block C_{\max}, \sum T_j$	MODWWO	[139]
	✓	$Fm \gamma, \rho, perm C_{\max}$	Greedy heuristic	[64]
	✓	$Fm blocking C_{\max}$	DIWO	[138]
	✓	$Fm ST_{SI}, no-wait \varepsilon(\sum T_j C_{\max})$	PA	[7]
Multi-objective $n/2/3/P/f$	✓	$F2 prmu, block C_{\max}$	TS	[146]
	✓	$F2 prmu, nwt C_{\max}$	BAT, GA	[115]

TABLE 3. Special permutation results with no-wait, considering makespan as objective.

Problem	Comments	Reference
$Fm S_{nsd}, R_{km} C_{\max}$	NPFS approach does not ensure optimality. NPFS makespan worst case: single time $(m-1)$ and $(k-1)/(m-k)$ PFS makespan.	[50]
$Fm \text{removal times } (R_{ik}) C_{\max}$	NPFS approach does not ensure optimality. NPFS makespan worst case: 1/2 times PFS makespan.	[172]
$Fm \text{time delays } (T_{i,n,m}) C_{\max}$	NPFS approach does not ensure optimality. NPFS makespan worst case: 1/2 times $\sum (I_c + P_c) / (CT_{i,n,m})$ PFS makespan.	[89]
$Fm \text{time delays } (C_{i,j}) C_{\max}$	NPFS approach does not ensure optimality. NPFS makespan worst case: ($ST_{i,q} = 0$) PFS makespan.	[100]
$Fm \text{learning effect } (\sum_j \mu_j, P_{j,i}) C_{\max}$	NPFS approach does not ensure optimality.	[137]
$Fm \text{block } (m_\pi, m^*) C_{\max}$	NPFS approach does not ensure optimality. NPFS makespan worst case: 3/4 times PFS makespan.	[44]

2.1. Permutation and non-permutation complexity: special cases

Since permutation and non-permutation with no-wait are far from being a subject of extensive research, we compile some significant outcomes that can serve as guidance for beginners or as a state-of-the-art resource for professional researchers or field practitioners. Firstly, PFS groups must achieve the same or better results as NPFS groups for similar problem-case since the former and latter comprise all the solutions of each other cases and more. The additional computational effort required to solve complex NPFS problems compared to PFS problems with no-wait is a highly relevant topic (Tabs. 3 and 4).

Johnson [53] presented the oldest result of PFS scheme for the general two-and-three stage production schedules (permutation) where each job can pass through stage one, and then stage two. Each machine can handle only one item at a time, without blocking the optimal solution. There are two arbitrary (positive) numbers given for each item representing the setup plus work time for that item to pass through each stage. Thus, for the case of $F2|C_{\max}$, F is optimal. This result is clearly validated in [59].

In consequence, the PFS approach becomes constructive for systems with more than three machines [24]. This analysis is being refined by newer results (Tab. 3). These rows address some special cases such as bound on the worst-case and where NPFS does not validate optimality even in m -machine cases due to some of the conditions of [25] which do not apply.

Other relevant research outcomes (permutation) describing complexities are:

- For a broader range of no-idle and no-wait constraints, it is more likely that the PFS schemes outperform NPFS schemes increase [26].
- The scheduling environment based on objective functions tardiness and the makespan would benefit more from the PFS scheme than NPFS scheme as the cumulative error is reduced to 60% [6]; and with setup times to tardiness and makespan, the cumulative error is reduced to 50% [7].
- The chances that the PFS scheme outperforms the NPFS approach for a range of sequence-dependent setup times [23, 67, 90].
- The possibilities of PFS schemes outperforming NPFS schedules increase for a range of processing times [36, 74].
- For a broader range of release-date constraints, the PFS scheme outperforms the NPFS scheme [128, 129].

TABLE 4. Special non-permutation results with no-wait, considering makespan as objective.

Problem	Comments	Reference
$F2 learning\ effect\ (\pi, P_{j,i}) C_{max}$	PFS approach does not ensure optimality. PFS makespan worst case: 2 times NPFS makespan.	[74]
$F2 time\ delays\ (d_j) C_{max}$	PFS approach does not ensure optimality. PFS makespan worst case: 3/2 times NPFS makespan.	[164]
$F2 removal\ times\ (r_{ik}) C_{max}$	PFS makespan worst case: 3/2 times NPFS makespan, and does not ensure optimality.	[148]
$F2 block C_{max}$	PFS approach does not ensure optimality.	[148]
$Fm C_{max}, F\ vs.\ Fm prmu C_{max}$	PFS makespan worst case: $\sqrt[2]{\min(m, n)}$ times NPFS makespan.	[170]

Conway *et al.* [25] presented the oldest result of the NPFS scheme for the flow shop group. The sequence (non-permutation) can be the same for the first and second machines without hindering the optimal solution. The optimum sequence of n -jobs is processing through m -machines to minimize flow time. The smaller the completion time, the less the overall flow time increases. Thus, for the case $Fm|C_{max}, F$ is optimal. This result is clearly validated in [108].

In consequence, the NPFS approach becomes constructive for two/three machines [58]. This analysis is being refined by newer results (Tab. 4). These rows address some special cases such as bound on the worst case, and where NPFS does not validate optimality in two/three and m -machine cases, due to some of the conditions of [25] which do not apply. The first four rows address special cases of bound on the worst case, and the last row indicates a particular case where PFS does not validate optimality in m -machine cases, because of certain conditions suggested by [25].

