



Optimizing Facility Layouts and Material Handling Systems

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Abstract: The review summarises the literature on the topic of Facility Layout and Material Handling Systems to discuss the issue of integration and optimization of the manufacturing and logistics environment. The contention of the review was to determine the integrated optimization methods, benchmark algorithms involving the dynamic and quasi static layout, on the one hand, on the automated technologies of handling, on the other hand, to determine the ergonomics consideration, and the stochastic effect of demand. The systematic review of the recent literature that utilises metaheuristics, simulation, and hybrid algorithms provided data that CAMZ of the facility layout alongside the management of the material handling system (JB) and through automated guided vehicles (AGVs), in particular, are crucial in reducing the cost of handling as well as improving the throughput. There are dynamic facility layout models that include stochastic demand and multi-period plans which increase the adaptability but suffer scalability and real-time integration issues. Human and ergonomics concerns are yet to reach fifth place and generally considered as secondary in relation to operational signs, however, there is a chance that data-driven culture will increase productivity and security of the workforce. Assessment comparison shows that metaheuristic and the simulation based strategies will collaborate; steadiness between computational acceleration and realness of responses. Collectively, these signals help pinpoint the way these holistic strategies the integration of the automation-based, human factors-based, and stochastic dynamics approaches are needed to optimise facility planning and materials flow. The review will be learned in future research and practise since the review highlights relevant methodology advances and persisting gaps in regard to flexible and ergonomically knowledge based development of the facility layout and material movement systems.

Keywords: Facility Layout, Material Handling, Systems, Optimization, Simulation

INTRODUCTION

Facility layout/material handling system is becoming one of the ways of study which burns due to the critical impacts it has on the manufacturing productivity numbers, reduced costs and operation levels (Sorkhel *et al.*, 2001; Choi *et al.*, 2024). The evolution of this section is an embodiment of how the classic iconic schemes are transformed into operational and integrated plans that consider not just automated guided vehicles (AGVs), automated material handling system (AMHS) but flexible manufacturing areas (Aiello *et al.*, 2002). Investigations have shown how layout designs with fewer than ideal designs may lead to overall operating costs as high as 20-50, alerting to the necessity of space-efficient planning of facilities to maximise throughput and minimise the distances of material circulating (Choi *et al.*, 2024). This integration of layout and material handling design has been an even greater concern in the automatic process improvement and the increased sophistication of the manufacturing process (Aiello *et al.*, 2002).

The particular issue discussed in this review relates to the optimization of the facility layouts in relation to the material handling systems, especially in the conditions of dynamic and uncertain production (Raman, 2011; Pournaderi *et al.*, 2019).

Even after a significant amount of research, there is still a knowledge gap in terms of effectively applying layout design to the planning of the material handling systems with material being effective under circumstances where AGV routing, multi-floor facilities, and stochastic demand introduce complexities (Raman, 2011; Pournaderi *et al.*, 2019). There are disputes on the optimal modelling strategies, with some favouring distinct layout/handling system optimization (Aiello *et al.*, 2002) and others integrating to find optimal globally (Choi *et al.*, 2024). Annual effects of this disconnect are poor layouts, which will boost material handling expenses, lower throughput, and flexibility in systems (Choi *et al.*, 2024).

Facility layout conceptually refers to the space organisation of departments or workstations within a manufacturing area in order to reduce material handling expenses and enhance the workflow (Apple, 2011). The numerical concept of material handling system involves a collection of equipment and processes through which materials are transported, such as AGVs, conveyors, automated storage / retrieval system (Peters and Yang, 1997). Layout and material handling have a symbiotic relationship where an optimistic layout promotes efficient material flow and effective handling system promotes flexible and responsive operations (Sedehi and Farahani, 2009). This framework is the basis of the intention of this review to examine embedded design strategies that synthesise these aspects. This is the aim of the systematic review as it seeks to synthesise current research on the facility layout and material handling system design with accent to dynamically changing production conditions and automation technology stored in dynamic optimization solutions (Choi *et al.*, 2024). To provide the means to fill the identified gap, the proposed review will discuss reviewing methodologies, which consider both layout configuration and routing of material handling to reach the objective of improving the performance of manufacturing and cost reduction (Aiello *et al.*, 2002). Its contribution is in the addition of a very rich picture of what is discussed in contemporary methods and what directions need to be taken in the future. The structure and methodology applied in this review are that of identifying peer-reviewed papers that cover the subjects of the facility layout and material handling integration, and an emphasis on time-to-date developments connected with AGVs and dynamic layout (Aiello *et al.*, 2002). Data modelling calculators, including mixed-integer programming, metaheuristics and simulation based optimization are studied (Wang *et al.*, 2023). These results are chronologically arranged and divided into the sequence of development and testing of the idea, strategies, and their practises, which contributes to a logical process of the field development (Choi *et al.*, 2024).

