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Methods for Assembly line balancing and worker allocation problem: an Overview

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Abstract
This paper presents a comprehensive tertiary-level review of solution methods for Assembly Line Balancing Problems (ALBP) and Worker Allocation Problems (WAP), synthesizing insights from 25 literature reviews published between 2006 and 2024. Unlike prior reviews, this study critically evaluates methodological trends, practical relevance, and the alignment between academic proposals and industrial implementation. Metaheuristic approaches, especially Genetic Algorithms, dominate literature, yet their adoption in real-world settings remains limited. The review also highlights the emergence of hybrid and AI-enhanced strategies, the growing attention to explainability and adaptability, and the methodological shortcomings of existing reviews regarding transparency and contextual analysis. This work contributes a structured taxonomy of methods, assesses their suitability across problem dimensions, and identifies future directions emphasizing industry integration, real-time responsiveness, and robust evaluation frameworks.

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1. Introduction

The Assembly Line Balancing Problem (ALBP) has been investigated for decades, originally framed by Salveson (1955), and it remains a central issue in operations management. Its classical forms (minimizing the number of stations for a given cycle time or minimizing the cycle time for a fixed number of stations) have evolved significantly (Scholl & Becker, 2005). Traditional models, however, often neglect real-world complexities such as multi-task stations, worker heterogeneity, and dynamic production demands.

The introduction of U-shaped lines and worker-sharing models led to variants like the Assembly Line Worker Assignment and Balancing Problem (ALWABP), addressing some of these practical constraints (Nakade & Ohno, 1999). More recently, the Worker Allocation Problem (WAP) emerged as a simplified, implementation-focused version of ALWABP, assuming fixed task sequences and targeting more realistic deployment (Battarra et al., 2021). In this context, WAP is commonly formulated as a double assignment problem, involving the allocation of tasks to workstations and the assignment of workers to these stations. Consequently, multiple and often conflicting objectives such as minimizing the number of workers, balancing workloads, and reducing walking time are considered, leading to the use of multi-objective optimization approaches (Sirovetnukul & Chutima, 2009).

Although numerous methods, such as exact, heuristic and metaheuristic, have been proposed for these problems, most reviews are either broad or outdated, and few critically evaluate solution methodologies within operational contexts. This review addresses that gap by offering a structured and comparative examination of solution strategies.

The following research questions guide the analysis:

RQ1: What solution methods have been proposed for ALBP and WAP?

RQ2: Which methods are most frequently used across literature?

RQ3: What are the strengths and limitations of methods?

1.1 Novelty and contribution of this overview

Unlike recent high-impact reviews that focus on specific problem variants, technological contexts, or methodological developments (e.g., Battaïa & Dolgui, 2022; Boysen et al., 2022; Petzoldt et al., 2023) this study provides a tertiary-level synthesis that critically analyses the review of literature itself. Rather than proposing new solution methods or problem formulations, this overview contributes by (i) systematically comparing how solution methods are reported, classified, and evaluated across reviews, (ii) identifying structural biases toward certain algorithmic families, and (iii) explicitly assessing the gap between methodological popularity and reported industrial application. In doing so, the paper generates meta-level insights that are not visible in single-review studies, particularly regarding methodological maturity, practical relevance, and reporting quality within the ALBP/WAP review literature.

2. Literature review

A considerable number of literature reviews have addressed ALBP. For instance, Scholl & Becker (2006) provided one of the foundational reviews that structured classical and modern problem variants. Later, Battaïa & Dolgui (2013) introduced sustainability aspects into balancing problems, and Boysen et al. (2022) offered a detailed examination of assembly line design strategies including recent technological developments.

While these studies have enriched the theoretical landscape, they tend to focus either on problem classification or on application context, without critically comparing the effectiveness, limitations, and trends among solution methods. For example, Scholl & Becker (2006) concentrated on precedence diagram structures but did not explore metaheuristic developments. Battaïa & Dolgui (2013) emphasized sustainable objectives but lacked a methodological deep dive into algorithmic strategies. and Boysen et al. (2022) proposed new research avenues yet offered limited synthesis of prior reviews.

In contrast, this paper offers a tertiary-level synthesis, which is review of 25 prior literature reviews from 2006 to 2024. This review identifies overlaps, contrasts, and gaps in the methodological content of those reviews. Specifically, we highlight which solution approaches have gained traction, how they evolved, and whether their practical deployment is considered.

This work makes a unique contribution by addressing the lack of a structured comparison of solution methods across reviews, a perspective that is also absent in the most cited works. Moreover, it provides a focused discussion on the alignment, or lack thereof, between theoretical advancements and industrial adoption, offering clarity to researchers seeking to enhance the real-world impact of their work.

In conclusion, although prior literature reviews have laid a strong foundation in understanding the ALBP and its variants, they often fall short in synthesizing methodological developments with a critical lens. This paper addresses that deficiency by not only categorizing and comparing the most prominent solution methods but also evaluating their practical relevance and limitations. By doing so, it bridges an important gap between theoretical development and industrial application, offering a structured resource for both researchers and practitioners.

3. Material and Methods

This tertiary review follows PRISMA and STARLITE protocols. The scope was limited to review articles published between 2006 and 2024, retrieved from Scopus and Web of Science. Reviews were included if they: (i) focused on ALBP or WAP; (ii) described at least one solution method; and (iii) peer reviewed. A total of 25 reviews were retained. Methods were coded by type, frequency, context, and reporting quality. We also performed quality assessment using criteria such as transparency of research, clarity of classification, and discussion depth. The way of achieved results – experiment, the case study.