Other research investigational outcomes (non-permutation) describing complexities are:

- The possibilities of NPFS schemes outperforming PFS schedules increase for a range of setup and processing times [116, 148].
- The makespan is 4% better in the NPFS scheme for a simple flow shop [153].
- The scheduling environments in which the objective functions are based on release-date and weighted tardiness would benefit more from the NPFS scheme than those in which they are grounded on completion time [164].
- It is more likely that the NPFS scheme outperforms the PFS scheme for a range of processing times [169, 170].
- For a broader range of minimal and maximal time lags, the chances that NPFS schemes outperform the PFS schemes in the number of tardy jobs and the makespan as the primary and secondary criterion [30].

3. TWO OR THREE-MACHINE NWFS PROBLEMS

The two or three-machine minimum makespan flow shop with the no-wait in the process is NP-hard. This flow shop problem contains “ n ” jobs simultaneously at time zero and to be processed by more than one machine(s) arranged in series with unlimited buffer in-process. It is required to plan “ n ” jobs on machines; therefore, to reduce the makespan, *e.g.*, the makespan can be minimized by finding non-permutation level $L: L(1), \dots, L(n)$ of all jobs. These are based upon the criterion of approach(s), machine input(s), job, and time estimates such as SDST, permutation, non-permutation, tardiness, no-wait, completion time (Tab. 5). The sequence-independent setup time is followed by the sequence-dependent setup time (SDST).

3.1. Research results and recommendations on C_{\max} for $F2/F3$

Ying and Lin [170] established an effective algorithm for the $F|k|C_{\max}$ problem. It has recommended the future research first as ACS offers many selections. The parameter sets should be thoroughly examined. Second, the advanced heuristic can be expanded with distinct performance criteria to other production environments and the FSP. Ahmadizar and Farahani [2] created an open shop scheduling hybrid GA with specific operators. The algorithm suggested a crossover operator preserves the relative order of machine employment. Samarghandi and Behroozi [128] regarded the no-wait flow shop issue with release/due date restraints and makespan criteria with no-wait constraint and are NP-hard. The graph simulation of the problem with the exact enumeration algorithm has presented.

Salido *et al.* [127] represented an expansion of the conventional job-shop scheduling problem. Each job must be performed at distinct rates by one machine. Khorasanian and Moslehi [55] investigated the two-machine flow shop scheduling problem with blocking. Another factor was the first machine's preemption, multi-task flexibility, and makespan minimization as a criterion.

Fu *et al.* [41] suggested the future research work necessary for developing multi-agent scheduling models. Based on this scheduling issue, the machine breakdown to the deteriorated scheduling and finite buffers is suggested. Sioud and Gagne [142] implemented two high-performance algorithms to minimize the makespan to fix a permutation flow shop issue with SDSTs.

The second algorithm is an optimization of migrating birds, improved by a revised neighborhood search. The sources are a first leader selection process, a tabu list, swap and forward insertion moves, and a restart mechanism. Kim and Lee [57] recommended own research which can be drawn-out by considering multiple workstations. These are recommended in sequence-dependent setup times between the jobs on the machines.

Additional developments in the B&B method will follow various branching patterns to substitute the rapid identification of ruling or governing scheduling decisions and decrease the result time [158]. Fonseca *et al.* [40] computed the heuristic h2, which contributes to the best average GAP. The loss grades charted by the heuristic h1 and the heuristics h2 shown to effort very fit with the Lagrangian method.

4. m -MACHINE NWFS PROBLEMS

The general m -machine flow shop problem is one where not all of the jobs follow the same sequence through " m " machines, *e.g.*, job 1 may go from machine 2 to 5, 3, 4, and 1, while job 2 may go from machine 3 to 1, 2, 4, and 5. The jobs are not preempted, and each job has " m " tasks with processing time. A pairwise J -ordering, to be called the J_m -ordering, whose objective is the ordering of " n " jobs in an m -machine flow shop. The sequence-dependent setup time (SDST) traces the sequence-independent setup time in the case of two/three machine problems.

4.1. Research results and recommendations on C_{\max} and $\sum C_j$ for Fm

Samarghandi and Behroozi [128] explained the computational results as the problem matures and ruling a possible result for $Fm|nwt, d_j|C_{\max}$ is not an easy job. Analytical results discovered that the enumeration algorithm outperforms the supplementary models. A thorough computational study of the expansion enumeration algorithm is a feasible way forward for future studies. This research must include many large-scale test issues to demonstrate further the computational efficiency of the algorithm developed. Finally, the development of tight upper and lower bounds for $Fm|nwt, d_j|C_{\max}$ is an exciting future direction of studies.

Deng and Wang [29] recommended the future work be focused on designing the CMA to solve the MODPFSP with other scheduling standards, such as cost minimization and carbon-efficiency. Nouri and Ladhari [102] performed a computational survey on different types of environments that demonstrate the effectiveness of the suggested NSGA-II algorithm. A comparative study between the algorithms such as ACO, Artificial Bee Colony, DE, MBGA, and PSO is an interesting prospect for future research.

TABLE 5. Summary of research problems on C_{\max} for $F2/F3$.