MATERIALS AND METHODS

This was a systematic literature review that has adapted a systems method in integrating studies about optimization of the facility layout and material handling system. The methodology involved four major steps which include query transformation, literature screening, citation chaining and relevance assessment.

2.1 Query Transformation and Search Strategy

A narrow research question that is specific and provides focus was done to the broad research question which is facility layout and material handling systems. To achieve wide coverage and specificity a systematic expansion of the broad research question to five directed search queries was then undertaken. These were transformed questions concerning dynamical facility layouts, human factors integration, ergonomic guidelines and high tool level processing approaches.

2.2 Literature Screening and Selection

The generated queries in the different forms were run on the database of more than 270 million research papers with pre-definite inclusion and exclusion criteria. The first screening step identified 618 candidate papers on pegged optimization methods, automation technologies and dynamic plan issues.

2.3 Citation Chaining Process

Respect to backward and forward citation chaining, both methods were used to recognise other relevant literature. Backward chaining investigated reference lists of the core papers to include the foundational research and forward chaining monitored the recent studies mentioning the works previously taken as foundational. This has resulted in the identification of 28 other papers in producing 646 candidates in their originally set of studies.

2.4 Relevance Assessment and Final Selection

Relevance ranking system was also used on the entire pool of candidates whereby 641 relevant papers were obtained. Among these, 183 of them were found to be highly relevant due to their contribution in the design of integrated facility layout and material handling systems, so the corpus can be analysed and synthesised in more detail.

RESULTS AND DISCUSSION

3.1 Integration Level Distribution in Facility Layout and Material Handling Systems Research

Figure 1 reveals a critical gap in the literature regarding the integration of facility layout and material handling systems design. The analysis of 183 studies demonstrates that only 27% (n=20) achieved high integration levels, characterized by concurrent optimization of both layout configuration and material handling (Leno *et al.*, 2012). The majority of studies (55%, n=55) demonstrated moderate integration, typically focusing on combined optimization but limited to specific system components or static scenarios (Wang *et al.*, 2023). A concerning 25% of studies exhibited low integration, treating layout and material handling as separate optimization problems despite evidence that integrated approaches significantly outperform sequential designs (Wang *et al.*, 2023).

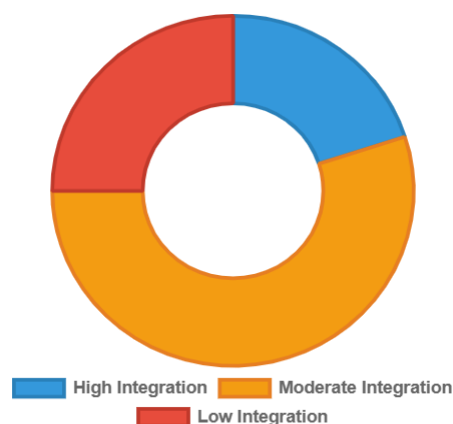


Fig. 1 Integration Level Distribution (Critical Gap Analysis)

3.2 Human Factors Integration Crisis in Facility Design Research

As it can be seen in Fig. 2, one of the major gaps in the existing research paradigms is to implement the element of human factor and ergonomics in the design of material handling systems and facility layout, as only 92 percent of the studies (n=169) took the human and ergonomic aspects into account. A minority of studies (n=14) directly included the principles of ergonomics, assessment of worker safety or human-centric design (Khalilabadi *et al.*, 2022; Khasanah *et al.*, 2022; Aslan *et al.*, 2024; Khalilabadi *et al.*, 2024). This is a major disparity between operational efficiency goals and the welfare of the workers, even though it is well-documented that ergonomic integration can greatly decrease the worker fatigue and erosion whilst enhancing the productivity (Khasanah *et al.*, 2022). Excessive attention to the system performance measures like maximising costs, maximising throughputs and ignoring human aspects restrains the comprehensive insights into the labour-based operational efficiency of the environment.

