Journal of Scientific & Industrial Research
Vol. 81, September 2022, pp. 972-981
DOI: 10.56042/jsir.v81i09.57607

Analysis of OM-Based Literature Reviews on Facility Layout Planning

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Received 26 November 2021; revised 25 August 2022; accepted 25 August 2022

This work consists of a systematized review of the state of the art of reviews for the problem of Facility Layout Planning (FLP) within the Operations Management (OM) field to support the decisions taken for the improvement of the manufacturing and logistics in a factory environment. The first phase begins by defining the search strategies for obtaining the scientific literature, for which we used ten databases. With these, a base of 112 articles was obtained, but after the systematized process was reduced to 32 directly related articles. In the second phase, we executed a Dimensional analysis of these literature review articles employing a quantitative analysis of the sections and subsections of the selected articles. The third phase comprises the identification of gaps and future research lines. Finally, the conclusions obtained from the systematized review process are presented.

Keywords: Classification of methodologies, Conceptual framework, Cyber-physical systems, Manufacturing layout, Plant layout

Introduction

Facility Layout Planning (FLP) involves a set of design problems related to the arrangement of the elements that shape industrial production systems in a physical space. The resulting decisions of this process are vital to the system performance since they introduce a set of constraints and limitations that should be respected during the system operation.[1]

However, the new context caused by the cyber-physical systems of Industry 4.0 and their associated technologies has caused many production and logistics systems in factories to be total or partially automated. Therefore, we will have a large amount of real-time data at our disposal, which could be an essential input for the dynamic application of traditional operations management techniques in production or logistics systems such as FLP.

The recent events of disruption in industrial supply chains caused by the COVID-19 pandemic have highlighted the need for new methodologies or tools that allow the cooperation between the new advances in automation, digitalization, and robotics with the interaction of human workers. Therefore, this integration is beneficial for both parties, and it should not have the objective of reducing the sources of jobs for human workers.

In other words, this approach seeks to use technological advances as a support tool for the correct decision-making by human operators, putting human operators again at the centre of crucial decision-making.[2–5]

Within the FLP field, the Systematic Layout Planning (SLP) methodology has traditionally been one of the first and most widely applied methods in various industries. [6] For example, Xiao *et al.* [7] in their study use SLP to improve the layout of their facilities and reduce their environmental emissions. The study by Yang *et al.* [8] combine SLP and Handling System Analysis methodologies to improve the facility layout and to reduce the transportation times between departments, and the research by Chakraborty *et al.* [9] combine SLP with spatial analysis techniques to improve the facilities layout and specifically storage operations.

The most recent SLP implementations for plant design or redesign are aligned with the following methodologies:

- Industry 4.0 approach and simulation techniques.[10,11]
- Big data and data analytics.[12]
- Artificial intelligence techniques (AI) include genetic algorithms.[13]

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- Lean methodologies.[14]
- A comprehensive industry 4.0 approach.[15]
- And tools that combine human interaction with virtual production environments.[16]

However, we can notice that the SLP has not yet exploited all the potential of new advances in automation, digitalization, and robotics as a support tool for human decision-making in factories belonging to Industry 4.0. For all of the above reasons, it is essential to review current state of progress of these implementations.

Over the years, many Literature Reviews (LRs) about the FLP have been done. Therefore, this work aims to organize existing knowledge by analyzing the related LRs to provide a general overview of state of the art on this topic, including the future research lines and gaps.

The results of this paper could be precious to get a quick overview of the state of progress in this field, to know the dimensions used by the different LRs to analyze existing works, allowing us to focus future revisions not on analyzed aspects, but more appropriate to the new technological context.

The rest of the paper is structured as follows. First, we presented the search strategy of LRs in the field of FLP and their results obtained.

Later, we performed a descriptive analysis of the selected LRs. Subsequently, we executed a dimensional analysis of the selected papers and defined new dimensions to classify them.

Finally, we analyzed the future research lines and gaps detected by the LRs of the FLP problem to bring conclusions.

FLP Literature Reviews Search Strategy

In order to select the most relevant papers for this study, the search strategy depicted in Fig. 1 was followed. Initially, we started by searching for papers on the FLP problem in the most common scientific databases that include the majority of the industrial fields and methodologies applied to the FLP problem to date. This would be an input to elaborate a global framework of reference on the FLP problem: Scopus, Web of Science (WoS), Science Direct (SD), Google Scholar (GS), Emerald insight (Emerald), Wiley Online Library (Wiley), Taylor & Francis Online (T&F), Springer Link (Springer), Inderscience (IS), and Informs PubsOnline (IPO). The Search Terms employed in the field of Title are the following: ("REVIEW" OR "STATE OF THE ART" OR "SURVEY" OR "CONCEPTUAL FRAMEWORK") AND ("LAYOUT DESIGN" OR "DESIGN OF LAYOUT" OR "MANUFACTURING LAYOUT" OR "FACILITY LAYOUT" OR "PLANT LAYOUT" OR "FACILITY LAYOUT PLANNING").

