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A REVIEW OF FACILITY LAYOUT PROBLEMS

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Abstract
In this article, a review of the Facility Layout Problem has been conducted in two parts. The initial part concentrates on conducting a bibliometric analysis utilizing data from the Web of Science. Subsequently, the second part of the review examines various solution methodologies applied in addressing both static and dynamic facility layout problems. Through this literature review, it is observed that the research study on facility layout planning has increased due to its significance in both the service and manufacturing sectors. The objective of this literature review is to understand the current trends and methods being used in facility layout planning. Also to identify potential areas for further research in facility layout planning.
Keywords: Facility Layout Problem; Static and dynamic environment; Heuristics and metaheuristics.

I. Introduction

A well-designed facility has a positive impact on the working environment and it satisfies the individuals. Suitable facility layout design for any industry and organisation makes itself a profitable asset. In manufacturing industries, effective design of facility layout helps firms to earn 10-30% more profit by reducing Material Handling Costs (MHC) [1,2]. The main objective of the Facility Layout Problem (FLP) is to reduce MHC, ease the transportation of materials and increase the organization's productivity. In FLP, it is observed that mainly two objective factors namely Quantitative and Qualitative [3] are considered. Quantitative factor relates to the minimization of material handling costs and Qualitative factors relate to plant safety, aesthetics, and noise. Objectives of solving FLP differ from organisation to organisation depending on decision maker criteria. In service sector organisations like healthcare, the objective is to minimize the patient movement from one clinic or department to another and it is observed that the cost of healthcare increased because of inefficient layout planning and undesired movement of patients and employees [4].

II. Review Method

Literature review is carried out in the following 4-steps. Step 1, study the available references and identify the keywords. Step 2, identifies the various databases search engine platform. Step 3, according to the keywords screening article by its titles and abstract, collects multiple papers from the databases. Step 4, identifies the different (methods and case studies) approaches for the solutions. Figure 1 illustrates the flow chart of the review methodology.
From Step 1, we understand the basic concept through available resources and identify the significant words. These words are in terms of expression, questions or titles and keywords that are relevant to our theme. Some of the keywords identified are Facility Layout Problems, heuristic methods, industrial layouts, hospital layout problems, Facility layout in health care services, genetic algorithm, quadratic assignment problems and present industrial layout.
In step 2, search the keywords in databases like Web of Science, Scopus, Emerald, Springer Link, Science Direct, Wiley Online and Taylor & Francis and also search in Google Scholar for related Articles and Journal papers. Obtained a large number of results and some of them do not address the topic directly but lead to understanding the concepts in fine structure. Since the study mainly focused on the genetic algorithm from heuristic methods.

Step 3 elaborates on search methodology, where, the research related papers are overlooked in the Web of Science database, and we found that there are a total of 303 articles on FLP are obtained from different journals. Articles also searched by using some of the keywords like, genetic algorithm, hospital facility layout, facility layout related to service organisation, and review on FLP and so on. Figure 2, shows a Network diagram of the most commonly frequently searched words related to the theme, which was published between 2000 to 2023 and the diagram shows, frequently used words in the articles' titles and abstracts. In early 2010, works are based on QAP, flexible manufacturing system, dimension space allocation and so on. From 2010 to 2023, we can observe that research work on topics related to metaheuristic approaches increased and authors focused on the improvement of FLPs by studied algorithms, optimization and simulation by simulated annealing, genetic algorithm, tabu search and slicing tree. To build this network diagram, we use VOS viewer to generate the rank of the most relevant terms.