Algorithm	Problem	Findings	Reference
B&B	$F3 C_{\max}, F$	Lower bounds in each subgroup	[78]
B&B	$F3 C_{\max}, F$	Rules for assigning the machines and listing the jobs	[83]
B&B	$F2 prmu, rj L_{\max}, F$	The flexibility of the capacity constraints on the machines	[45]
Algorithms Gilmore–Gomory algorithm	$F2 nwt C_{\max}, L_{\max}, F_{\text{ave}}$	Schedule with minimal maximum lateness with minimal mean flow times	[126]
Johnson algorithm	$F2 C_{\max}, F$	A single transporter and unlimited buffer space between machines	[109]
B&B	$F2 C_{\max}, F$	Effective solution approach to complex FSP	[98]
Hybrid GA and B&B	$F2 C_{\max}, F_{\text{ave}}$	A GA based metaheuristic	[99]
B&B and constructive heuristic	$F2 C_{\max}, T_{\max}$	Minimized the total number of tardy jobs	[49]
TS	$F2 prmu, block C_{\max}$	Inter-machine buffer execution with ready times, due dates and rain-max cost criterion	[146]
B&B and heuristic	$F2 C_{\max}, F$	The processing times of individual jobs	[60]
B&B with effective branching rules	$F3 prmu C_{\max}, \sum D$	Hybrid permutation FSP	[167]
GA	$F2(PM) nwt C_{\max}$	Multiple parallel identical machines schedule	[160]
Kuhn–Munkres algorithm	$F2 con, NW, LE C_{\max}$	The convex resource-dependent processing times	[74]
BAT and GA	$F2 prmu, nwt C_{\max}$	Neighborhoods in a sequence	[115]
GA	$F2 C_{\max}, F$	Reducing the total energy consumption	[166]
Mixed integer programming	$F2 C_{\max}, T$	Parallel FSP reprocessing lines, and parallel reassembly workstations	[58]
The hybrid monkey search algorithm	$F2 C_{\max}, F$	A sub-population based NP-hard type bi-objective function	[80]
IDCOA	$F2 C_{\max}, F$	Minimized the makespan of a three-stage assembly FSP	[59]
(BBO)	$F2 C_{\max}, T$	Finalized the interfering job sets	[157]
Direct combinatorial algorithms	$F2 synmv, plbl C_{\max}$	Validated a mixed-integer program and a two-stage approach	[21]
Hybrid multi-objective evolutionary algorithm	$F2 AG_{1,2} C_{\max}, T_{\max}$	Minimized the makespan and the total tardiness of the first agent and the second agent respectively	[41]
A novel decoding method for job permutation and GA	$FH3, FHm \left(\left(RM^{(k)} \right)_{Mk=1} \right) M_j \sum T_j$	Dynamic scheduling to avoid tightness problem and job re-sequencing	[174]
SWWO	$F2 prmu, nwt C_{\max} \pi^*$	A single-wave mechanism for the NWFSF	[177]
B&B	$F2 CVaR, no-wait C_{\max}$	Robust scheduling approach under resource availability, uncertainty and cycle time	[158]
B&B	$F3 w_{i1}, w_{i2} C_{\max}$	Randomly generated instances in a reasonable amount of the CPU time	[57]
Hybrid Lagrangian metaheuristic <i>via</i> . volume algorithm	$F2 CD C_{\max}$ and $F2(P) CD C_{\max}$	The cross-docking FSP and a time-indexed formulation	[40]

TABLE 6. Research on C_{\max} and $\sum C_j$ for Fm no-wait flow shop scheduling problems.

Algorithm	Problem	Findings	Reference
B&B	$Fm prmu C_{\max}$	An arbitrary number of machines	[20]
B&B	$Fm prmu C_{\max}$	A new lower bound	[9]
Heuristics	$Fm prmu, nwt C_{\max}$	Infinite intermediate storage	[121]
The SPT-LPT rules	$Fm nwt C_{\max}, F$	Mean flow time criterion	[110]
B&B	$Fm prmu C_{\max}$	Computation reduced by over 50% for some more significant problems	[114]
B&B	$Fm prmu C_{\max}$	Some proposed new lower bounds for a B&B method	[87]
A TSP and approximate algorithm	$Fm SDST, block C_{\max}, T$	Approximate solutions to the infinite storage space cases	[48]
Optimality conditions	$Fm prmu C_{\max}$	Formulated a generalization of the classical FSP	[150]
An additive model	$Fm prmu, SDST C_{\max}$	Examined the performance of the additive approximation	[151]
Specially structured processing time matrices	$Fm nwt C_{\max}$	Specially structured distance matrices for the TSP	[159]
A new B&B	$Fm prmu C_{\max}$	Schedule for the permutation FSP	[54]
A heuristic algorithm	$Fm prmu C_{\max}, I_{\text{sum}}$	Minimized the number of machine idle intervals	[68]
Simple heuristic algorithm	$Fm NWT C_{\max}$	Heuristic preference relations and job insertion	[119]
Heuristic algorithms	$Fm SDST C_{\max}, F$	Separable and SDST	[50]
Heuristics TS and SA	$Fm prmu C_{\max}, F$	Permutation FSP with batch setup times	[147]
Lagrangian relaxation technique	$Fm prmu T_{\max}, F$	Introducing the virtual sequence	[75]
GA	$Fm prmu C_{\max}, F$	Processing times dependent on resources	[52]
Enhanced TSP-based heuristic	$Fm s_{ijk}, prmu C_{\max}$	Hybrid heuristics for the SDST flow shop and the TSP	[85]
B&B	$Fm s_{ijk}, prmu C_{\max}$	Evaluated a B&B scheme for the SDST FSP	[84]
B&B and proposed Allahverdi and Aldowaisan heuristic (PAAH)	$Fm nwt C_{\max}, C_w, F$	Bicriteria of minimizing a weighted sum of makespan and TCT	[5]
Hybrid discrete particle swarm optimization (HDPSO) algorithm	$Fm nwt, prmu C_{\max}$	No-idle permutation FSP criteria	[105]
HDDE	$Fm nwt, prmu C_{\max}$	Permutation to balance global exploration and local exploitation	[28]
A constructive heuristic and Rajendran and Chaudhuri heuristic, and Bertolissi heuristic	$Fm nwt, d_j F$	Principle of the initial sequence	[130]
Hybrid genetic algorithms (HGA)	$Fm SDST, prmu C_{\max}$	SDST condition to hybrid GA	[88]
Hybrid metaheuristic evolutionary cluster search (ECS_NSL)	$Fm ST_{sd}, no-wait, r_j C_{\max}$	SDST to an evolutionary method (ECS_NSL)	[96]
MBO	$Fm prum, SDST C_{\max}$	Permutation FSP with SDST	[14]
Multi-objective NEH-MONEH-MMOIG algorithm	$Fm prmu C_{\max}, F$	Productivity-related criterion and a sustainability-related criterion	[31]
BRILS	$Fm prmu C_{\max}, \Psi$	Non-smooth objective function	[39]
VBGA and AIS	$Fm prmu C_{\max}$	Immune-genetic algorithms to the permutation FSP	[15]
Integer linear programming approach	$FFm nwt, block C_{\max}$	Two-stage flexible flow shop with a shared buffer	[42]
MNEH constructive heuristics	$Fm nwt C_{\max}$	A set of 2000-jobs and 20-machine problems hard-and-large NWFS problems	[72]