After searching the ten databases by search terms, 103 articles were found, and then we applied a filter that allowed us to the true review articles related to our study topic. To do this, we eliminated the duplicated articles. We refer to an article as a duplicate when it can be found in several databases simultaneously, for example, those articles that are published in the Scopus database and at the same time in the Web of Science (WoS) database or even in more databases. Later we excluded the articles unrelated to the central studied topic or called the exclusion for relevance. Resulting in 32 LRs directed related to FLP.

Descriptive Analysis of LRs

As shown in Fig. 2, LRs on FLP has been published since 1985 to date. Although a low production on this subject can be observed in the 80s and 90s, there has been considerable growth from 2017 to the present. This fact may be due to the boom in use, and formal definition of resolution approaches for mathematically formulated FLP-type problems. Which, in turn, make use of intelligent approaches within which Machine Learning (ML) and Neural Network (NN) techniques have been included.[17,18]

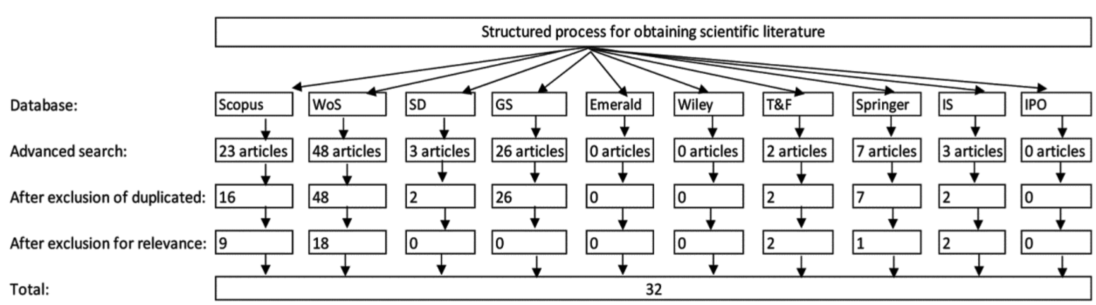

Fig. 1 — Search strategy for selecting the LRs of FLP problem.

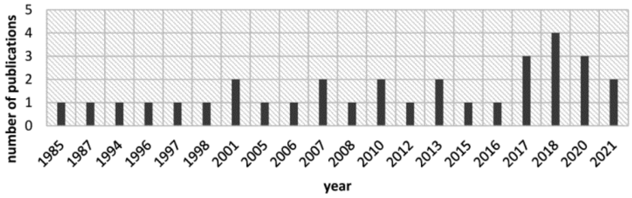

Fig. 2 — Number of review articles published per year

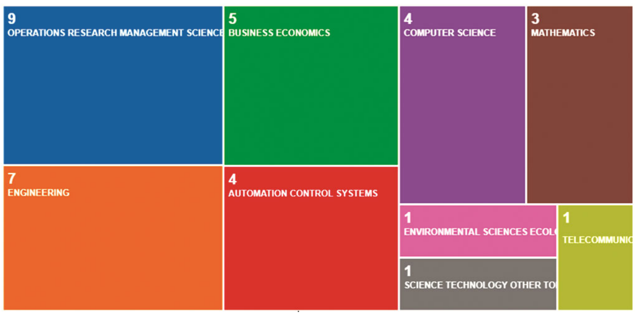

Fig. 3 — Research areas from selected WoS LRs

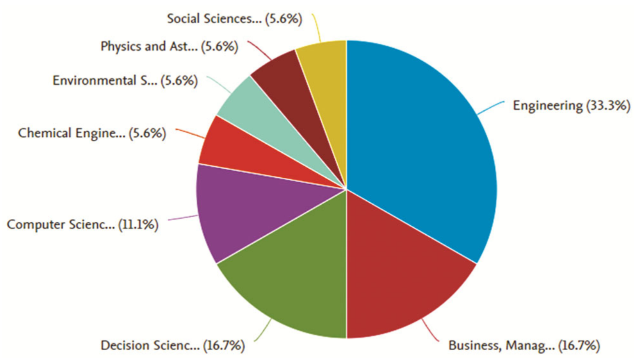

Fig.4 — Subject areas from selected Scopus LRs

As shown in Fig. 1, from the main database of 32 LRs directly related to FLP for this study, we extracted 18 LRs from WoS (as shown in Fig. 3) and 9 LRs from Scopus. It can be noted that the main research areas of the LRs of FLP are operation research, management science, and engineering.