3.1 Review Strategy and Protocols

This review follows a tertiary-level review model, synthesizing prior literature reviews. (Newman & Gough, 2020; Polanin et al., 2017). According to Schmid et al. (2024), systematic reviews of reviews provide an overview of prior research without deeply analysing primary studies, making them valuable for evaluating past research or supporting decision-making.

The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) is a set of guidelines that ensure clear and consistent reporting of review and meta-analysis methods, covering the process from literature search to result presentation (Page et al., 2021). Additionally, STARLITE (Further, the Sampling strategy, Types of studies, Approaches, Range of years, Limits, Inclusion criteria, Terms used, and electronic sources) defines standards for literature searches (Booth, 2006).

3.2 Search Process and Databases

A systematic search was conducted in three major databases: Scopus and Web of Science. The keywords used included: “Assembly Line Balancing Problem,” “Worker Allocation Problem,” “solution methods,” “heuristics,” and “review.” The search covered publications from 2006 to 2024.

The selection process involved an initial screening of titles and abstracts, followed by full-text evaluation. Backward snowballing was applied by screening the reference lists of the selected reviews. Forward snowballing was not performed.

Table 1 provides an overview of the STARLITE standards operationalized for this study.

Table 1. Operationalization of the STARLITE Standards for Systematic Reviews.

Element	Operationalizations in the present overview
S: Sampling strategy	Selective search for any type of reviews of the assembly line balancing or worker allocation problem
T: Type of studies	Any type of reviews
A: Approaches	Search in electronic databases
R: range of years	2006-2024
L: limits	Published in English and open access

I: inclusion criteria	Any type of review about ALBP, WAP, and solution methods for ALPB and WAP
T: Term used	Search string 1 (S1): Scopus: TITLE-ABS-KEY(("assembly line balancing" OR "assembly line balancing problem") AND ("solution method*" OR heuristic* OR algorithm*) AND review) Web of Science: TS=(("assembly line balancing" OR "assembly line balancing problem") AND ("solution method*" OR heuristic* OR algorithm*) AND review) Search string 1 (S2): Scopus: TITLE-ABS-KEY(("worker allocation" OR "worker assignment" OR "workload allocation") AND problem AND ("solution method*" OR heuristic* OR algorithm*) AND review) Web of Science: TS=(("worker allocation" OR "worker assignment" OR "workload allocation") AND problem AND ("solution method*" OR heuristic* OR algorithm*) AND review)
E: Electronic sources	Web of Science (WoS), Scopus

3.3 Inclusion and Exclusion Criteria

Initially, 121 papers were identified. The PRISMA methodology was applied through four phases, as represented in Figure 1:

Identification: Duplicates were removed, leaving 66 records.

Screening: 17 records were excluded, publications predating 2006.

Eligibility: 24 papers remained. Reviews that were not related to ALBP, WAP, or solution methods were excluded.

Included: 25 papers were selected for synthesis.

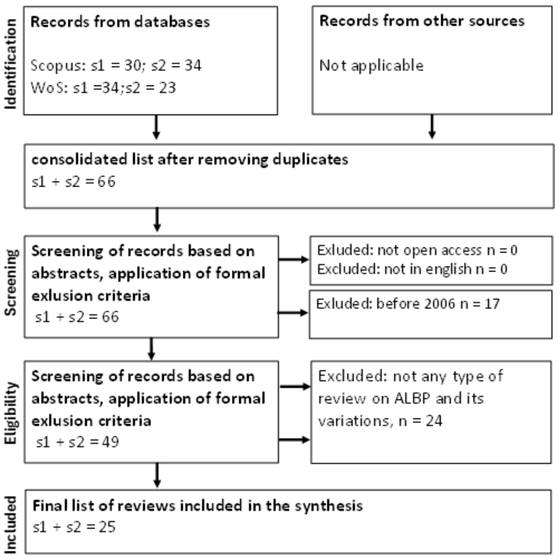

Fig. 1. PRISMA steps applied in the present study

3.4 Criteria for Industrial Application

To distinguish between methods discussed in the literature and those applied in industrial contexts, explicit classification criteria were adopted. A method was considered to have industrial application only when validation extended beyond benchmark or hypothetical instances.

Specifically, a study was classified as an industrial application if it explicitly reported at least one of the following evidences (E):

E1. Implementation in a real production or assembly line;
E2. Collaboration with an industrial partner;
E3. Use of real industrial data;
E4. Integration or compatibility with industrial systems (e.g., ERP or MES); or
E5. evaluation using operational performance indicators (KPIs) under real-world constraints.

Studies relying solely on benchmark problems, randomly generated data, or conceptual models were classified as discussion in literature.

In addition, studies that include realistic or industry constraints without explicit evidence of implementation in an operating production system. To avoid overstating industrial adoption, such borderline cases were conservatively classified as discussion in literature unless a clear link to at least one industrial application criterion mentioned in 3.4 was documented.

3.5 Coding Scheme and Classification

According to Polanin et al. (2017), the results of an overview can be summarized by describing each review separately, through descriptive synthesis, or via meta-analytic methods. This study primarily employed a descriptive synthesis to answer RQ1 and RQ3, while a quantitative descriptive synthesis approach was used to answer RQ2.