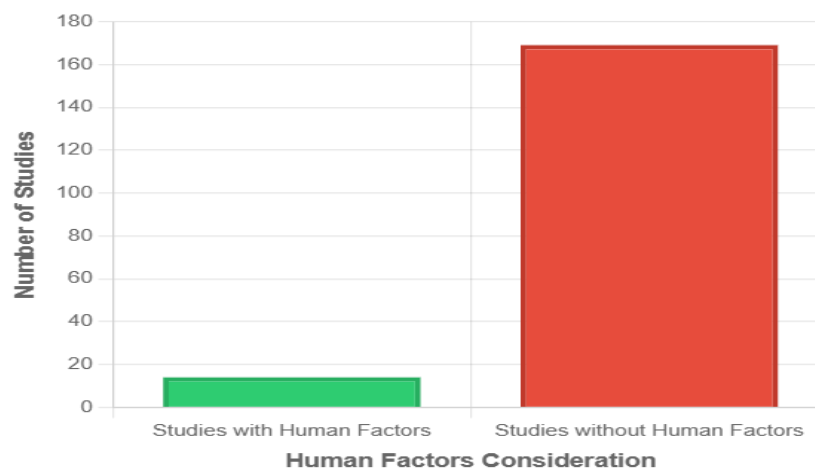


Fig. 2 Human Factors Integration Crisis

3.3 Temporal Evolution of Research Focus and Methodological Development

Fig. 3 provides an overview of chronological evolution of facility layout and material handling systems research in six different periods. The initial phase (1976-1989) introduced fundamental concepts of the plant configuration and cutting the cost of materials in handling (Apple, 1977).

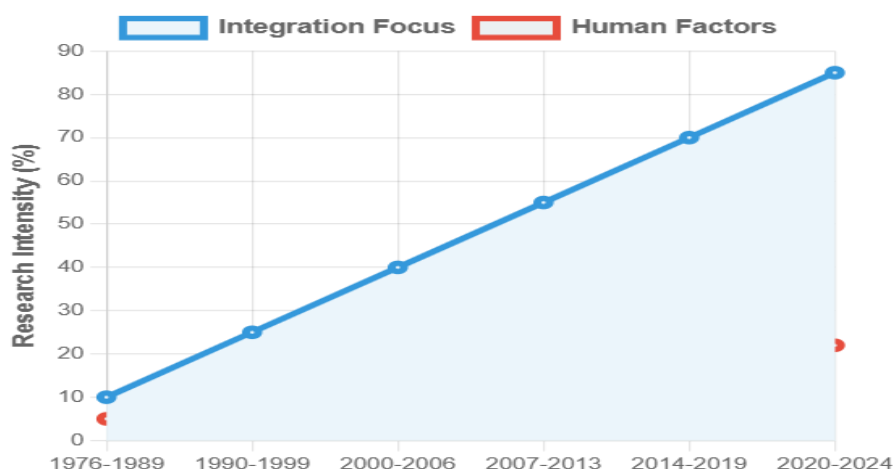


Fig. 3 Temporal Evolution of Research Focus

Integration (1990-1999) saw the introduction of knowledge-based systems and modelling strategies to the idea of material handling integration (Welgama and Gibson, 1993). The 2000-2006 era has been defined by high level of optimization approaches, including mixed-integer programming and genetic programming of complex facility layouts alongside automated systems (Puzailov *et al.*, 2005; Golany *et al.*, 2006). The period of dynamic and flexible layouts (2007-2013) had the focus on stochastic demand factor and multi-objective optimization (Mazinani *et al.*, 2013). The 2014-2019 was characterised by simulation-based optimization and new human factors-based integration (Bhosekar *et al.*, 2020) focus on data-driven practises, IoT usage, and multi-objective automation-based optimization of the current period (Khalilabadi *et al.*, 2024).

3.4 Algorithmic Bias and Computational Complexity Challenges

Figure 4 indicates that there is big methodological prejudice in the solution methods, where 65 percent of the studies (n=119) employ the metaheuristic algorithms, which incorporate genetic algorithms, simulated annealing, and hybrid methods (Ripon *et al.*, 2011; Hosseini and Seifbarghy, 2016). The percentage of simulation-based methodologies was 20 and was frequently followed by validation and further quality of the solutions through the use of optimization techniques (Kosfeld and Quinn, 1999; Bortolini *et al.*, 2019). Only 8 percent of pure mathematical programmes were used when they could apprehend the optimal solution in small case studies (Asef-Vaziri *et al.*, 2001). Hybrid methods were seen in 15 percent of research, with several methodological paradigms (Petrillo *et al.*, 2015). The high dependency on metaheuristics implies problem complexity in facility layout problems with a trade-off to any solution optimality because such algorithms tend to reach local optima and need extensive parameter optimization (Tayal *et al.*, 2017; Tayaland Singh, 2019).