The selected LRs obtained through the Scopus database show that the main subject areas of FLP are engineering, business management and decision sciences. As shown in Fig. 4.

Co-occurrence Analysis Among the Selected LRs

For our review work, a co-occurrence analysis was employed among the 32 selected LRs of FLP, specifically by using the VOS viewer software. Based on the full counting method, a minimum of two occurrences were considered as a condition for a keyword to appear in the final graph. Thus, about 48

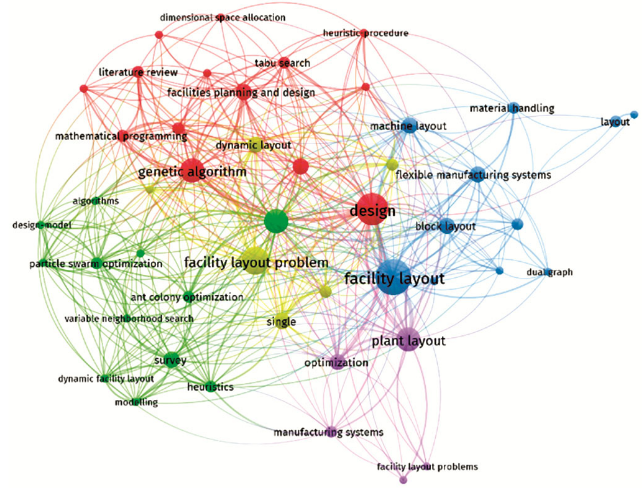

Fig. 5 — Map of co-occurrence with keywords related to the scope of the facility layout problem from the 32-selected LRs.

keywords were selected by the program to appear in the resulting graph.

The resulting graph shows us the relations between the keywords of the 32 selected LRS. In addition, these keywords were classified into five connected clusters. As shown in Fig. 5. In the following lines, we describe these relationships in the clusters obtained using VOS viewer.

Cluster 1 (in red) relates the LRs that contain layout design and planning terms with modeling and in turn, with heuristic and optimization algorithms, among which the Tabu Search (TS) Algorithms and Genetic Algorithms (GA) stand out. GA has historically been the most used in the solution of FLP type models and the most interrelated with other key terms within the FLP subject matter.

Cluster 2 (in green) relates LRs that deal with heuristics for the solution of the different FLP models such as Variable Neighborhood Search (VNS), Simulated Annealing (SA), and Ant Colony Optimization (ACO). In addition, the GAs established a direct connection with the LRs belonging to clusters 1 and 3. In addition, this cluster contains LRs that deal with cellular manufacturing systems and the Dynamic Facility Layout Plan (DFL).

Cluster 3 (in blue) covers essential terms in developing the different FLP models, such as flexible manufacturing systems, graph theoretic, and material handling. In addition, the block layout and Quadratic Assignment Problem (QAP) models are considered to deal with FLP.[19]

Cluster 4 (in yellow) contains LRs that deal with FLP modeling concepts such as dynamic modeling and Fuzzy modeling for the FLP case. In the end, a relationship is established between this cluster and cluster 1 through the GA.

Cluster 5 (in purple) groups LRs that work with manufacturing systems and optimization concepts.

Dimensional Analysis

The publications on The LRs finally selected adopted different dimensions to analyze the contributions of existing FLP research. We have joined similar dimensions in a set of 11-dimensional groups and systematically classified each LRs based on them. Through this procedure, the frequency of appearance of each dimension group has been assessed, thus making it possible to identify the most and most minor used dimensions when analyzing existing works and those that have been undefined. The following dimension groups have been defined.

Overview of facility layout problem (O): Here, we indicated if the LRs contain an analysis of the different FLP type problems, which in most cases are classified according to the modeling approach or model solution technique

Facilities Characteristics (FC): When designing entirely new plants or especially redesigning existing plants, it is crucial to consider the physical aspects and constraints that may affect the result of the resulting layout. Such as the number of facilities, the number of floors, the shape and area of departments, the flow of operations, the surface on which the facilities and machines will be placed, the use of bays, ergonomics and safety of workers, among other physical constraints that may be present in the FLP.