TABLE 6. (Continued.)

Algorithm	Problem	Findings	Reference
Hybrid metaheuristic (ACO-SA)	$Fm nwt C_{\max}, F$	Ant colony algorithms with the simulated annealing	[122]
An enumeration algorithm	$Fm nwt, d_j C_{\max}$	Release date constraints and makespan criterion	[128]
HDTPL	$Fm nwt C_{\max}, D$	Hybrid discrete optimization	[134]
Hybrid PSO algorithm	$Fm nwt, TFT C_{\max}$	Minimizing TFT with relatively low computational efforts	[16]
BS-HH	$Fm prum C_{\max}$	Distributed assembly permutation flow-shop scheduling problem (DAPFSP)	[73]
CMA	$Fm prmu C_{\max}, T_{\max}, F$	CMA for solving the multi-objective distributed permutation flow shop scheduling problem (MODPFSP)	[29]
MBGA based on NSGA-II and NEH	$Fm prmu, block C_{\max}, F$	Total flow time under blocking constraints	[102]
Heuristics, CDR by GP	$Fm SDST F_{ave}, T$	Effective CDRs for solving a DFFL problem	[56]
Two quadratic MIPs, and two constraint programming (CP) models and the exact enumeration algorithm	$Fm nwt, dj C_{\max}$	Release date constraints and makespan criterion	[129]
Metaheuristic based on probability teaching-learning mechanism (mPTLM)	$Fm nwt C_{\max}, F$	Hybrid mTLBO	[136]
HHS	$Fm n m P C_{\max}\pi_i, m_j$	Efficient job-sequence mapping scheme	[176]
DWWO	$Fm no-wait C_{\max}$	WWO algorithm to avoid falling into the local optima	[177]
PAAH	$Fm no-wait \varepsilon(TT/C_{\max})$	Reduces the error of the best existing algorithms A-FISA, A-MNEH, A-AIG1, R-ILS, and R-IGA by 60%	[6]
TPM	$Fm nwt, ST_{si} C_{\max}$	Sequence-independent and SDST	[171]
Hybrid ACO	$Fm P_{jk}, O_{ji} C_{\max}(\Pi) = MC(\Pi)$	HACO has found the smaller average NRPD than ALA and GEN-2	[36]
IG	$Fm p^{j,h,r+1}, p_{i,h,r} TFT(\Pi), p_{i,h,r}$	YND6 is validated through comprehensive statistical experimentations	[67]
DWWO	$Fm no-wait C_{\max}$	Integrated the IG algorithm into the framework of the WWO	[179]
IGA	$Fm c_{j,k,f}, T_{k,f} C_{\max}$	Distributed permutation blocking flow shop scheduling problem (DBFSP) allowed the modelling of the scheduling process	[124]
ACSNDP	$HFSP(m > 3) FK$	Exploitation abilities of ACO/ACS	[61]
FPAPSO and VNS	$(Pm_1, \dots, Pm_k) size_{ij} C_{\max}$ $Fm nwt C_{\max}(\Pi)$	Avoiding the particles being trapped in local optima	[179, 180]
MINLP and HILS	$H_{ij-k} M$	Size dimensionality, computational time, and solvability	[184]
DLR-DNEH	$1 TC_{\min}, cost_{\text{setup}}$ $Fm prmu C_{m,j}, C_{\max}$	DPFSP with total flowtime criterion	[108]
MILP	$F nwait, s_{i,j,k}, PM(j) C_{\max}$	Preventive maintenance (PM) operations are integrated with m -machine NWFSF	[90]

Zhao *et al.* [177] recommended the future work as if higher efficient local search tactics can be applied to the two parts. Thus, the performance of the DWWO algorithm will be superior. Engin and Guclu [36] proposed that parallel applications be grouped and cross-combined and that the characteristics of no-wait flow shop scheduling techniques be tuned.

Ying and Lin [171] refer several possible directions for further research first by extending the proposed TPM algorithm to solve $Fm|nwt, ST_{si}|C_{\max}$ and $Fm|nwt, ST_{sd}|C_{\max}$ problems with other constraints, such as those with considering ready times. The future study may consider setup times or the option of using a standardized or independent flow shop [124]. It is usually the case that firms purchase new lines to boost ability, thus outperforming older lines. Both aspects link the problem closer to most industrial environments. Kurdi [61] suggested that the fundamental concept behind the suggested Non-DaemonActions is a promising study issue. It is worth further investigation of other optimization problems as it yields improved premature convergence, primarily applied to HFSPMT, which is the case of optimization problems too intractable combinatorial.