Content analysis began by organizing papers by author, year, publisher, source, document type, database citation, and type of review. Each paper was assigned an identification code (PP1, PP2, … PP25) for use throughout the analysis. See Table 2.

Table 2. Codes to identify the articles and citations

Paper	Author, year	Citations
PP1	(Aida Husna Ahmad et al., 2024)	0
PP2	(Thawfee Kur Rahman et al., 2023)	0
PP3	(Chutima, 2023)	4
PP4	(Boysen et al., 2022)	77
PP5	(Çimen et al., 2022)	3
PP6	(Mohammed et al., 2021)	1
PP7	(Jiao et al., 2021)	16
PP8	(Kharuddin & Ramli, 2020)	1
PP9	(Eghtesadifard et al., 2020)	54
PP10	(Chutima, 2020)	14
PP11	(Ayoub El Ahmadi et al., 2019)	4
PP12	(Razali et al., 2019)	12
PP13	(Hazir & Dolgui, 2019)	15

PP14	(Belfiore et al., 2018)	9
PP15	(Li et al., 2017)	79
PP16	(Sahu & Pradhan, 2016)	10
PP17	(Sivasankaran & Shahabudeen, 2014)	231
PP18	(Rashid et al., 2012)	158
PP19	(Boysen et al., 2008)	390
PP20	(Scholl & Becker, 2006)	716
PP21	(Becker & Scholl, 2006)	864
PP22	(Battaïa & Dolgui, 2013)	591
PP23	(Battaïa & Dolgui, 2022)	56
PP24	(Petzoldt et al., 2023)	12
PP25	(Yelles-Chaouche et al., 2021)	107

3.6 Criteria for methodological quality assessment

Following Polanin et al. (2017) and Gough (2007), the methodological quality assessment considered:

c1: Research question and inclusion criteria
c2: Written study protocol
c3: Justification for inclusion/exclusion of studies
c4: Comprehensive literature search
c5: Data collection methods
c6: Future research recommendations
c7: Limitations discussion

This study adapted elements from the AMSTAR 2 and EPHPP tools (Evans et al., 2015; Shea et al., 2007). Each category was scored as 0 (not done), 1 (done), or 2 (partially done).

4. Results

4.1 Output of publications from 2006 to 2024

Figure 2 presents the temporal distribution of the 25 selected literature reviews published between 2006 and 2024. The observed increase in reviewed publications over time, particularly after 2018, reflects not only a growing academic interest in assembly line balancing but also a response to the increasing complexity of modern manufacturing systems. This trend coincides with the diffusion of flexible manufacturing paradigms and Industry 4.0 initiatives, which have intensified the need for structured and comparative assessments of existing solution methods rather than isolated algorithmic proposals.

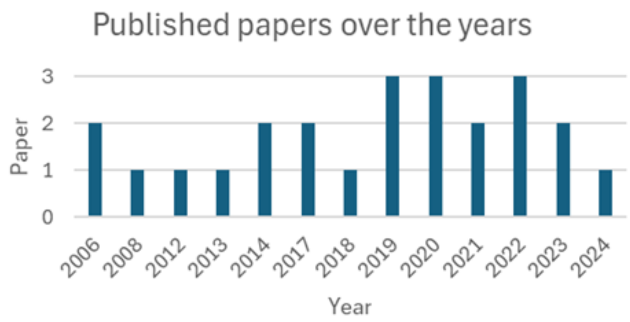

Fig. 2. Literature reviews across 2006 - 2024

The reviews vary in scope: some focus exclusively on ALBP, others target WAP, while several span a broader spectrum of balancing-related problems. Table 3 summarizes the focus and problem variants addressed in each reviewed article. More than 96% of the studies incorporate ALBP, and around 32% address WAP or ALWABP, indicating increasing concern with human-centric configurations.

The reviewed studies also differ in scope and problem focus. While most reviews concentrate primarily on Assembly Line Balancing Problems (ALBP), a smaller yet growing subset explicitly addresses Worker Allocation Problems (WAP) or ALWABP variants. As summarized in Table 3, more than 96% of the articles include ALBP, whereas approximately 32% incorporate worker related dimensions. This imbalance suggests that, despite increasing recognition of human-centric considerations, literature remains predominantly oriented toward task-based balancing formulations, with worker allocation aspects still underrepresented at the review level.

Table 3. Focus and Problem Variants Addressed in Reviewed Articles

Category	Description	Articles (count)	Percentage
Includes Assembly Line Balancing (ALB)	Most review papers included ALB either as the primary focus or as part of a broader context.	24	96%
Includes Worker Assignment (WAP) or Assembly Line Worker Assignment and Balancing Problem (ALWABP)	A significant number of articles included worker-related considerations, such as task allocation based on human skills or incorporating ergonomic factors (which directly relate to worker well-being).	8	32%

4.2 Findings about solution methods (RQ1 and RQ2)

Table 4 in Appendix A summarizes the classification and frequency of solution methods reported across the 25 reviewed articles. Overall, the literature exhibits a strong concentration on metaheuristic approaches, which appear in most reviews. The dominance of Genetic Algorithms, followed by Ant Colony Optimization and Particle Swarm Optimization, reflects the preference for flexible and easily hybridisable methods capable of handling large-scale, multi-objective, and highly constrained assembly line balancing problems.