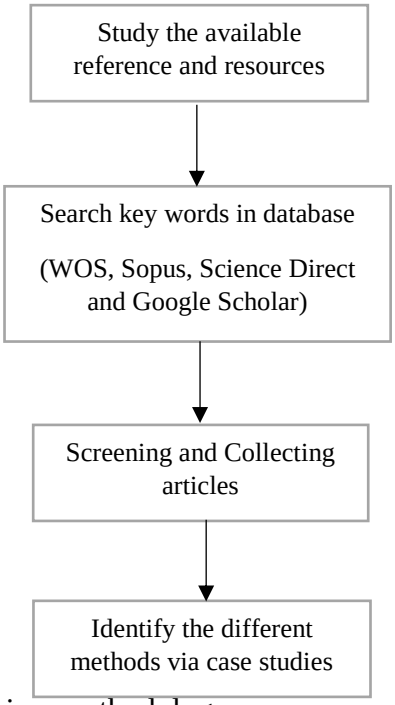

Figure 1: Flow chart of literature review methodology

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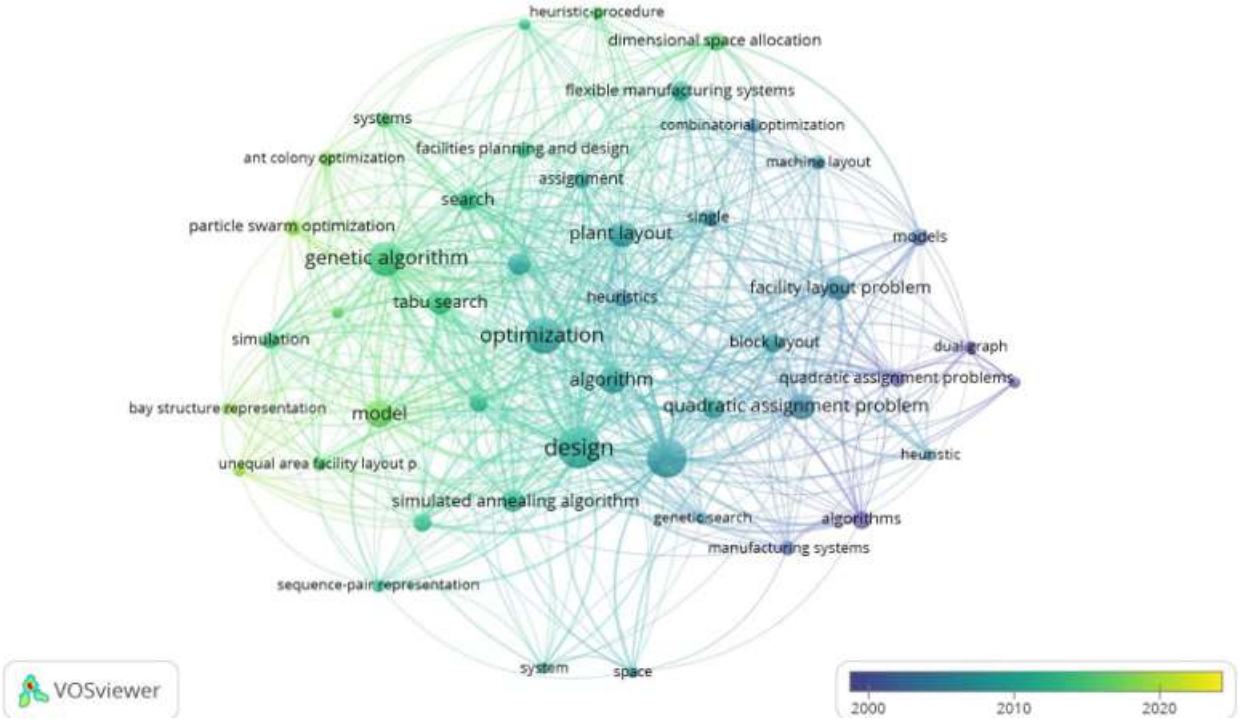