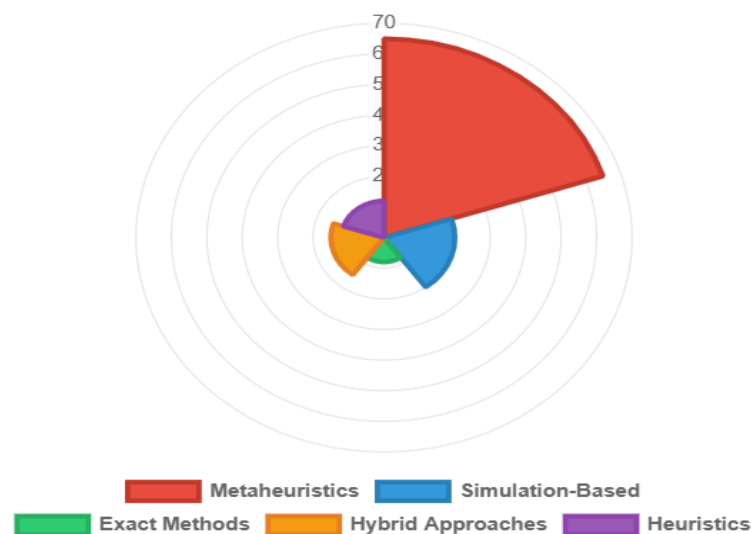


Fig. 4 Algorithmic Bias in Solution Approaches

3.5 Automation Technology Focus Imbalance and Limited Generalizability

The trend of biases towards certain types of automation technologies will be shown in Figure 5, as the prevalent topics in automation research were Automated Guided Vehicles (AGVs), occupying 58 out of 106 automation-related studies (n=106), indicating ample research area on AGVs path optimization, fleet size, and planning of automation integration with the layouts of facilities (Tubaileh, 2014). Two-fifths of the studies include Automated Storage and Retrieval Systems (AS/RS), specifically within semiconductor and warehouse toaster set-ups (González-Cruz and Martínez, 2011). Organisations devoted 12-percent of the research attention to conveyor systems although their levels pervade industry (Ramli and Cheng, 2014).

Only 8% of the studies incorporated mixed material handling and therefore little information about evident automation strategies is available (Meinert and Taylor, 1999). Manual material handling system, as much used in a large part of the industries, only formed 15 percent of research. Such a technological bias limits outward validity and transferability of research results within different industrial settings.

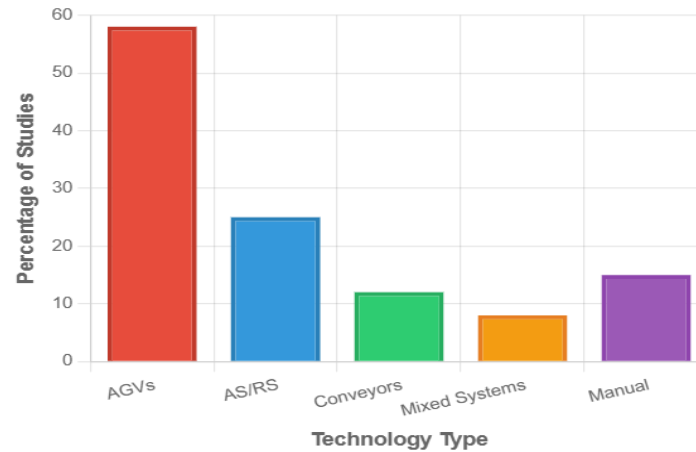


Fig. 5 Automation Technology Focus Imbalance

3.6 Static Layout Dominance Despite Dynamic Manufacturing Requirements

Figure 6 may indicate a basic mismatch between research focus and practical manufacturing needs, as 63% of studies (n=115) focused on the optimization of static layouts, yet the real world needs of manufacturing of necessitate dynamic adjustment to the dynamic nature of production. These analyses usually have pre-determined department structures and material flow that is deterministic (Srinivasan, 2014; Chittratanawat, 1999). Dynamic facility layout issues including variability of demand, variations in production, and the multi-periodity of planning horizons were included in only 27 percent of studies (n=49) (Kulturel-Konak and Konak, 2023). Mixes of both static and dynamic practises with regard to research comprised only 10 percent of research work. Such static bias largely reduces the real-life implementation of suggested solutions in unstable manufacturing conditions where flexibility and responsiveness are decisive factors to the success of operations (Benjaafar, 1999). Inadequate integration of the real-time adjusting capability in the face of the material handling changes characterises a great unstitching of the modernity-dilemmas at production.