Material Handling Systems (MH): This dimension analyzes the flow and movement of materials within the plant, usually using systems composed of elements for the efficient flow of materials such as elevators, automated guided vehicles, conveyors and, more recently, the use of robots in a factory.[20]

Manufacturing Systems (MS): This dimension takes into account the type of manufacturing system used in the production operations, such as Flexible Manufacturing systems, Cellular, Lean, Agile, Prefabricated and Reconfigurable Manufacturing systems, so that the FLP can be configured to adapt to it.

Distance Metrics (DM): In this dimension, we analyze the geometric metrics used for the mathematical formulation of the FLP, among which we can mention: Rectilinear, Euclidean, Squared Euclidean, Chebychev, Contour-based or Flow path-based metrics.

State (S): Also known as the planning approach, it refers to the layout evolution in the planning horizon. If the material flow changes during the planning horizon, it periodically evaluates and modifies the layout. It is called DFLP (dynamic). On the contrary, if it does not change over a long planning horizon, it is known as SFLP (static).[21]

Uncertain Environment (U): Several sources of uncertainty affecting the FLP problem can be considered when representing it, such as product demand, among others. For this reason, knowing which parameters have been considered uncertain when addressing this problem is interesting.

Modeling Approach (MA): This refers to the approach used for the representation of a specific FLP problem, i.e., whether the problem will be represented as Discrete or continuous, as well as its formulation using optimization techniques such as Linear Programming (LP), Integer Programming (IP), QAP, Mixed Integer Programming (MIP), Nonlinear Programming (NLP), Graph Theory (GT), among others.

Solution Methods (SM): In this dimension, we include all methods, enabling technologies, algorithms, or approaches for solving the problems formalized as FLP. Within this dimension, we distinguish four main groups: exact, heuristic, and metaheuristic methods. This group also includes the simulation of discrete events.[18]

Solution Methods by Intelligent Approaches (SMIA): recent developments in methodologies for solving FLP problems include Expert Systems (ES) or Machine Learning (ML) methods. Expert systems (ES) represent the expert knowledge on a series of situations and scenarios for FLP that have been studied extensively in the field of operations research, but these expert systems cannot adapt to the constant changes in the FLP scenarios. Furthermore, this could be corroborated in our co-occurrence analysis. Therefore, their use has declined in recent years [17]. That is why in this paper, we will only mention them. On the other hand, we will emphasize the study of Machine Learning (ML) techniques whose learning ability makes them adapt to the constant changes that may occur in the FLP.[17]

Computational Comparison (CC): Through this dimension, the computational performance of various FLP models and resolution methods are generally compared in terms of computational performance. Specifically based on the execution time and solution quality.[22]

Table 1 lists the LRs grouped in the recently described dimensions, intending to know the most exploited dimensions and the existing gaps, with a view to contributing to the important field of FLP.

Results and Discussion

Based on the dimensional analysis, we can deduce that near of 40% of the LRs on FLP contain Modeling Approaches (MA) and Solution Methods (SM) approaches, which means that mathematical modeling and resolution is a crucial aspect of this field of study. In addition, O, MH, FC, U and S, which belongs to the field of mathematical modeling, complement the central part of the cumulative percentage in the Pareto chart. Therefore, it can be understood that research on FLP has mainly a quantitative focus. As seen in Fig. 6.

The following dimensions that the LRs have mostly covered are the S, MS, SMIA, CC and DM, it shows us the importance of the LRs on FLP in the correct modeling of the manufacturing and material handling systems of industrial supply chains and in applying OM techniques oriented to meet the real physical requirements of industrial facilities.

However, there is a lack of exploitation of the SMIA dimension, which includes intelligent approaches for FLP-type problem solving using