In contrast, heuristic approaches such as priority rules and constructive procedures are reported less frequently and are mainly discussed in earlier reviews. This trend suggests that, despite their computational efficiency and interpretability, heuristic methods are increasingly perceived as offering limited generality or novelty within the academic literature, which may contribute to their declining visibility in more recent reviews.

Exact methods, including Branch and Bound and Integer Programming formulations, appear in nearly half of the reviewed studies but are predominantly positioned as benchmarking tools. Their limited scalability restricts their applicability to small or simplified problem instances, reinforcing their role as reference methods rather than practical solution techniques for complex industrial settings. Simulation-based and queueing approaches are mentioned only sporadically, typically in specialized or hybrid studies, indicating their niche role in capturing system dynamics rather than serving as standalone optimization frameworks.

Figure 3 illustrates the temporal evolution of the most frequently cited metaheuristics in the ALB literature. Genetic Algorithms have consistently maintained a dominant position over time, which can be attributed to their adaptability, robustness across diverse problem variants, and long-standing presence in the field. The growing attention to hybrid strategies, such as GA combined with local search mechanisms, reflects a methodological shift toward performance refinement and solution robustness rather than purely exploratory search.

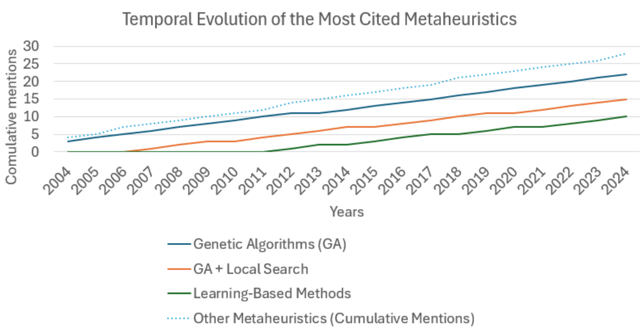

Fig. 3. Evolution of the most cited metaheuristics methods

Learning-based approaches, including reinforcement learning and supervised learning, show an increase in mentions after 2015; however, their presence remains limited when compared to traditional and hybrid metaheuristics. This suggests that, although such methods are frequently highlighted as promising within the context of Industry 4.0, their adoption remains exploratory, constrained by data availability, model transparency, and integration challenges in real production environments.

The category referred to as "Other Metaheuristics", which includes approaches such as Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO), Simulated Annealing, and Tabu Search (TS), collectively accounts for a substantial number of citations across the reviewed literature.

Rather than indicating the dominance of a single algorithm, this dispersion reflects a sustained interest in diversified search strategies that allow researchers to explore different balance intensification trade-offs.

The continued presence of these methods suggests that methodological diversity is valued as a means of addressing heterogeneous problem settings, even though many of these approaches remain confined to experimental or hybridized applications. In this context, the increasing combination of such metaheuristics with learning-based or adaptive components points toward a gradual shift from standalone optimization techniques to more intelligent and flexible solution frameworks.

4.3 Key Problem Characteristics and Application Situations

Several reviews provide insights into the suitability of different method families with respect to specific problem characteristics. Table 5, in Appendix B synthesizes these insights by cross-referencing solution method families with key dimensions of problem complexity. Rather than merely cataloguing available methods, this mapping highlights the underlying rationale guiding method selection and reveals patterns that are often implicit or overlooked in traditional classifications.

The comparison considers six major method families Priority-Rule Heuristics, Metaheuristics, Simulation Models, Mathematical Programming, Hybrid Methods, and Learning-Based Methods across four critical dimensions: precedence flexibility, task variability, workforce heterogeneity, and dynamic constraints. The resulting patterns suggest that method choice in the literature is largely driven by theoretical problem structure rather than implementation feasibility.

Priority-rule heuristics are predominantly associated with deterministic and static settings, reflecting their reliance on fixed task sequences and homogeneous workforces. Metaheuristics, by contrast, are repeatedly linked to scenarios involving task variability, flexible precedence relations, and complex line configurations, which explains their widespread adoption in academic studies addressing non-standard or highly constrained problems.

This contrast underscores a trade-off between methodological simplicity and modelling flexibility that shapes much of the existing literature.

Simulation-based approaches, particularly discrete-event simulation, are well suited for capturing stochastic behavior and dynamic system interactions. However, their limited presence in the reviewed studies reflects the high modelling effort and computational cost required, which often restrict their use to complementary or hybrid roles. Similarly, mathematical programming methods are primarily applied to problems with clearly defined and static parameters, reinforcing their function as analytical or benchmarking tools rather than scalable industrial solutions.

Hybrid and learning-based methods emerge as attempts to bridge these limitations. Hybrid approaches are frequently positioned to balance solution quality and computational tractability, especially in contexts involving heterogeneous workforces or variable task structures. Learning-based methods, although still at an early stage of adoption, are increasingly framed as mechanisms for enhancing adaptability in dynamic environments, particularly in the context of Industry 4.0 and human–robot collaboration.

Despite this apparent methodological diversity, a critical shortcoming across the reviewed literature is the limited discussion of real industrial application. Table 6 in Appendix C illustrates a pronounced gap between the frequency with which methods are discussed and the extent to which they are validated in real manufacturing environments. Widely cited approaches, such as Genetic Algorithms, Ant Colony Optimization, and Particle Swarm Optimization, are rarely accompanied by evidence of deployment on real production lines or evaluation using industrial performance indicators.