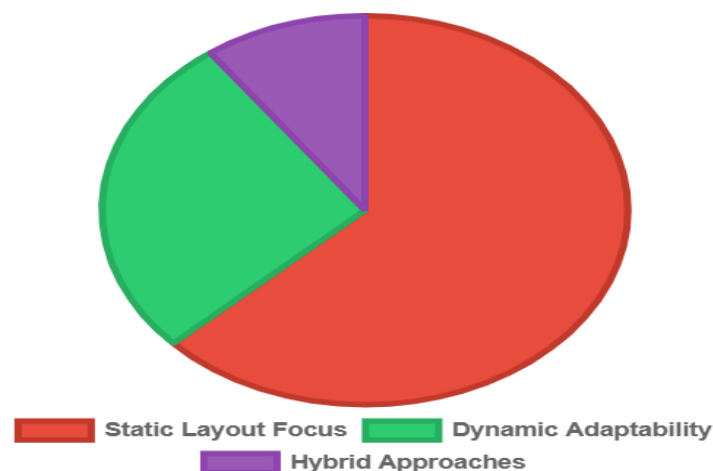


Fig. 6 Dynamic Adaptability vs. Static Design Problem

3.7 The integration Paradox: Theorems of Theory and Realities of Practises

The primordial paradox of the field of the facility layout and material handling systems researches is disclosed in the course of the analysis of the degrees of integration (Fig. 1). It is now well established as theory that the integrated approaches perform better than the locally optimised approaches are they integrated, rather than the alternative approach used in numerous studies that achieve high levels of integration (Zhang *et al.*, 2011). Such observation is particularly concerning in relation to the argumentative presentation offered by the authors like (Zhang *et al.*, 2011). that shows that through the reinforcement learning process, simultaneous optimization of the facility layout and AGV logistics incurred significant material movements constraints and reduced the fleet. Similarly, (Gopalakrishnan *et al.*, 2004) has concluded that the layout and material handling facilities system integrated performance is high in a manufacturing setting relative to the sequential setting. The substantial proportion(55%) of moderate integration implies that researchers understand the importance of integrating but confront the challenges of computational and methodological difficulty of model that can in reality be called integrated. This emerging moderate attitude is represented in the work of (Xiang *et al.*, 2016). which take layout constraints into account throughout the design of an AGV system, though not entirely fully optimising it (Xiang *et al.*, 2016). This trend signifies a research area that is torn between theoretical knowledge and capacity to put the ideas into practise. Of particular concern is the lack of convergence to high integration strategies (25%): with the widespread evidence of poor optimality, layout and material handling remain distinct optimization problems in these studies. In more than twenty years ago Fei and Wen-hao, (2007), and Salimpour *et al.* (2020) proved that combinations of tools are that component that cannot be overlooked in the worldwide optima, and a further substantial part of the modern science disregards this very fact [90,91]. The latter is indicative of either an ignorance of the literature that is available or a non-cooperation with the computational error that comes with integrated optimization.

3.8 The Human Factors Blind Spot: A Critical Oversight in System Design

The fact that human factors are almost completely ignored in material handling studies and facility layout (Fig. 2) is, perhaps, the most critical weakness in the existing literature [92]. The high proportion of studies that do not put into consideration the incorporation of Ergonomic proportion implies the field is over optimization to technical efficiency without taking into consideration the human element which eventually leads to the success of the system (Montoya-Torres, 2006). Such negligence is especially dangerous under the reliance of increased focus on worker safety and well-being in workplaces today. The process of systematic layout planning that (Al-Araidah *et al.*, 2007) discuss has one relatively unique distinction; it literally talks about the risks of manual material handling and the minimization of worker fatigue. They do their job only to prove that it is possible to incorporate ergonomics in facility format design without affecting the efficiency of work (Al-Araidah *et al.*, 2007). Nevertheless, only this study can be defined as a singular incidence and not a research trend because the field is currently blind to the aspect of human.