Zhao *et al.* [179] directed the need to change the factorial representation to decrease the algorithm's complexity with the option of encoding different evolutionary algorithms. The latter involves a biogeography-based optimization and differential evolution algorithm to address the NWFS issues. Zohali *et al.* [184] directed future research as outspreading the problem and research outcomes to other economic lot-sizing sequencing problems (ELSPs) on various shop floors. The suggested ELSP-HFS may be expanded to instances where distinct products have distinct cycle times.

4.2. Research results and recommendations on $\sum C_j$ for Fm

Xiao *et al.* [164] defined overlapping operations to the no-wait job shop environment in which distinct products can follow distinct routes. Bai *et al.* [11] researched the flexible flow shop scheduling problem to decrease total k -power completion time ($Fm|r_j|\sum C_{jk}, k \geq 2$). Thus, the B&B algorithm is provided to optimize the small-scale cases where lower bound and branching rule efficiently saves runtime.

Shahvari and Logendran [132] suggested more parameters of the problem, such as capacities for job processing, different machine eligibilities, changing machine availability times, changing job release times, and the stage skipping possibilities. Pessoa and Andrade [111] recommended a primal-dual gap of up to 8% for the remainder of the cases as the future direction of work for new research avenues. For instance, the structural characteristics of the issue could be recognized to design better upper limits. The aim is to provide a more precise validation of the quality heuristic approaches.

4.3. Research results and recommendations on C_{\max} for FFm

Fung *et al.* [42] pointed to the extended minimal covers, and the integer programming model with valid inequalities are the causes. The investigation of the structure of a typical schedule can be a future direction. Liu *et al.* [76] recommended the unlimited capacity of the buffers. Since the scheduling issue with the state-dependent setup time is a reasonably new study subject, the complexity findings are still open. The IoT-based scheduling practice and methodologies will attract researchers to optimize the energy efficiency target and fuzzy feature of the problem.

Zhonghua *et al.* [181] implemented variable processing time (FFSP-VPT) to solve a flexible flow shop problem. This paper simulated the selection mode of jobs, detection, processing time, and rework mode. It establishes the FFSP-VPT model and sets up a no-wait two-step encoding mode.

Dios *et al.* [32] analyzed the empirical hardness, an in-depth study of distinct processing times. Besides, the missing activities can occur at any phase of the shop, and these could be worth studying.

Because of the research gap of this kind of new problem $FFm|mixed, no-wait, ST_{SD}|C_{\max}$, many extensions such as designing exact methods and metaheuristics are worthy of further research in the future [23]. Zhao *et al.* [179] suggested the application of HBV to other combinatorial optimization problems, such as traveling salesman problems, job shop scheduling problems, etc. (Tab. 7).

TABLE 7. Research summary on C_{\max} for FFm no-wait flow shop scheduling problems.

Problem	Algorithm	Reference
$FFm SDST Cw, Tw$	MILP	[131]
$FFm nwt, block C_{\max}$	ILP	[42]
$FFm lsm C_{\max}$	MILP	[62]
$FFm SDST C, T_{\max}, Ww$	GA	[76]
$FFm(PM) retr C_{\max}, Zq, D$	MLPGA	[24]
$FFm(RM) T, T_{\max}, C_{\max}$	NSG	[65]
$FFm C_{\max}, F$	BAT and VPT	[181]
$FFm skip C_{\max}, W$	GA	[73]
$FHm(PM) skip C_{\max}$	Dispatching rule	[32]
$FFm ST_{sd}, rj, Mj, skip \sum wj, Tj$	PSO/LSA	[132]
$FFm mixed, no-wait, ST_{SD} C_{\max}$	MILP and PIG	[23]
$FFm nwt, IG C_{\max}$	HBV	[179]
$FFm w_1C_{\max} + w_2f C_{\max} \geq C_{js}$	PSO	[81]

4.4. Research results and recommendations on C_{\max} for Z_{cost}

Ziaefar *et al.* [182] recommended a grouping of the processor project with the hybrid flexible flow shop and can be a future research direction. It is assuming comprehensive consideration and engaging further heuristics or metaheuristics. Babaei *et al.* [10] proposed the future direction as the other metaheuristics application such as an imperialist competitive algorithm (ICA), particle swarm optimization (PSO), and simulated annealing (SA) to solve MILP model. It is only feasible by considering maintenance operations, infinite workstations and buffers among levels, the stochastic process time, machine breakdown, and invites additional participation.

Sukkerd and Wuttiornpun [149] recommended HGATS algorithm still has some limits. The lot-sizing strategy under concern is only a lot-for-lot. The impact of separate lot-sizing strategies has not been explored, and the overtime is not permitted. All job centers must have the same operational sequence as the permutation schedule. New metaheuristics such as ant colony optimization (ACO), particle swarm optimization (PSO) and simulated annealing (SA) should be examined to find out superior hybrid dynamic algorithms. Multi-criteria optimization and other renowned production shops such as flexible manufacturing shops and job shops and are the main focus here. Thus, more research is required to advance and analyze a novel algorithm to minimize restrictions.