This discrepancy suggests that methodological prominence in the literature is not a reliable indicator of practical relevance. Many methods are justified primarily through benchmark performance or theoretical advantages, while empirical validation remains sparse and inconsistently reported. Even when industrial case studies are mentioned, performance assessment is often limited to qualitative claims rather than standardized KPIs or operational metrics.

Addressing this gap requires a stronger emphasis on practice-oriented validation, including closer collaboration with industrial partners, explicit reporting of deployment contexts, and the adoption of evaluation criteria aligned with real manufacturing constraints. Without such efforts, the transferability of advanced solution methods from academic research to industrial application is likely to remain limited.

4.4 Strengths and Limitations of Methods (RQ3)

Although frequency-based indicators provide an overview of methodological popularity, they do not capture the robustness or contextual suitability of different solution approaches. Table 7, in Appendix Dsynthesizes the main strengths and limitations of each method family, allowing a more nuanced assessment beyond citation counts.

Metaheuristic approaches are widely recognized for their flexibility and ability to address complex, large-scale, and multi-objective problem formulations. However, their reliance on extensive parameter tuning and the absence of guaranteed optimality limit their transparency and reproducibility, particularly in industrial settings where robustness and ease of deployment are critical. Genetic Algorithms are frequently highlighted for their hybridization potential, yet their performance often depends on additional local refinement to ensure convergence within acceptable computational time.

Heuristic methods, while computationally efficient and easy to interpret, tend to struggle with large or highly constrained problem instances. Their continued relevance lies in contexts where solution speed, simplicity, and managerial interpretability outweigh the need for optimality, such as manual or semi-automated task assignment scenarios.

Exact methods offer theoretical guarantees of optimality and remain indispensable for benchmarking and methodological validation. Nevertheless, their computational complexity severely restricts their applicability to small-scale or highly simplified problems, limiting their role in real-world production environments characterized by variability and uncertainty.

Simulation and queueing-based models provide valuable insights into system-level performance under stochastic conditions, capturing variability that optimization-based methods often overlook. Despite this strength, their limited adoption is largely due to high modelling effort, data requirements, and challenges associated with integrating simulation outputs into decision-support or optimization frameworks.

4.5 Emerging Trends and Future Directions

An analysis of post-2018 literature reveals a marked increase in interest in AI-enhanced and adaptive metaheuristics within the assembly line balancing (ALB) domain. As illustrated in Figure 4, this growth encompasses concepts such as reinforcement learning, hyper-heuristics, hybrid intelligent systems, explainability, and real-time adaptability. Rather than representing a purely technological shift, this trend reflects a response to the growing limitations of traditional optimization approaches when confronted with dynamic, data-rich, and human-centric production environments.

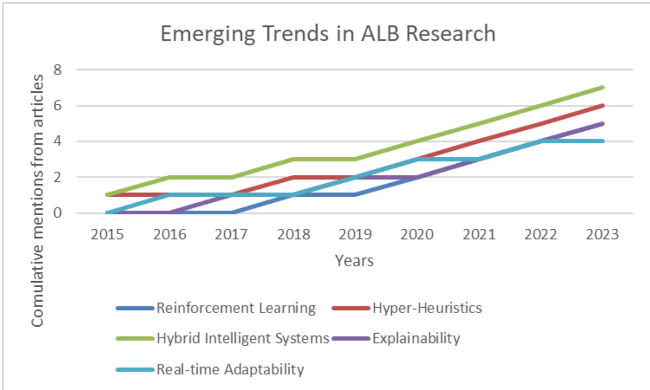

Fig. 4. Emerging Trends in ALB Research

The rising prominence of hybrid intelligent systems and hyper-heuristics suggests a strategic move toward combining exploration, exploitation, and domain knowledge within a single framework. These approaches are increasingly perceived as suitable for managing complex, multi-objective problems where static optimization models struggle to remain effective. Reinforcement learning, while still relatively underrepresented, is gaining attention as a mechanism for continuous adaptation under uncertainty; however, its current use remains largely experimental and constrained by data availability, training stability, and interpretability concerns.

In parallel, explainability has emerged as a recurring theme in recent reviews, signaling a shift in evaluation criteria for ALB solutions. As optimization methods move closer to operational deployment, performance alone is no longer sufficient; algorithms are increasingly expected to provide transparent and interpretable decision logic that supports managerial trust, validation, and accountability.

Another frequently cited research direction concerns real-time adaptability, particularly in contexts involving human–robot collaboration and intelligent manufacturing systems. Despite its conceptual appeal, the literature reveals persistent implementation gaps. Integration with industrial platforms such as ERP or MES systems is rarely addressed in detail, and few studies report the development of deployment-oriented tools or interfaces capable of supporting real-time decision-making.

Taken together, these emerging trends indicate a methodological transition toward more intelligent, interpretable, and context-aware optimization frameworks. At the same time, they expose a clear need for applied research that moves beyond conceptual promise, focusing instead on system integration, real-time validation, and demonstrable industrial impact.

4.6 Methodological Quality of the Reviewed Literature

A structured quality assessment was conducted across the 25 reviewed articles using five core dimensions: (1) clarity of research questions; (2) transparency of search and inclusion criteria; (3) quality of solution method classification; (4) depth of critical discussion; and (5) presence of real-world contextualization.