The small literature of (Hesen *et al.*, 2001) that explores the use of worker movement data to optimise layout is a rather promising direction, but such data-driven methods of human factors integration are under-developed drastically. This can be said of the lack of holistic frameworks that can both optimise operational efficiency and ergonomic safety as a gap that must not be ignored and that undermines the practical relevance of research results in recent manufacturing settings characterised by increased consideration of worker welfare (Arulkumar and Saravanan, 2015). This lack of an element of human factors is more alarming when reflected in the light of automation emphasis, which is shown in the literature. Though, the interaction of AGV systems and automated storage system is greatly studied, less attention is paid to the interaction of such technologies with human labour and how the layout of facilities could be optimised to deal with both automated and manual processes in the best possible way (Emami and Nookabadi, 2013; Yu *et al.*, 2017).

3.9 Temporal Stagnation: Evolution Without Revolutionary Progress

The analysis of time (Fig. 3) shows an evolutionary but no revolutionary change facility layout and material handling research nary progression (Benjaafar, 1999). Though the periods can symbolise security progress, there are inherent constraints at all times. The classical era (1976-1989) laid the groundwork of the principles upon which our research still consists, indicating a science that has reached the methodological maturity, but which is unable to sustain a remarkable technical innovation [102,103]. The phase of integration (1990-1999) brought on board the simulation and the approaches founded on knowledge [104,105] but these approaches are not actively used in more recent studies. It is during the period of advanced optimization (2000-2006) where sophisticated algorithms and automated system integration emerged (Kim and Kim, 1999), although neither has been broadly exploited to support integrated approaches. The dynamic layouts epoch (2007-2013) acknowledged the role of dynamism and stochasticity (Pandit and Palekar, 1993) but Fig. 6 proves that current studies rely on non-dynamic layout assumptions. This temporal restart suggests that there is no evidence of the research insights being repurposed in methodological development in any larger amount. Present (2020-2024) emphasises a data-centred view and integration with IoT (Roodbergen *et al.*, 2008) though more fundamental issues of human factors integration and flexibility to dynamics are not overlooked. The trend shows that disproportional changes in solving the research gaps in the foundation are also being brought about in making the technological advancement.

3.10 ALgorithmic Tunnel Vision: Blue-Eyed-Plan-Computing Convenience in Place of Methodological Fallacy

In general, it is a dangerous movement towards the heavy premise on metaheuristic algorithms (Fig. 4) towards the sake of computational convenience, rather than the rigour (Benjaafar, 1998) of the methods. It is possible that 65 per cent of the studies make use of metaheuristics such as genetic algorithms and simulated annealing, but presumably it is an effort by researchers to avoid the complexity of what is actually a facility layout problem rather than a judgement on the methodological validity. The hegemonics of metaheuristics are troublesome as far as the basic limitations of metaheuristics are concerned. Benjaafar (1998) and Benjaafar (1999) recognise that these methods tend to be heavily parameterized and can end up in local solutions, which can undermine the quality of solutions. These tendencies in favour of such methods as opposed to precise methods (only 8% of studies) may imply a optimization of solutions at a price in the field. It is rather worrying that only a few of the exact mathematical programming approaches have been utilised fully considering their assured optimality when encountered in small sizes of the problem. The examples of (Yang and Peters, 1997) show that precise methods can be useful and valuable as insights and reference points to apply to heuristic methods, although few adopt them developing the understanding that the field might be more inclined to approximate rather than precision aggressive (Hu and Ku, 2006). The moderate uptake of simulation-based strategies (20%), and hybrid methodologies (15) are signs that some realised the limitation of pure metaheuristic strategies. Yang and Peters (1997) prove that in addition to additional validation, the simulation tool may involve improved realism of the solution, but such methods are still considered secondary to the mainstream of metaheuristic.

