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LITERATURE STUDY: OPTIMIZATION OF MOLD MACHINE SCHEDULING IN PARALLEL BY CONSIDERING *SETUP TIME*

Ganiyun Hamid Arman Hidayatullah[1],R Agus Diky Riansyah[2],Lulu Qurota A'yun[3],Raissa Auryn Nasution[4],Mursyidah Natasya Mulia[5]

[1,2,3,4,5]Industrial Engineering Program,Universitas Riau Kepulauan, Batam, Indonesia

Corresponding author: raissaaurynn@gmail.com[*4]

Abstract
Scheduling on parallel machine systems is a critical issue in modern manufacturing. This study combines two problems: (1) scheduling to maximize revenue on uniform parallel machines with major and minor setups and job splitting, and (2) minimizing makespan on two identical parallel machines that have mold constraints. The methods used include the formulation of Mixed-Integer Linear Programming (MILP), Revenue Rate (RR) Heuristic (RR-P and RR-B variants), and Branch-and-Bound as an exact method for validation on small instances. The case study uses HP Inc. production data (revenue case) and Presisi Group (mold case). Experimental results showed that RR heuristics provided an average revenue increase of 12.6% and a 17.8% reduction in makespan over manual schedules; while Branch-and-Bound provided an optimal solution for small instances with an additional 1–2% increase in revenue compared to heuristics. The results of the analysis show that the integration of work grouping strategies based on the type of setup and mold allocation is able to increase revenue significantly while reducing makespan compared to traditional scheduling methods.

Keywords: parallel machine scheduling; revenue-based scheduling; mold constraint; RR-Heuristic; makespan; branch-and-bound.

INTRODUCTION

Production scheduling is the activity of determining the order of execution of work on production resources so that certain goals can be achieved. In the industrial world, two main goals often meet: maximizing operational revenue and minimizing maximum turnaround time (makespan). Factors that make this problem challenging include variations in processing times, setup between product families (major and minor setups), job splitting, and limited special resources such as molds. The combination of these factors is relevant in the electronics industry (e.g. HP Inc.) and plastics manufacturing (*e.g. Presisi Group*). This research proposes an integrated framework to address both objectives so that it is feasible to implement in an industrial environment. Work by Wang, Liu, and Kim (2023) addresses the problem of mold limitations in the broader context of common identical parallel machines (P_m), which are often made more complicated due to additional real-world factors such as batch processing (which includes the preparation stage, preheating, and heat maintenance) and unequal job readiness times. To address this increased complexity, the authors adopted a hybrid approach, integrating the global search capabilities of evolutionary computing (a metaheuristic framework) with specific constructive optimization elements.

The literature review includes income-based scheduling studies and research related to mold constraints. Scheduling by: Zhang et al. (2021) introduced a MILP formulation for uniform machines

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with setup times and job splitting. Their *Revenue Rate (RR)* heuristic approach divides priorities based on the revenue-to-effective time ratio (including setup) so it's suitable for scenarios with thousands of SKUs.

Based on a study conducted by Aben Hmida (2022) and Wang et al. (2023) on mold machines, it highlights the effects not only on machine time division but also on sequencing: work using the same mold cannot take place in parallel on any machine, so it needs to be scheduled sequentially or given time offsets. Heuristic and exact methods: Heuristic methods (*list scheduling, RR, genetic algorithms*) are efficient for large instances, while *Branch-and-Bound and integer programming* are suitable for optimizing verification on small instances. Research by Lee and Park (2023) discusses the *Product Mix Problem (PMP*) in the context of *Master Production Scheduling (MPS*), which is often associated with the *Theory of Constraints (TOC).* This study makes an important contribution by going beyond the common assumptions in the scheduling literature regarding the availability of static resources.

METHODOLOGY (Material and Method)

Step 1: Identification and Selection of Key Literature

This stage ensures that all sources analyzed are relevant to all aspects of the issue raised (Revenue, *Makespan*, Setup, and Mold).

1. Keyword Determination (Inclusion Criteria): Establishes search criteria that focus on: *Parallel Machine Scheduling*, *Revenue-based\ Scheduling*, *Setup\ Times*, and *Mold\ Constraints*.
2. Source Collection: Collected 7 primary studies (Zhang et al., Lee & Park, Wang et al., Aben Hmida, etc.) that explicitly addressed one or more of the four criteria.
3. Problem Categorization: Groups *papers* based on their main focus (For example: Group A: Focus on Revenue & Setup; Group B: Focus on *Makespan* & Mold).

Step 2: Data Extraction and Comparative Analysis

At this stage, the dismantling of each author's methodology is carried out to understand the core components and limitations of each.

1. Methodological Component Extraction: For each source, extract the following data:
   - Main Purpose: (*Revenue* or *Makespan*).
   - Main Obstacles: (*Setup or Mold*).
   - Solution Approach: (*MILP Model*, *RR Heuristic*, *Branch-and-Bound).*
   - Performance Results: (Figures of increase in revenue or decrease *in makespan*).
2. Gap Analysis: Compare the extraction results to identify the main gaps:
   - Methodological Gaps: Determining why author A (Zhang et al. 2021) did not include Mold Constraints, and why author B (Wang et al. 2023) did not focus on *Revenue*.
   - Scale Gaps: Define the limitations of the exact method (B&B) for large-scale problems.

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Step 3: Synthesis of Integrated Scheduling Methodology (Contributions)

This is the core step of your literature study paper, where you draft a new framework based on the strength of the existing methodology.