Table 8 in Appendix E summarizes the evaluation. The results reveal that while 11 articles clearly articulate their research aims, only 7 provide any form of real-world validation or industrial case discussion. Furthermore, transparency regarding search strategy and inclusion criteria is notably weak, with only 6 articles detailing such methodological components.

Overall, 13 of the 25 reviews achieved high methodological quality by meeting at least three of the five evaluation dimensions. The most frequent weaknesses include superficial categorization of solution methods, limited engagement with practical implementations, and lack of explicit search protocols.

These findings highlight a structural issue in the ALBP/WAP review literature. Although many articles offer extensive lists of algorithms and solution types, relatively few adopt a systematic or critical comparative framework. This limits their ability to guide practitioners or identify methodological gaps with precision. Strengthening methodological rigor, particularly in the use of transparent search criteria and contextual evaluation, represents a key opportunity for future reviews to enhance their impact and practical relevance.

5. Discussion

The findings from this review underscore several critical insights. First, while metaheuristics dominate literature, their practical adoption remains limited, suggesting a disconnect between academic exploration and industrial needs. This disparity is particularly evident in the low percentage of reviews (24%) that report real-world validation.

The dominance of metaheuristic approaches in the reviewed literature can be partly explained by their flexibility, scalability, and suitability for multi-objective formulations, which align well with academic benchmarking practices and publication incentives. Metaheuristics allow researchers to demonstrate performance improvements on standardized test instances without requiring deep integration into industrial systems. This may contribute to their frequent appearance in reviews despite limited real-world deployment.

It implies that future research must prioritize application-oriented studies and foster collaborations with industry to bridge this gap.

Second, the low industrial reporting of simpler heuristics reveals a different limitation. Although priority rules and constructive heuristics are computationally efficient and interpretable, they are often perceived as offering limited novelty or generality, reducing their attractiveness for academic publication. As a result, their practical use may be underreported rather than absent. These dynamics highlight a structural situation between academic optimization objectives and industrial decision-making needs, which remains insufficiently addressed in the current literature.

Third, although many methods are widely cited, the lack of standardized performance benchmarks across reviews complicates the comparative evaluation of effectiveness. The absence of consistent KPIs and industrial case studies hinders the development of best practices. It also reduces the utility of these reviews for practitioners who require actionable insights.

Four, the trends observed, such as the rise in AI-enhanced methods, reflect a shift in methodological expectations. However, this evolution must be accompanied by discussions on algorithm explainability, robustness under uncertainty, and integration with production systems such as ERP or digital twins. Without this contextual grounding, even sophisticated methods may fail to deliver practical impact.

Finally, the methodological assessment of the reviewed literature reveals that many reviews lack rigor in search strategy, classification, and critical depth. This undermines their contribution to advancing the field and emphasizes the need for adherence to systematic review standards in future work.

In summary, this review not only maps the landscape of ALBP and WAP solution methods but also highlights the need for more critical, contextual, and practically grounded research. Addressing these dimensions will enhance both academic relevance and industrial applicability.

6. Conclusion

This review provides a comprehensive synthesis of solution methods for Assembly Line Balancing Problems (ALBP) and Worker Allocation Problems (WAP), based on a tertiary analysis of 25 literature reviews. The main findings demonstrate a dominance of metaheuristics, a growing interest in hybrid and AI-based strategies, and a significant gap in practical validation.

Distinct from prior reviews, this study critically evaluates methodological trends, contextual application, and practical relevance, revealing inconsistencies and opportunities that have not been thoroughly addressed. One key contribution is the structured comparison of solution methods not only by frequency but also by strengths, limitations, and deployment potential.

In addition to the dominance of metaheuristic approaches in literature, this review highlights several structural reasons why many existing methods fail to achieve widespread industrial adoption. First, a significant number of proposed algorithms require extensive fine tuning and expert intervention, which limits their usability in real production environments. Second, most methods are validated primarily on benchmark instances or simplified assumptions, neglecting data uncertainty, worker variability, and operational disruptions commonly observed in practice. Third, the lack of alignment between academic objective functions and industrial performance indicators (e.g., throughput stability, reconfiguration effort, or managerial interpretability) further reduces practical relevance. Finally, limited integration with existing industrial systems, such as ERP or MES platforms, creates additional barriers to real-world deployment.

Future research should focus on enhancing real-world deployment, integrating advanced analytics with ERP/MES systems, and developing explainable and adaptable algorithms that align with Industry 4.0 goals.

Moreover, the methodological quality assessment revealed that many existing reviews suffer from insufficient transparency in search protocols, weak classification schemes, and a lack of critical discussion. Addressing these shortcomings is essential to improve the credibility, usefulness, and impact of future research in this domain.

To improve the methodological quality of future reviews concrete actions are recommended. First, reviews should explicitly report search strategies, following established protocols such as PRISMA and STARLITE. Second, solution methods should be classified not only by algorithmic type but also by problem characteristics, application context, and validation strategy. Third, stronger emphasis should be placed on real-world validation, including the use of standardized industrial KPIs and clearly documented case studies. Finally, future reviews should adopt a more critical comparative perspective, moving beyond frequency-based reporting toward systematic assessment of applicability, limitations, and implementation readiness.