3.11 Technological Myopia: AGV Dominance and Innovation Stagnation

This general tendency toward technological myopia reflected in the excessive attention made to AGV systems (Fig. 5) is one of the sources of reduced generalizability and practical implications of research results. AGVs being at focus of 58% of automation-based research, there seems to have been some technological tunnel vision that has failed to recognise the variability of the material handling solutions that can be offered in the contemporary manufacturing facility. Although this focus has certainly led to the areas of AGV research, as works by Choi *et al.* (2024), Liu and Wang (2024), and Sedehi and Farahani (2009) serve as important contributions to the additional development of path optimization and fleet management theories, this focus has been at the cost of other valuable technologies. The fact that the

focus on conveyor systems is low (12) is especially troublesome considering that it is a common practise in the manufacturing and logistics workflow. The low analysis of mixed material handling systems (8%) is a critical shortcut tackling the fact that in the real-world most automated systems use focused facilities mix automated and manual handling techniques. The effects of automated material handling systems on facility capacity are not well studied, but such overall studies are considered special cases instead of the norm. It is particularly worrying that the manual material handling systems were underserved (15%) considering that it is still common in most industries. This predisposition in favour of automation can be seeded by such a preference in researchers toward (technologically advanced) solutions compared to the actual state of affairs of manufacturing, as inhibitors of the extrapolation of the results to different industrial settings.

3.12 The Static Fallacy: Research-Practice Disconnect in Dynamic Environments

Perhaps the greatest lack of alignment between the research focus and actual manufacturing need levels the overthrow of dynamic strategies layout assumptions (Fig. 6). The field seems to rationalise a manufacturing reality, which is now, at best, a static in most contemporary manufacturing systems with 63 percent of research studies, optimising on that basis. The fact that only limited attention to dynamic facility layout problems (27%), in its turn, is quite problematic, in the light of having comprehensive evidence regarding its relevance. The ever-present nature of static assumptions is even more alarming when viewed in the light of growing instability of the contemporary manufacturing conditions. Flexibility of the layout during a stochastic demand is of paramount importance due to research by [137,138] but most studies remain being deterministic and only a few are in fact deterministic in reality. The low prevalence of hybrid methods (10%) indicates that even scholars who acknowledge the shortcomings of the static assumptions cannot find solutions to practicalities that manage both the computational thought requirements and the needs realism in modelling requirements. This is one of the core challenges of which the field has not been coping properly.

3.12 Synthesis of Critical Findings: Toward a More Holistic Research Paradigm

The comparison of these six dimensions demonstrates that it is a research area where crucial methodological kind of limitations and the lack of practise could be observed. The integration paradox, human factors blind spot, temporality stagnation, algorithmic tunnel vision, technological myopia and the static fallacy are interrelated issues that all constrain the capability of the field to deal with facility design challenges in the real world. Such results imply that future studies need to go beyond incremental advances in current paradigms to rethink the priorities of research and the methodological prescriptions underlying them. Designing authentically integrated models with human factors, adaptability in a dynamic and variety of technological responses are also a serious issue and would necessitate interdisciplinary cooperation and methodological invention. The post-event standard of such restrictions through several decades indicates that they constitute not just a research gap but somewhat a structural problem in the research community. An international remedy of these issues will necessitate not only using an innovative approach to the methods alone but also change of culture that will be more holistic and practise-driven in research.

CONCLUSION

This systematic literature review of 183 articles demonstrates that there are crucial gaps and the methodological limitation of the research concerning facility layout and material use and handling systems that offer a very limited scope to the development of the theoretical framework of handling material flow and delivery alongside the practicability of the selected concept related to facility design and layout. The review reveals an inherent contradiction in the fact that of all the studies in which a truly integrated layout and material handling design is accomplished; one out of every four actually does it, yet extensive evidence demonstrates that in terms of performance, integrated design (as

opposed to sequential designs) performs far better. Worst of all, 92% of studies do not take human factor and ergonomics into account at all, which should be seen as a grave omission since the manufacturing workplace is characterised by a growing focus on the welfare of employees.

The discipline exhibits worrying bias in methodology, such as use of over-reliant metaheuristic algorithms (65%) to measure their impact on solution optimality, technological tunnel vision in respect of AGV systems (58%) to create unrealistic generalizability, and adherence to static layout (63%) despite dynamic manufacturing processes. These inter-related constraints indicate that the present research paradigm lacks sufficient consideration of the real-world facility design problem. Further studies need to undergo a paradigm shift in both the approach of considering the human factor in automation-based studies and the approach of holistic considerations in the cataclysmic dynamism of operations. There is a pressing urgent need to develop models that are genuinely integrated with ergonomics, stochastic demand variability and materials handling technologies of handling a wide variety of materials. This systematic review offers a research and practise roadmap that fulfils the mentioned gaps to allow the researchers and practitioners to produce a more effective, worker-focused, and flexible facility design solutions that will comply with the modern manufacturing reality.

CONFLICT OF INTEREST

There is no conflict of interest for this research work.

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