Figure 2: Network diagram of most frequent words

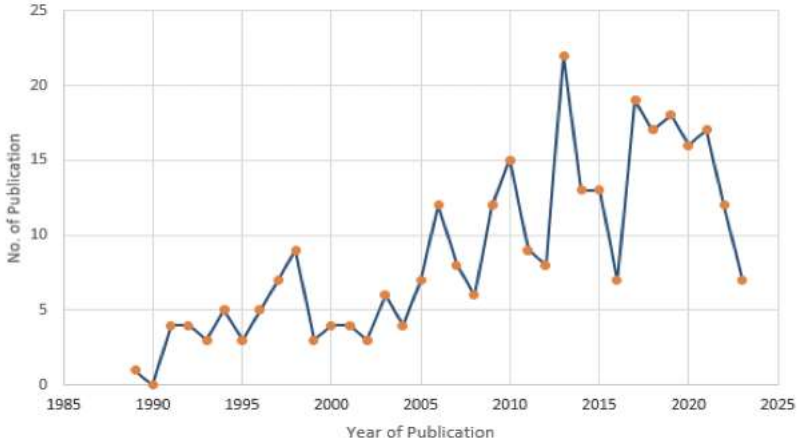


Figure 3: Publication per year

Web of Science database covers 292 articles and 11 conference papers on FLP from 1985 to 2023 and the total database contains 303 research papers on FLPs. Figure 3, shows the number of articles published concerning the scope of the study. The statistics indicate that studies on FLP have increased subject-wise drastically over a period and decreased to some extent because of low awareness of its application in material handling systems and current FLP design irrespective of the material handling system, it focused on individual ergonomics.

Figure 4: Subject areas (Web of Science Categories)

Figure 4 summarises the WOS database on the subject area vice and the highest number of articles published by Operations Research Management, industrial engineering and Manufacturing Engineering about 51, 34 and 31 per cent respectively. Further, subjects like Economics, Cybernetics and Hardware Architecture in Computer Science, Mathematics, Business and Environmental Studies have a small percentage of work on FLPs. According to Benitez et al., [5], 43% of work carried out on FLP is in the field of Engineering and medicine discipline. They supported their statement by quoting "Engineering field provides the mathematical background (mostly from operations research) to solve complex optimisation problems such as healthcare facility design, medicine provides the context for applications".

In this article, a survey has been made to sum up the current and future trends of research of different optimization techniques and layout environments. The paper focused on solution methodologies under various software packages by using metaheuristics such as genetic algorithm, simulated annealing, and tabu search used to solve by different organisations. Articles are Collected from various databases and are structured as follows, Sec 1 contains the overview of FLP, Sec 2 Solution methodology in FLP and Sec 3 Concludes the paper.

III. Overview of FLP

The article based on the survey on Facility layout problems was carried out by various scholars [4-14], and their works are analysed according to the approaches. It is observed that FLP is a complex NP-Hard problem and it can be adopted by manufacturing and service industries, used to place electronic components on printed circuit boards, arrange facilities in civil construction sites, VLSI circuit design and also Web page layout design [6]. categorised the FLP approaches into Equal Area and Unequal Area FLPs, Multi-floor and Row FLP and Equal area FLPs are represented by the discrete space and Unequal Area FLPs are represented by continuous space FLP. Further, discrete space and continuous space FLPs are categorised based on different parameters like distance measures, production environment, facilities shape, decision variable, objective and solution methodologies.

Common objective functions for designing FLP are quantitative, qualitative and multi-objective functions. The quantitative factor was for minimizing Material Handling Costs by enhancing the centre-to-centre distance of the layout and the qualitative factor was related to maximising the total closeness rating. The multi-objective function is a combination of both quantitative and qualitative criteria and its best optimal solution is obtained by the Pareto-optimal method [15]. Solution

Methodology is another important factor, where methods will vary depending on the production environment. If the production layout has discrete space with an equal or unequal area, then use a QAP mathematical model and minimise the layout area by REL chart and relationship diagram. For Continuous space FLPs use the MIP [16] and MILP [17], mathematical model or develop a graph theoretic solution. Methods for generating solutions are the same in discrete and continuous space problems.