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Appendix A. Findings about solution methods (RQ1 and RQ2)

Table 4. Classification and Frequency of Solution Methods in Assembly Line Balancing Reviews

Solution Method Category	Specific Methods	Frequency (Out of 25)	Percentage	Notes
Metaheuristic Methods	Genetic Algorithms (GA)	22	88%	Dominated, often to solve many cases.
	Ant Colony Optimization (ACO)	19		
	Particle Swarm Optimization (PSO)	14		
	Simulated Annealing (SA)	19		
	Tabu Search (TS)	15		
Heuristic Methods	Priority Rules (e.g., RPW, LCR)	13	52%	Prevalent in earlier reviews, often used as a baseline for comparison.
	Constructive Procedures	8		
Exact Methods	Branch and Bound (B&B)	12	48%	Generally used for benchmarking purposes due to scalability issues.
	Integer Programming	5		
Simulation-Based Methods	Discrete Event Simulation (DES)	5	20%	Often associated with specialized or hybrid studies.
Queueing Methods	Queueing Theory, Queueing Network	2	8%	Often associated with specialized or hybrid studies.

Appendix B. Key Problem Characteristics and Application Situations

Table 5. Method Types vs. Problem Characteristics

Method Type	Precedence Flexibility	Task Variability	Workforce Heterogeneity	Dynamic Constraints	Relevant references
Priority-Rule Heuristics	Low – fixed task orders	Low – assumes uniform tasks	Low – homogeneous workers	Limited – assumes stable systems	PP2 PP11 PP1 PP14
Metaheuristics	High – flexible task sequences	High – handles variable tasks	Medium – can model skills	High – explores vast state spaces	PP15 PP23 PP20 PP13 PP6 PP4
imulation Models	Moderate – depends on model	Very High – stochastic modeling	High – complex worker interactions	Very High – captures dynamic behavior	PP16 PP8 PP7 PP3
Mathematical Programming	Medium – with constraints	Low – often static parameters	Low – assumes uniformity	Low – typically static formulations	PP22 PP20 PP21 PP5 PP19
Hybrid Methods	High–integrated control	High – mixes deterministic and variable	High – can include worker profiles	High – allows dynamic responses	PP23 PP3 PP10 PP9
Learning-Based Methods	Emerging – adaptive through learning	High – learns from data patterns	High – models personalized adaptation	Emerging – responsive via learning	PP10 PP23 PP24 PP25

Appendix C. Key Problem Characteristics and Application Situations

Table 6. Literature vs. Industrial Use of Methods

Method	Discussion in Articles (n=25)	Industrial Application (n=25)	Discussion (%)	Industrial Use (%)	Evidence (1–5)	Relevant references
Genetic Algorithms (GA)	22	4	88	16	E1, E3, E5	PP23 PP6 PP15
Ant Colony Optimization (ACO)	19	3	76	12	E1, E3, E5	PP23 PP15 PP13
Particle Swarm Optimization (PSO)	14	2	56	8	E3, E5	PP15 PP6
Simulated Annealing (SA)	19	2	76	8	E1, E3, E5	PP15 PP20
Tabu Search (TS)	15	1	60	4	E1, E3	PP15 PP23

Priority Rules	13	2	52	8	E1, E5	PP2 PP11
Constructive Heuristics	22	2	88	8	E1, E3	PP17 PP2
Mathematical Programming (IP, B&B)	12	2	48	8	E1, E3, E5	PP22 PP20
Simulation Models	5	3	20	12	E1, E3, E5	PP16 PP8
Learning-Based Methods	4	2	16	8	E3, E5	PP3 PP23

Appendix D. Strengths and Limitations of Methods (RQ3)

Table 7. Strengths and limitations of each method

Method Family	Main Strengths	Main Limitations	Relevant references
Metaheuristics	Flexible, suitable for complex/multi-objective problems; adaptable to hybridization; applicable to large-scale models.	Require parameter tuning; no guarantee of global optimality; possible slow convergence without refinement.	PP15 PP23 PP6
Heuristics	Simple, fast, interpretable; effective for deterministic or small-scale settings; suitable for manual assignment	May yield poor quality solutions in complex or constrained cases; limited scalability.	PP2 PP11 PP17
Exact Methods	Guarantee optimality; rigorous; useful for benchmarking and validation.	Computationally intensive; not scalable to large or highly variable problems.	PP20 PP22 PP21
Simulation Models	Capture stochastic behavior; realistic modeling of variability and process flows	High complexity; demanding data requirements; challenging integration with optimization tools.	PP16 PP8 PP7
Queueing Models	Model system-level performance under uncertainty; helpful in theoretical flow and waiting time analysis	Rarely used in practice; abstract assumptions; difficult to calibrate in real settings.	PP9 PP14
Learning-Based Methods	Adaptive and responsive; potential for self-learning and generalization in dynamic environments.	Still emerging; limited evidence of large-scale deployment; dependent on high-quality data.	PP10 PP23 PP24