Table 1 — Dimensional Analysis of LRs from the FLP problem

Year	LRs authors	Dimension group[A]										
		O	FC	MH	MS	DM	S	U	MA	SM	SMIA	CC
1985	Levary & Kalchik[23]	×	×	×	—	—	—	—	—	×	—	×
1987	Hassan & Hogg[24]	—	×	×	×	—	×	×	×	×	×	—
1994	Banerjee & Nof[25]	×	—	—	×	—	—	×	×	—	×	—
1996	Meller & Gau[26]	×	×	×	—	×	×	×	×	×	—	×
1997	Mavridou & Pardalos[27]	×	×	—	—	—	—	—	×	×	—	—
1998	Balakrishnan & Cheng[28]	×	×	×	—	—	×	×	×	×	—	×
2001	Chen & Sha[29]	×	—	—	—	—	—	—	×	×	—	—
2001	Caccetta and Kusumah[30]	×	—	—	—	—	—	—	×	×	—	×
2005	Asef-Vaziri & Laporte[31]	×	—	×	×	—	—	—	×	—	—	—
2006	Singh & Sharma[5]	—	—	—	—	—	—	—	×	×	—	—
2007	Loiola *et al.*[19]	×	—	—	—	—	—	—	×	×	×	×
2007	Drira, Pierreval & Hajri-Gabouj[20]	×	×	×	—	—	×	—	×	×	—	—
2008	See & Wong[32]	×	—	—	—	—	—	—	×	×	—	—
2010	Roslin, Dawal & Ahmed[33]	×	—	—	—	—	—	—	×	—	—	—
2010	Davoudpour, Jaafari & Farahani[34]	×	×	×	—	—	—	×	—	×	—	—
2012	Moslemipour, Lee & Rilling[35]	×	—	—	—	—	×	×	×	×	×	—
2013	Hungerländer & Rendl[22]	—	—	—	—	—	—	—	×	×	—	×
2013	Aiello *et al.*[36]	×	×	×	×	—	—	×	×	×	—	—
2015	Keller and Buscher[37]	—	—	×	—	×	—	×	×	—	—	—
2016	Sharma & Singhal[38]	×	×	×	—	—	×	×	×	×	—	—
2017	Ahmadi, Pishvaee & Jokar[21]	×	×	×	—	×	×	×	×	×	—	—
2017	Anjos & Vieira[39]	×	×	—	—	—	—	—	×	×	—	×
2017	Besbes *et al.*[40]	×	—	×	—	—	—	—	×	×	—	—
2018	Hosseini-Nasab *et al.*[41]	×	×	×	×	—	×	×	×	×	×	—
2018	Malik, Abdallah & Ala'raj[42]	—	×	×	×	—	—	—	×	×	×	—
2018	Kikolski and Ko[43]	—	—	—	×	—	—	—	×	×	×	—
2018	Zhu, Balakrishnan & Cheng[44]	×	—	—	—	—	×	×	×	×	—	—
2020	Al-Zubaidi, Fantoni & Failli[18]	×	—	—	×	—	—	—	×	×	—	—
2020	P Pérez-Gosende, Mula & Díaz-Madroñero[45]	×	—	—	—	×	×	×	×	×	×	—
2020	Pablo Pérez-Gosende, Mula & Díaz-Madroñero[46]	×	—	—	×	—	×	—	×	×	—	—
2021	Burggräf, Wagner & Heinbach[17]	×	—	—	—	—	—	—	×	×	×	×
2021	Perez-Gosende *et al.*[1]	×	×	×	—	×	—	—	×	×	—	—
	Total of publications	26	14	15	9	5	11	13	30	28	9	8
	Percentage[B]	81.3	43.8	46.9	28.1	15.6	34.4	40.6	93.8	87.5	28.1	25

Dimension groups legend[A]: O: Overview of facility layout problem; MH: Material Handling Systems; MS: Manufacturing Systems; DM: Distance Metrics; S: State; U: Uncertain Environment; MA: Modeling Approach; SM: Solution Methods; SMIA: Solution Methods by intelligent approaches; CC: Computational comparison

Percentage[B]: represents the percentage of each dimension group in relation to the total 32 LRs related to FLP expert systems based on experience. On the other hand, these SMIA could use ML systems whose learning capabilities allow them to adapt dynamically to the constant changes that may occur in any component of the FLP, such as changes in product demand. Thus, be able to provide dynamic solutions in the facility layout design. Additionally, these ML systems could benefit from recent advances in automation, digitalization, and robotics.

In addition, it can be noted that the least exploited dimensions are CC and DM, i.e. it was observed that only eight LRs on FLP support their comparisons between modeling or resolution techniques with a more

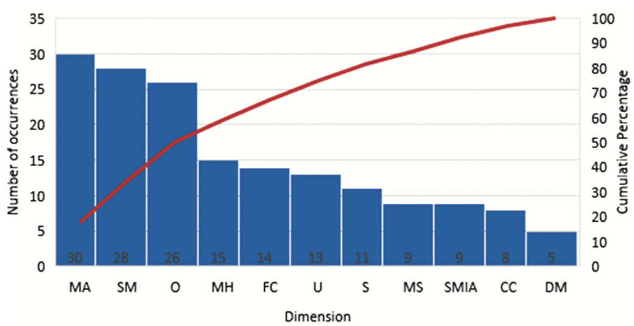

Fig. 6 — Pareto chart of the LRs dimensions

formalized computational comparison or under a mathematical, statistical or combinatorial optimization comparison scheme. This fact would give them greater methodological rigour and credibility to the review work, especially if it has a quantitative or OM approach.