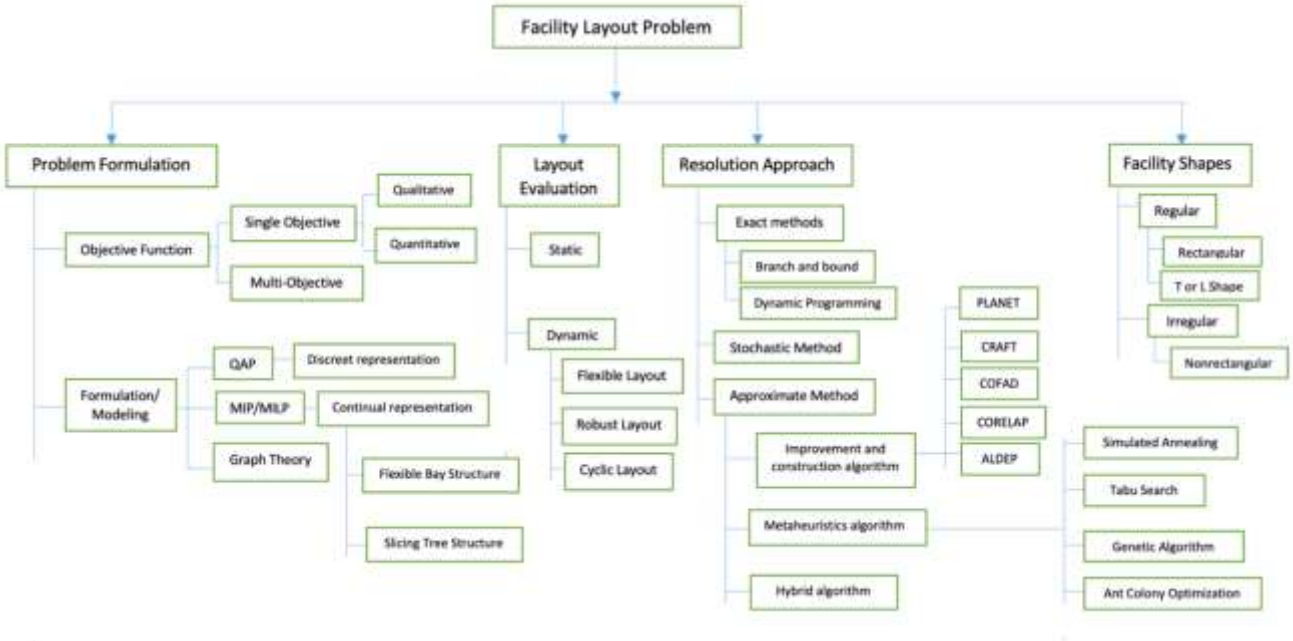


Figure 5: Various parameters used in solving FLP

Industries have mainly two kinds of production environments, static and dynamic. Statics Facility Layout Problem (SFLP) is the one, where flow of materials is constant between the facilities. In a dynamic environment, the material flow depends on demand in the market and it fluctuates throughout the period in the production horizon. This kind of facility layout problems in the literature named as Dynamic Facility Layout Problem (DFLP) [18] and Dynamic Plant Layout Problem (DPLP) [2]. The dynamic facility layout problems are solved using two popular approaches called Adaptive and Robust approaches. The Adaptive approach assumes the layout will be modified from period to period with considering the rearrangement cost. Whereas the Robust approach considers the aggregate flow of material among all periods of the planning horizon without relocating the facilities in various periods of the planning horizon.

IV. Solution Methodology

FPLs are computationally more complex (NP-Hard) problems [2]. Hence, Finding an optimal solution for FLPs with the exact method is very difficult. Hence, in recent years metaheuristic algorithms have gained popularity in solving FLPs.

Solution Methodology for Facility Layout Problems is classified into two kinds [10], Constructive Solution Methods and Improvement Solution Methods. In both methods, developing the model program is the same and it is classified into

- Mathematical approach
- Heuristic and Meta-Heuristic approach
- Systematic Layout Planning

4.1 Mathematical approach: solution methodologies for FLPs include mathematical programming techniques such as linear programming, mixed-integer linear programming, and nonlinear programming. These algorithms are particularly useful for large-scale FLPs where finding an optimal solution using traditional mathematical programming techniques may be computationally expensive.

Since 1960, this approach has been considered to solve the n! solution for different facilities in all manufacturing and other service industries. Particularly, in the design of hospital facility layout [19] modelling incorporates essential requirements such as the arrangement of departments in a predefined area, and motion in vertical and horizontal directions. The motion will reduce the distance between departments and develop high interaction for increased demand. This can be achieved by minimising travel frequency between the departments. QAP (Quadratic Assignment Problem), MIP (Mixed Integer Problem) and Graph Theoretic problems are major mathematical approaches for solving facility layout problems.

QAP was first introduced by Koopmans and Beckmann in 1957 [20], it is used for locating a set of economic activities and then formulated for equal and unequal area facility layout in discrete space problems. FLP in discrete space, can simplify the problem but it gives an unrealistic solution [15] and also QAP is considered NP-hard, which specifies computation carried only for a small number of facilities (less than 18 facilities).