Ramezani *et al.* [120] suggested time performance events. It could be regarded as mean tardiness, total completion time, maximum tardiness in place of the cost criteria. It is extending the proposed study to permit other production environments such as job shops and flow shops. Future studies should simplify the asymptotic optimality of the SPTA heuristics to explore the dynamic flow shop learning effect problem. Besides, some metaheuristics such as the local search scheme to DDE algorithm, should be simulated to get a relevant result for medium-scale problems.

Abikarram *et al.* [1] proposed a mathematical optimization model. It can manage up to 5 machines with 15 jobs per machine and 13 machines with four jobs per machine. It could be feasible to generate results with reasonable solution times without using specially designed metaheuristics. The development of a scalable metaheuristic to solve larger-size problems has been left for future work.

Biele and Monch [17] considered the planning techniques in a rolling horizon setting. The objective is to adjust the effect of many sources of uncertainty. It seems probable to extend the optimization and simulation background proposed by [17]. The simulation model can be used to look more specifically at the improbability of the objective function level. It could be possible by using simulation-based optimization techniques (Tab. 8).

TABLE 8. Research summary on C_{\max} for Z_{cost} no-wait flow shop scheduling problems.

Problem	Algorithm	Reference
$HFm(PM) \ C_{\max}, Z_{\text{cost}}$	GA	[182]
$Fm SDST Z_{\text{pih_cost}}, I_{\text{sum}}$	GA	[10]
$Fm \ Z_{\text{cost}}, F$	HGATS	[149]
$Fm SDST Z_{\text{pih_cost}}, C_{\max}$	Fix-and-relax heuristic (F&R)	[82]
$F2 \ C_{\max}, Z_{\text{cost}}$	MILP and ARIMA	[175]
$Fm \ Z_{\text{cost}}, W_{\text{ave}}$	I-ICA	[120]
$F2 \ Z_{\text{cost_pih}}, D$	Two-stage stochastic	[66]
$Fm E_{\min}, CT_{i,n,m} Z_{\text{cost}}$	TLBO and Jaya	[89]
$Fm r_j, le f_k(c_j)$	MIP and B&B	[12]
$Fm TWT, c_j Z_{\text{cost}}, C_{\max}$	Random-key GA	[17]
$Fm De * d + \sum w, e, E Z_{\text{cost}}(\min)$	Mathematical optimization model	[1]
$Fm \ Z_{\text{cost}}, F \ TEC(\min) \ C_{\max}$	AM-VNS	[163]

5. A QUANTITATIVE ANALYSIS OF THE LITERATURE

This review has examined about 300 papers, demonstrating the scheduling group, including hybrid flexible flow shop variants. This investigation surveys thoroughly other appraisals, as [29, 31] on multi-objective flow shop constructions and [8, 35] on hybrid flow shop problems.

A noteworthy feature of this scheduling group literature is that more than 58% of the documents have been published after 2010 (Fig. 1). Set over the apparent trend of a growing quantity of publications, while even small matched to those dedicated to other well-developed scheduling concerns, we can reason that FSP with due dates, costing, and lot-sizing are a hopeful field for further developments.

Figure 2 demonstrates the different flow shop problems that have been studied in the literature, showing the number of papers dedicated to each sort of objective utility and performance measure.

The completion-time based is by far the utmost recurrent objective functions: 47% of the papers' attention on them. A particular event of the completion-time module is makespan, covered by 62% of the written document. Additional classes of completion-time objectives are broken down into 16% of the publications. This fact is not shocking, giving the priority of makespan over added objective functions in the literature on scheduling, as directed in [23, 72]. The remaining 54% of the literature addresses other cases of objective functions. From them, release/due-date based objective functions represent only the 4%, lot-sizing 5%, and costing 4% of the publications, advising that these essential objective functions are under-presented, needing more profound attention. This fact has been underlined in particular in [1, 45, 66].

The circulation of the several optimization techniques employed in the literature is illustrated (Fig. 3). The exact approach mathematical programming and heuristics are mostly used, representing an equal highest share of 13% of the literature. Another exact approach B&B is showing 7% of the literature. Unique examples of metaheuristic, GA, SA, TS, PSO, NSGA II, NEH, MILP, DWWO, VNS/DVNS, ACO, BBO, TLBO, BRILS, and greedy error optimization algorithms are the most commonly used approaches of solution.

The exact approaches appear not to be the most satisfactory for the issue of medium and large size problems. The heuristics and metaheuristic approaches have proved able to bring forward solutions for them of excellent and outstanding caliber. On the other side, the tested metaheuristic methods bring better results than previous ones. [157] put on metaheuristics (A-BBO) to an optimized m -machine scheduling problem with merging job sets. These jobs fit two different agents, one of whom was minimized the maximum completion time of jobs, and the other minimized the total tardiness at the same time. Similarly, meta-heuristic suggested a Lagrangian methodology with parallel-docks and time-indexed formulation for cross-dock FSP.

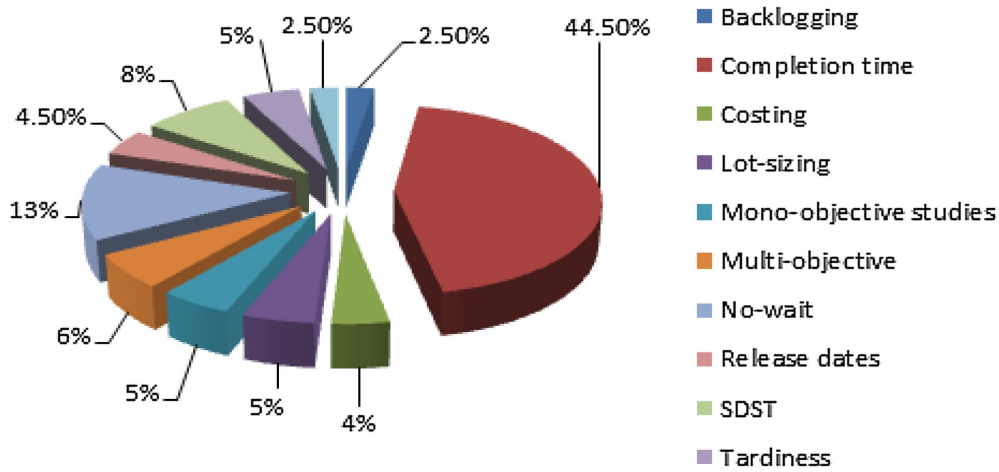


FIGURE 2. Distribution of objective functions considered in the literature.