Likewise, only five papers under this dimension noted low use of the DM dimension. This indicates that few papers emphasize analyzing geometrical and spatial aspects to define adequately the metrics used in creating the mathematical models to treat the different types of FLP. In addition, some LRs recommend as future research lines the development of FLP models that use three spatial dimensions (3D) instead of a generalized view in two spatial dimensions (2D) modified in each case of the FLP.[45]

Besides, dimensions such as product characteristics (e.g. perishability) or manufacturing strategy are not considered when performing reviews on the topic.

Future Research lines analysis

In this section, the future research lines of the 32 selected LRs have been assigned in one of the 11-dimensional groups specifying the publishing year and their frequency of appearance (Table 2) to be used in future research.

Table 2 — Classification of future research lines per year and related dimension group

Dimension group[A]	Year																			
	1985	1987	1994	1996	1997	1998	2001	2005	2006	2007	2008	2010	2012	2013	2015	2016	2017	2018	2020	2021
Overview of facility layout problem (O)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Facilities Characteristics (FC)	—	—	—	—	—	—	—	—	—	1	—	1	—	—	—	—	1	1	2	—
Material Handling Systems (MH)	—	—	—	—	—	—	—	—	1	—	—	—	—	—	1	—	—	1	1	1
Manufacturing Systems (MS)	—	—	1	1	—	—	—	1	—	—	—	1	—	—	—	—	—	1	1	—
Distance Metrics (DM)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2		1	2
State (S)	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	1
Uncertain Environment (U)	—	1	—	—	—	1	—	—	1	—	—	—	—	1	—	—	—	2	—	1
Modeling Approaches (MA)	—	1	1	1	—	—	—	—	1	2	1	1	—	1	1	—	3	4	1	2
Solution Methods (SM)	1	—	—	—	1	1	—	—	1	1	1	—	—	2	1	1	2	2	2	1
Solution Methods by intelligent approaches (SMIA)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	1	1	2
Computational comparison (CC)	—	—	—	1	1	—	—	—	—	—	—	—	—	2	—	—	—	1	1	1
Total of publications	1	3	2	3	2	2	0	1	4	4	2	3	0	6	4	1	8	14	11	11
Percentage[B]	3.1	9.4	6.3	9.4	6.3	6.3	0.0	3.1	12.5	12.5	6.3	9.4	0.0	18.8	12.5	3.1	25.0	43.8	34.4	34.4

Dimension groups legend[A]: O: Overview of facility layout problem; MH: Material Handling Systems; MS: Manufacturing Systems; DM: Distance Metrics; S: State; U: Uncertain Environment; MA: Modeling Approach; SM: Solution Methods; SMIA: Solution Methods by intelligent approaches; CC: Computational comparison

Percentage[B]: represents the percentage of each dimension group in relation to the total 32 LRs related to FLP

The Pareto chart's first group comprises the "Modeling Approaches – MA" and "Solution Methods – SM" dimensions, comprising about 50% of the recommendations for future work by the selected LRs. Thus, we can note a high recommendation for further work that treats the FLP as a problem that first can be modeled mathematically in discrete or continuous form. Subsequently, given the nature of the FLP as an NP or NP-hard problem, it is recommended to apply different approaches to solve the mathematical model. The solution approach can be exact, heuristic, metaheuristic, or event simulation tools. In conclusion, it is possible to note that most of the authors of the 32 selected LRs agree that it is necessary to continue to carry out work using MA and SM, and historically this is how the FLP review work has been carried out since 1985 to date, as shown in Table 2 and Fig. 7.

Concerning the future research lines recommended by the related LRs, About 9% of the authors recommend considering the "Uncertain Environment – U" dimension by creating specific FLP models that could model the uncertainty in the input data. Such as product demand, uncertainty in the management of MHS and their volumes within the factory supply chain, the use of scales for qualitative assessment instead of exact values, and the uncertainty for the access to economic resources, among others.[42,28]