Furthermore, the QAP model is difficult because of unequal area, irregular shape and continuous space facility layout problems. The MIP model used for continuous layout representation, facility dimensions and coordinates of facility location (horizontal width, vertical height, centre coordinates and distance between the centres) were considered as their decision variables [18]. The MIP model avoids the overlap of facilities and solves optimally, even with facilities placed anywhere within the site [7, 21].

The Graph Theory approach also represents the formulation of continuous space FLPs. Where facilities are denoted by node and distance between nodes are connected by arc, indicates the closeness relationship between facilities. Initially, GTA is concerned with generating the layout by fulfilling immediate adjacent vacant activity and generating a map of the interrelationship matrix [11]. The objective is to maximise the closeness rating and transform to a block layout dual graph. GT is similar to QAP, used for small size facility problems and also, cannot solve small size unequal area problems optimally [3].

4.2 Heuristic approach: The heuristic approach is based on a discrete model and this approach divides the discrete into small squares of fixed area. Heuristic is designed to find approximate solution when classical methods are hard to find exact solutions [11]. In the layout process, a layout planner must be able to understand the current state of layout to make additional decisions or to review previous decisions. For decision aids, a layout planner follows the classical decision-making approach by creating and evaluating block layouts and converted into detailed planned layouts. Classical layout programs CORELAP, ALDEP and PLANET are construction algorithms, used to solve QAP. The construction algorithm had the drawback of generating only one layout for the final optimal solution [13]. Improvement algorithm, CRAFT [22] developed the program by altering the original block layout and the Grid size of the block determines the precision of the facility. It represents, a smaller the grid size and more precise facility representation [23,14]. The program accuracy is estimated by scoring models such as the Adjacency Based scoring model, Distance Based scoring model and Distance Weighted Adjacency based scoring model [24].

4.3 Meta-heuristics approach: Meta-heuristics algorithms are used for finding the global optimisation, that is the solution is optimal not only for a specific range but across all ranges. Meta heuristics method was designed to find an Approximate solution and it was invented by Fred Glover in 1986 [25]. It is used to solve complex combinatorial optimization problem by directing heuristic algorithms, which are derived from the biological, evolutionary and physical science concepts and improve their performance when classic heuristics fail to get approximate solutions [11]. Various metaheuristics such as Simulated Annealing (SA), Genetic Algorithm (GA), Tabu Search (TA), Artificial Bee Colony (ABC) [26,27], Migration Bird Optimisation (MBO) [19], Swarm Optimisation Algorithm (SOA) [28], Ant colony optimisation [29].

4.31 Simulated Annealing: SA was introduced by Kirkpatrick et al., (1983) [30] and SA solution based on thermodynamic process and optimization of combinatory problem. SA is used for solving

Flexible Bay Structure (FBS) using an average material flow matrix [18] and some of the work on SA is tabulated below.

Sl no	Reference	Year	Formulation	Heuristic
1.	Madusudhan Pillai et al.,[2]	2011	QAP	Simulated Annealing
2.	Hunagund et al., [15]	2020	MILP	Simulated Annealing
3.	Hunagund et al., [18]	2018	MIP	Simulated Annealing
4.	Vahit Tongur et al., [19]	2019	MIP	Simulated Annealing
5.	Krikpatric et al., [30]	1983	QAP	Simulated Annealing
6.	Hamidreza Navid et al., [31]	2012	MOP	Simulated Annealing
7.	Chen et al., [32]	2001		Simulated Annealing
8.	G. Moselemipour [33]	2018	QAP	Simulated Annealing
9.	Baykasoglu and Gindy [34]	2001	MQAP	Simulated Annealing

Table 1: List of SA based FLP papers

4.32 Genetic algorithm: GA is based on the biological philosophy called fittest survival by Darwinian evolution and it was developed by John Holland in 1970 [35]. GA involves generating offspring by crossover the parent chromosomes and values are optimised using fitness function. GA follows phases such as initialization, evaluation, reproduction, crossover and mutation to generate offspring [36]. The Genetic Algorithm (GA) operates based on the Stochastic search method. Unlike other search methods, GA does not terminate when it reaches a local optimum; instead, it continues to track the population until it reaches the limit of computer clock time [35].Table 2, provides GA-related work on FLP.