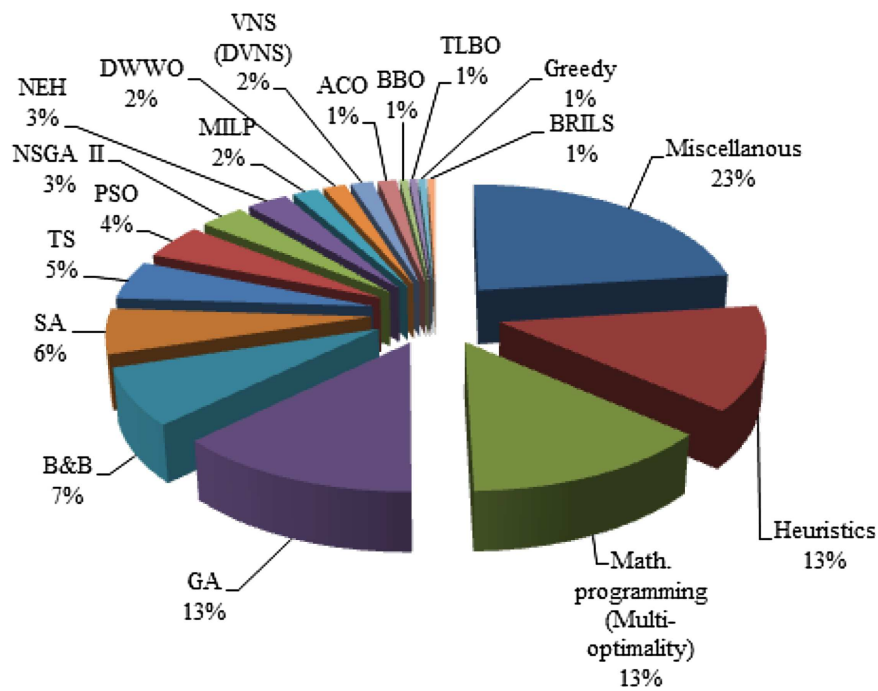


FIGURE 3. Distribution of optimization tools used.

5.1. Bibliometric analysis

It is also of concern to present some bibliometric evidence in the literature on FSP. We adopt the style of other analyses, such as [71, 86, 131, 155] who demonstrated that bibliometric statistics could be convenient for the assessment of the study on a new topic. The relevant facts include the list of journals in which papers have been published, the frequency of publication, and its impact. Graham *et al.* [46] focused his attention on the

TABLE 9. List of journals depicting two or more articles published on FSP.

S. no.	Journal name	Papers count	Percentage
1	Computers & Industrial Engineering	30	10
2	The International Journal of Advanced Manufacturing Technology	29	9
3	Computers & Operations Research	26	8
4	European Journal of Operational Research	24	8
5	Journal of the Operational Research Society	22	7
6	Applied Soft Computing	19	6
7	Expert Systems with Applications	17	5
8	Annals of Operations Research	12	4
9	Journal of Cleaner Production	10	3
10	IFAC-PapersOnLine	10	3
11	International Journal of Production Economics	10	3
12	AIIE Transactions	8	3
13	Swarm and Evolutionary Computation	8	3
14	Journal of Manufacturing Systems	8	3
15	Omega	8	3
16	Management Science	7	2
17	Applied Mathematical Modelling	7	2
18	Engineering Applications of Artificial Intelligence	8	3
19	Global Journal of Flexible Systems Management	7	2
20	Procedia Engineering	7	2
21	OR Spectrum	7	2
22	International Journal of Industrial Engineering: Theory, Applications and Practice	4	1
23	Miscellaneous	26	8

Notes. Percentile calculated over the total of papers reviewed.

latter in the amount of citations reported by Google Scholar when the article was obtained. This fact implies, in our case, June 2019.

The journals mentioned in Table 6 present the review work published in two or more papers. Accordingly, the Computers & Industrial Engineering Journal and The International Journal of Advanced Manufacturing Technology have remained the outlet for 10% and 9% of all the articles respectively in the area. The Computers & Operations Research Journal and European Journal of Operational Research are closely tracing to each other by a published count of 26 and 24 respectively. As far as conference proceedings are concerned, we consider and have written those indexed in Google Scholar and Scopus.

Journals covering at least one article published on FPS are Annals of Discrete Mathematics, Acta Mathematica, Applied Mathematics and Com, Archives of Civil and Mechanical Engineering, Chinese Journal of Mechanical Engineering, CIRP Annals-Manufacturing Technology, Information Sciences, Inform Journal of Computing, Journal of Applied Mathematics and Computing, Knowledge-based Systems, Naval Research Logistics, Procedia Manufacturing, and Production Engineering (Tab. 9).