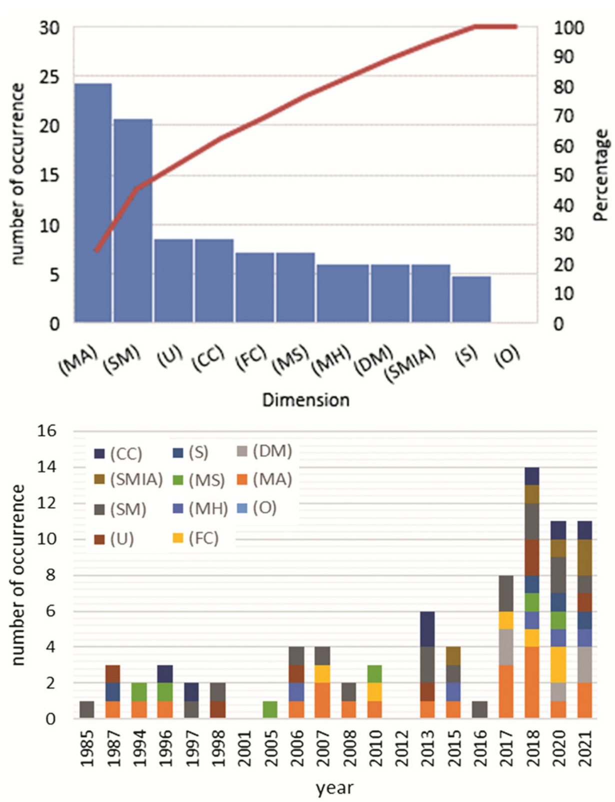

Fig. 7 — Pareto chart and stacked bar diagram of future research lines per dimension and per year

The LRs included in the "Computational comparison – CC" dimension recommend for future FLP work to include rigorous computational comparisons between the methods or algorithms used to solve FLP-type problems, addressing statistical methodologies and even using combinatorial analysis. So that, the validity of a solution algorithm or method can be determined under large instances and in classical FLP problems that are difficult to solve.[22,46,1]

The LRs classified in the "Facilities Characteristics - FC" dimension recommend for future work to study the use of graphic and virtual reality tools.[20] On the other hand,[39] to consider improving the multi-floor layout and symmetry aspects to adequately model manufacturing systems' handling, it additionally,[44] recommends future work to study the aspects of unequal areas between departments in a factory.

About 7% of the LRs indicate future work on models that consider the characteristics of "Manufacturing Systems-(MS)" specifically; it recommended modeling the use of manufacturing cells, lean manufacturing systems, prefabricated, Flexible Manufacturing System (FMS), Reconfigurable Manufacturing System (RMS) and Agile Manufacturing System (AMS).[18]

Around 6% of the LRs "within the Distance Metrics-(DM)" dimension recommend for the FLP modeling process to consider the appropriate use of Rectilinear, Euclidean, Squared Euclidean, Chebychev, Contour-based, Flow path-based metrics, depending on the real case to be solved. Likewise,[21] they indicate that most FLP papers overlook this correct mathematical model development requirement.

Likewise, the LRs pigeonholed within the Material "Handling Systems - (MH)" dimension are of more recent appearance, i.e. from 2015 to date, these LRs recommend improving the MH of the factory through robust modeling that considers the details of the business supply chain.[37] Likewise,[43] they recommend working future work on improving Material Handling jointly the manufacturing process and the distribution of workstations.[45] it recommends that configurations of the transport system for materials, and the same author the following year, [1] agrees again that it is still necessary to develop FLPs that consider the configuration of the material handling system.

The "Solution Methods by intelligent approaches – SMIA" dimension presents only in 6% of the LRs whose future lines can be considered in this dimension. It is essential to mention that this is perhaps the most exciting dimension for our review work since it shows the number of works that have included intelligent approaches as solution methods. Specifically, in 2015 Keller *et al.*[37] proposed the use of expert systems in the case of FLP. Then, in 2018, Malik *et al.*[42] suggested using Supported Vector Machines (SVM) to improve FLP for a hospital. Later, the work of Gosende 2021[(1)] suggests the case of artificial intelligence techniques in FLP. At the same time, Burgaf *et al.* in 2021[(17)] present what is for us, a complete LRs on the use of ML for the case of FLP. In future research lines, this suggests using deep learning techniques to visually evaluate the suitability of a specific layout and suggests leveraging computer vision techniques to identify objects in a layout.

The LRs placed within the "State (S)" dimension agree on the importance of using dynamic modeling techniques that evidence the evolution of the state of the layout within the planning horizon since the parameters of the initial model can change dynamically and require the change of the layout according to those changes. The factors that can change could be qualitative factors such as closeness rating between facilities, plant safety, and flexibility of layouts. Simulation and queuing theory can be used to overcome this drawback. Hence, the idea of continuous layout representation should be considered in addition to the discrete representation[24]. Then, Zhu *et al.* in 2018[(44)] indicate that the DFLP problem considering muti-floors is still presenting modeling challenges, while Gosende *et al.* in 2020[(45)] indicate that the DFLP system configurations should be considered in addition to the discrete representation. In addition, it should be considered for the material transport system configurations not yet addressed in the case of DRLP. The same author in 2021[(1)] indicates that it is necessary to consider budget constraints to formulate DFLP optimization models and that it is necessary to contemplate the three-dimensional space for DFLP.