Appendix E. Methodological Quality of the Reviewed Literature

Table 8. Methodological Quality Assessment of ALB Literature

Relevant references	Clarity of Research Questions	Transparency of Search Criteria	Quality of Method Classification	Critical Discussion Depth	Real-world Contextualization	Criteria Met (out of 5)	Strong Quality Review (≥3)
PP2	1	0	1	1	0	3	YES
PP1	1	1	1	1	0	4	YES
PP5	1	0	1	0	0	2	NO
PP18	0	0	0	0	1	1	NO
PP8	0	0	1	0	1	2	NO
PP13	1	0	1	1	0	3	YES
PP11	0	0	1	0	0	1	NO
PP21	1	1	1	1	1	5	YES
PP9	0	1	1	1	1	4	YES
PP22	1	0	1	0	0	2	NO
PP17	1	0	1	1	0	3	YES

PP6	1	0	1	0	0	2	NO
PP16	1	0	0	0	1	2	NO
PP14	1	0	1	0	0	2	NO
PP4	1	1	1	1	0	4	YES
PP19	0	0	1	0	1	2	NO
PP3	1	1	1	1	1	5	YES
PP7	1	0	1	0	0	2	NO
PP15	1	0	1	1	1	4	YES
PP23	1	1	1	1	1	5	YES
PP12	0	0	0	0	0	0	NO
PP25	1	1	1	1	0	4	YES
PP10	1	0	1	1	1	4	YES
PP24	0	0	0	1	1	2	NO
PP20	1	1	1	1	0	4	YES

Appendix F. Analyzed papers

Table 9. Analyzed papers

Code	Author, year	Publisher	Source	Document Type	Database	Citation	Type of review
PP1	(Aida Husna Ahmad et al., 2024)	Akademia Baru Publishing	Journal of Advanced Research in Applied Sciences and Engineering Technology	Journal Article	Scopus	0	Comprehensive Literature review
PP2	(Thawfee Kur Rahman et al., 2023)	Institute of Electrical and Electronics Engineers Inc.	IEEE	RJournal Article	Scopus	0	Literature review
PP3	(Chutima, 2023)	Growing science	International Journal of Industrial Engineering Computations	Journal Article	Scopus	3	Literature review
PP4	(Boysen et al., 2022)	Elsevier	European Journal of Operational Research	Journal Article	Scopus	77	Systematic literature review
PP5	(Çimen et al., 2022)	Emerald Publishing	Assembly Automation	Journals & Books	Scopus	3	Literature review
PP6	(Mohammed et al., 2021)	American Institute of Physics Inc.	AIP Conference Proceedings	Book	Scopus	1	Literature review
PP7	(Jiao et al., 2021)	SAGE Publications Ltd	Concurrent Engineering Research and Applications	Conference Proceedings	Scopus	16	Literature review
PP8	(Kharuddin & Ramli, 2020)	Institute of Physics Publishing	IOP Conference Series: Materials Science and Engineering	Conference Proceedings	Scopus	1	Literature review
PP9	(Eghtesadifard et al., 2020)	Elsevier	Computers and Industrial Engineering	Journals & Books	Scopus	54	Systematic literature review
PP10	(Chutima, 2020)	Chulalongkorn University, Faculty of Fine and Applied Arts	Engineering Journal	Report	Scopus	14	Literature review
PP11	(Ayoub El Ahmadi et al., 2019)	International Conference on Industrial Engineering and Operations Management	International Conference on Industrial Engineering and Operations Management	Journals & Books	Scopus	4	Literature review
PP12	(Razali et al., 2019)	Emerald Publishing	Engineering Computations (Swansea, Wales)	Conference Proceedings	Scopus	12	Literature review
PP13	(Hazir & Dolgui, 2019)	Elsevier	IFAC-PapersOnLine	Conference Proceedings	Scopus	15	Literature review

PP14	(Belfiore et al., 2018)	ResearchGate	17th International Conference on Modeling and Applied Simulation,	Journal Article	Scopus	9	Literature review
PP15	(Li et al., 2017)	Elsevier	Computers and Operations Research	Journals & Books	Scopus	79	Comprehensive Literature review
PP16	(Sahu & Pradhan, 2016)	IEEE	International Conference on Automatic Control and Dynamic Optimization Techniques	generic	Scopus	10	Comprehensive Literature review
PP17	(Sivasankaran & Shahabudeen, 2014)	Springer-Verlag London Ltd	International Journal of Advanced Manufacturing Technology	Journal Article	Web of science	231	Comprehensive Literature review
PP18	(Rashid et al., 2012)	Springer-Verlag London Ltd	International Journal of Advanced Manufacturing Technology	Conference Proceedings	Scopus	158	Literature review
PP19	(Boysen et al., 2008)	ScienceDirect	International Journal of Production Economics	generic	Web of science	390	Literature review
PP20	(Scholl & Becker, 2006)	Elsevier	European Journal of Operational Research	Journal Article	Scopus	716	Comprehensive Literature review
PP21	(Becker & Scholl, 2006)	Elsevier	European Journal of Operational Research	Journals & Books	Scopus	864	Literature review
PP22	(Battaïa & Dolgui, 2013)	Elsevier	International Journal of Production Economics	Journal Article	Scopus	591	Literature review
PP23	(Battaïa & Dolgui, 2022)	Elsevier	International Journal of Production Economics	Journal Article	Scopus	56	Literature review
PP24	(Petzoldt et al., 2023)	Taylor & Francis	International Journal of Computer Integrated Manufacturing	Journal Article	Web of science	12	Systematic literature review
PP25	(Yelles-Chaouche et al., 2021)	Taylor & Francis	International Journal of Production Research	Journal Article	Web of science	107	Literature review