6. CRITICAL REVIEW

This article classifies permutation and non-permutation scheduling group problems with the no-wait constraint. The machine and job inputs, manufacturing and assembly lines, setup types, performance measures, dynamic shop environments, and other parameters are the basis. Many possible research venues are proposed. Some articles have individually analyzed the problems. For instance, the problems such as $F3||C_{\max}$, F were independently addressed by around ten papers, and their results have not been validated. The core permutation

problem such as $F2||prmu, rj|L_{max}, F$ and $F3||prmu|C_{max}, \sum D$ were addressed by 25 papers which are fully validated from the results. On the other side, $F2||nwt|C_{max}, F_{ave}$ problem which is a core non-permutation no-wait problem, has addressed by about 20 papers. Wang and Liu [160] addressed one problem $F2(PM)|NWT|climax$, which is an ideal example of permutation and non-permutation with the no-wait constraint. The beauty of this problem is that it has considered the two-stage no-wait hybrid flow shop problem with a single workstation on the first stage (Tab. 2). The multiple parallel identical workstations on the second stage have to minimize the makespan, considering the NP-hardness of the problem. As the future scope of this problem, researchers can continue perspective to assembly line balancing where the m -machine concept is there.

Since the latest problems of the year 2018 and 2019 such as $FH3, FHm((RM^{(k)})_{Mk=1})|M_j|\sum T_j$ [174] becomes a one-of-the most excellent problem as it is referring to a novel programming method for job permutation demonstration. It suggested the dynamic scheduling that utilizes a mechanism to capture the machine to prevent problems with tightness. The job resequencing strategy in workstation buffers is also recommended to moderate the controllability problem. Similarly, problems such as $F2|CVaR, no - wait|C_{max}$ [158] has focused on the residual work content to conditional value-at-risk (CVaR) of the problem. The problem $F3|w_{i1}, w_{i2}|C_{max}$ [57] stressed on overlapping waiting time constraints. The dual-problems $F2|CD|C_{max}$, and $F2(P)|CD|C_{max}$ [40] have focused on Lagrangian metaheuristic approach for the parallel-docks to cross-dock FSP. However, assembly line balancing (ALB) operations and release-date associated performance measures are only addressed in about 12% of the articles. Therefore, more research on scheduling problems with due/release date and dual ALB performance measures is needed.

The infinite mainstream of research has addressed the job-end time associated performance events, *i.e.*, C_{max} and $\sum C_j$. The C_{max} performance measure was discussed by more than 55% of articles, while approximately 20% of articles discussed the performance measurement of $\sum C_j$. Performance measure $\sum C_j$ measures the hybrid open shop and job shop and environments. The performance measure C_{max} explains the flow shop environment. However, Shahvari and Logendran [132] have addressed problem $HFM|ST_{sd}, r_j, M_j, skip|\sum w_j, T_j$ in which two MILP models were established to find the precise results. It has developed excellent class lower bounds to assess non-exact techniques with due date constraint correspondingly. The critical aspect here is the identification of performance measures. Similarly, job due date performance measure is also addressed in about 10% of papers. Further, the related performance investigation on scheduling problems with release/due-date interrelated performance procedures is needed.

Regarding the latest research articles, problem $F_m|nwt, ST_{si}|C_{max}$ [171] addressed one grouping and cross-combination of two performance measures, SISTs, and SDSTs for the very first time. Another problem $Fm|c_{j,k,f}, T_{k,f}|C_{max}$ [124] has focused on one research gap which has worked very first time on total tardiness with parallel blocking. It has got attention in the research community. Only 1% of work has been done on this issue, which is novel with the meager work done on the hybridization of parallel blocking issues.

The permutation and non-permutation scheduling problems of real-life address supplementary than a solo-criteria, *i.e.*, multiple-criteria, organize about 18% of the papers. Most of the current results are for flow shop scheduling environments. Therefore, hybrid open shop or job shop scheduling problems with multi-objective for permutation and non-permutation with the no-wait constraint and its performance measures are venues for new research.

7. CONCLUSION AND FUTURE INTERVENTIONS

The permutation and non-permutation scheduling with the no-wait constraint have addressed mainly in chemical, manufacturing, plastic, processing, and pharmaceutical industries. It is essential to take the right scheduling decisions to increase productivity and reduce waste. Therefore, scheduling with the no-wait will grow interest in the industries and among researchers.

The work synthesized here has been classified as per the alternatives of the scheduling problem undertaken in them, containing the constraints, objective functions, assumptions, and result approaches functional by the researchers. The completion-time based performance measure is found the most frequent among no-wait flow

shop problems. The makespan as the objective function is the most intensively studied as more than half of the articles. The other multi-objective criteria and optimization approaches such as due-date and cost analysis, are under-represented in the literature and have covered in less than a quarter of all the publications.

The no-wait constraint under permutation and non-permutation problem is a latest and underdeveloped research theme (matched with conventional production scheduling group), and thus an encouraging subject for advance research directions. This critical review encourages us to recommend some related appraisal issues.

(i) The formulation of the bi-criteria problem based on grouping and cross-combination of PFS and NPFS approaches. (ii) The comparative investigation of PFS and NPFS approaches to dynamic and conflicting markets multi-objective problem(s). (iii) The framing of the heuristics matrices for trial and error of machine scheduling about the process index. (iv) The determination of the simulation-optimization approach for batch control and work-in-process. (v) The NPFS with release date and cost-based objective purposes. (vi) The factual case studies are validating the due-date and cost issues. (vii) The execution of novel metaheuristics to report complicated NPFS systems. (viii) The NPFS problems with three or supplementary objectives. (ix) The scheduling uncertainty is an attention-grabbing problem for which rescheduling could aid in advance clarifications.

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