In the final part, the LRs boxed within dimension "Overview of facility layout problem (O)" indicates, due to their absence, that it is not recommended to do more LRs on the FLP. This makes sense since searching the ten scientific databases used to carry out this review work, 112 LRs could be found, which have been carried out continuously since 1985 to date and contain in their Title the term FLP review, which shows that this field of science is over-saturated.

The main results found after the dimensional analysis are discussed below. Initially, it is essential to mention that after this literature review, it was possible to observe the low amount of works carried out under the ML dimension and that in the most recent literature revision works from 2018 to date, the use of ML techniques is being recommended in the FLP. As well as in our analysis of co-occurrence, the term ML is almost imperceptible since we parameterize our VOS viewer to group works with more than two occurrences. This reaffirms that there are very few works on the application of ML as resolution approaches for the case of the FLP. In addition, the product characteristics and the manufacturing strategy are not considered when addressing the FLP problem. These aspects, jointly with the use of ML techniques to static or dynamically design the layout, are devised in this work as future research lines.

After the co-occurrence analysis with VOS viewer Tool based on the number of apparitions from keywords of related LRs we obtained 5 clusters that also could be grouped into two groups. The first group consists of clusters 1 and 2 and deals with heuristic and metaheuristics techniques used to solve FLP problems with bigger databases. However, in these clusters, modeling aspects are treated superficially. The second group contains cluster 3, cluster 4 and cluster 5. Essentially, these clusters treated the techniques to model FLP problems in mathematical or statistical mater, taking into account the particularities of each factory treated and their supply chain or manufactory system.

On the other hand, with our dimensional analysis, we have defined 11 dimensions encompassing the FLP review work currently available. Thus, the first eight dimensions have been dedicated to aspects of the modeling of FLP-type problems in different types of factories. While dimensions 9, 10 and 11 deal mainly with techniques for solving FLP-type problems previously modeled and applied on instances that can represent significant computational challenges. As we can notice, our Classification of 11 dimensions proposes an orderly process for dealing with FLP-type problems, which starts by reviewing the FLP problems, then the options for their modeling and finally moves on to their resolution. This is a more organized and more precise process than the clusters presented by the co-occurrence analysis of the keywords obtained with VOS viewer.

Conclusions

First, with our dimensional analysis of the LRs it was possible to define more precise dimensions within the FLP problem than simply analyzing the problem with the VOS viewer software since our dimensions cover more extensively the aspects within the FLP theme.

Subsequently, by grouping the LRs in these dimensions, we could notice in quantitatively form the lack of works that take into account the Distance Metrics and geometric-spatial aspects (DM), as well as not enough works that include in the analysis of their results a solid Computational comparison (CC). In addition, by grouping the LRs in our proposed dimensions, we could notice that the future lines that remain to be exploited within this exciting subject are the Solution Methods by intelligent approaches-SMIA, within which we include the use of ML as a resolution method and the modeling of the FLP problem in a dynamic way-DFLP. That is, considering the variation of the FLP factors as a function of time, such as Costs, Prices, Demand and Inventory levels of materials and resources.

As limitations, our work defines a group of dimensions that cover entirely the FLP problem, with which it would be possible to analyze this problem in a more holistic way, that is, without neglecting key aspects that historically have taken into account in the field of Operation Management-OM. However, this work could lose its effectiveness if it is analyzed from the perspective of Operations Research (OR) or from the field of Machine Learning-ML, which could be interested in dealing with the case of FLP.

The future scope of this work lies in defining the future lines and gaps within the FLP problem in a more quantitative way so that work can continue within this interesting topic without relegating certain lines or dimensions that have been carried out. Specifically, the dimensions proposed in this work could develop a multi-phase method or model that deals more comprehensively with the FLP problem without discarding key aspects of this topic, such as the dynamic modeling mentioned in the State-S dimension, or the Uncertain Environment stated in the U dimension.

Acknowledgements

Authors of this publication acknowledge the contribution of the “Centro de Investigación de Gestión e Ingeniería de Producción” (CIGIP), belonging to UniversitatPolitècnica de Valencia for supporting this investigation. In addition, the authors are immensely grateful for the support given by the SDAS Research Group (www.sdas-group.com).

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