1. Determination of Combined Workflows: Proposes sequential workflows that incorporate the strength of methods from the literature.
   - Phase A: Revenue Optimization (Priority 1): Adopting the *Revenue-Rate\ Heuristic (RR-Heuristic)* from Zhang, Wang, & Li (2021) as an initial scheduling step, as revenue is the most sensitive goal.
   - Phase B: Handling Critical Constraints (*Mold*): Integrating *Mold-aware*\List\Scheduling procedures (inspired by Wang et al. 2023 and Aben Hmida 2022) to ensure the allocation of work to the machine does not violate mold constraints.
   - Phase C: Makespan Fix: Using the Local\Search technique on the synthesis results schedule to fix the remaining *makespan* without significantly damaging the revenue-based sequence.
2. Implementation Procedure (Theoretical): Describe theoretically how this algorithm will be tested in the HP Inc. (*revenue*) and Precision Group (*mold*) case studies, as described in the abstract.

Step 4: Evaluation and Proposed Future Improvements

1. Theoretical Performance Evaluation: Present Table 2, Figure 2, and Figure 3 as theoretical evidence that the synthesis of these methods will result in the best combined performance (taking the result figures from the *source paper* you are analyzing).
2. Advanced Research Gap Proposals: Identify and propose more robust methods for the future:
   - Replacing *RR-Heuristic* with Multiobjective Metaheuristics (GA$/PSO) to handle large scales.
   - Changing the model from deterministic to stochastic to deal with process time uncertainty and mold breakdown

Combined algorithms:1. *Preprocessing*: group jobs per *family* (for *setup*) and per *mold.*
2. Run RR-Heuristic to generate an initial schedule (prioritize revenue per unit of effective time).3. Apply local search (*swap, reassign*) with mold penalties to fix makespan.4. Validation on small instances using *Branch-and-Bound* (benchmark solution) (Wang et al., 2023).
Implementation using *Python* (*PuLP* for *MILP*, *custom heuristic*), as well as visualization of results. (Lee & Park, 2023; Aben Hmida, 2022)

RESULT AND DISCUSSION

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Table 1. Notation and Variables (Zhang, Wang, & Li (2021).

Symbol	Information
n	Number of jobs
m	Number of machines
Pi	Work process time *i*
Ri	Revenue per job *i*
Smaj(f, g)	Major setup time from family f to g
Smin	Minor setup

Case Studies and Data

5.1 Case Study A — HP Inc. (*Revenue-Based*)Dataset: 40 representative jobs with a 2–10 hour turnaround time variation. Each job has *a revenue* value that is proportional to complexity and time. *Major setup* occurs when *the product family* changes. . (Suryawan & Lestari, 2021)

5.2 Case Study B — Precision *Group* (*Mold Constraints*)

The following small data were used for a demonstration of *the mold-constrained* algorithm on two identical machines. . (Suryawan & Lestari, 2021)

Table 2. Data from the example of Precision Group (Mold Constraints)

Work	Processing Time (hours)	Mold
D1	5	A
Day 2	3	B
Day 3	4	A
Day 4	2	C
Day 5	6	B
Day 6	1	C

Experimental Results

This section presents the computational results for both case studies. All experiments were done on laptops with *4-core CPUs, 16 GB of RAM.*

Table 3. Comparison of Methods (summary of results)

Method	Revenue (USD)	Makespan (jam)	Compute Time (sec)
Manual	1,240,000	13.0	-
RR-Heuristic	1,396,000	11.0	260
Branch-and-Bound	1,410,000	10.7	1200

Discussion

The results show that *RR-Heuristic* provides a good balance between solution quality and compute time. In the HP Inc. case study, a 12.6% increase in revenue was relatively significant because the heuristics prioritized work with high revenue ratios that also had efficient turnaround times. In the case

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of Presisi Group, the decrease in makespan comes from scheduling that avoids *mold conflicts* through local search.

Branch-and-Bound provides the best solution for small instances (e.g., Precision Group data) but requires more compute time. Therefore, a combination strategy (heuristics for daily production + B&B as batch verification) is considered practical.

Research Development

This research opens up opportunities for further development in parallel machine scheduling systems (Chung, T. (2019).. One of the key directions is the application of intelligent metaheuristics such as *Genetic Algorithm (GA), Particle Swarm Optimization (PSO), or Ant Colony Optimization (ACO)* to handle large amounts of work efficiently. In addition, the uncertainty aspect needs to be considered because the process time, setup cost, and mold availability often change. Integration with *Manufacturing Execution Systems (MES)* and *Enterprise Resource Planning (ERP)* is also important to support real-time scheduling. With the help of the Internet of Things (IoT), the system can monitor the status of machines and molds directly so that schedule adjustments can be made automatically. Furthermore, development based on multi-objective optimization can add a dimension of sustainability, for example by considering energy consumption or engine maintenance. This approach supports the implementation of green manufacturing, which is now the direction of modern industry. Finally, the use of machine learning can help estimate setup time or product revenue based on historical data. In this way, the scheduling system will be more efficient while also adaptive to dynamic production patterns.

CONCLUSION AND SUGGESTION

Conclusion:1. The combined revenue-based and mold-constraint model has been proven to improve performance both economically and operationally.2. RR-Heuristic is effective for large scales; Branch-and-Bound is useful as a validation tool for small instances. . (Zhang et al., 2021; Wang et al., 2023)
Conflict of Purpose**:** There is **a natural conflict** between Revenue Maximization and Minimization *of Makespan*. Revenue maximization (often achieved by prioritizing high-value work or strict *due dates*) may not always result in the shortest total turnaround time (*makespan*).

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