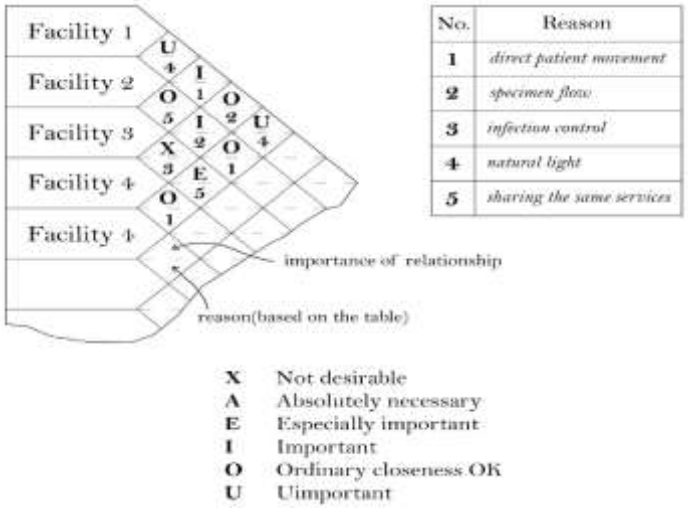
Sl no.	Reference	Year	Formulation	Heuristic
1.	Jiazhen Huo et al., [20]	2021		Genetic Algorithm
2.	Shiwang Hou et al., [22]	2019	MOP	Genetic Algorithm
3.	Michael and wang., [37]	2004	QAP and QSP	Genetic Algorithm
4.	Mazihani and abedzdesh et al., [38]	2013	MIP	Genetic Algorithm
5.	Wu and Appleton [39]	2002		Genetic Algorithm
6.	Gulsun et al., [40]	2022	QAP	Genetic Algorithm
7.	Yang et al., [41]	2011	Multi Objective Problem (MOP)	Genetic Algorithm
8.	Hernandez el al., [42]	2016		Genetic Algorithm
9.	El-Baz [43]	2004	QAP	Genetic Algorithm
10.	Rahim Ahmad et al., [44]	2006	QAP	Genetic Algorithm
11.	Attila islier [45]	1998	MIP	Genetic Algorithm
12.	Rajashekaran et al., [46]	1998	MIP	Genetic Algorithm
13.	Hauser and Chung [47]	2006	QAPLIB	Genetic Algorithm
14.	Srinivas et al., [48]	2014	QAP	Genetic Algorithm
15.	Mak et al., [49]	1998	QAP	Genetic Algorithm
16.	Amir Sadrzad et al., [50]	2012	QAP	Genetic Algorithm
17.	Abdum Rahim et al., [51]	2006		Genetic Algorithm

Table.2: List of GA based FLP papers

4.33 Tabu Search (TS): the algorithm first proposed by Glover in 1989 [52] for combinatorial optimisation problems. TS is a local search-based optimisation method and uses swap and insertion operations for evaluating global optimal solutions. It operates on short-term and long-term memory structures. Short term memory is used to select the best possible solution and generate a new solution called tabu [19, 53]. TS and mathematical programming combine to form Tabu Search Mixed Integer Problem (TSMIP), which is used to solve DFLP on continuous planes with unequal area layouts [54].

4.4 Systematic Layout Planning: SLP is the most popular approach used for layout design and it was developed by Muther in 1973 [55]. The SLP method provides a systematic procedure for planning and designing the layout of a facility or department [56]. The SLP method takes into consideration various factors such as the flow of materials, equipment and manpower, space requirements, communication flows, and safety regulations. It also aims to maximize efficiency, productivity, and convenience for the users of the facility. In traditional SLP, the process starts with analysing material and non-material flows within the facility to understand the relationships and interactions between different departments or workstations. SLP procedure is applied to production, transportation, and storage activities to identify potential improvements and optimize the layout [56].

Flow analysis is relates to quantitative basis and aims to understand the movement of materials, people, and information within a facility or department. Relationship is expressed as some function of material handling cost and distance travelled. Typically REL chart could serve as a useful tool in conducting flow analysis to visualize and analyse the relationships between different workstations or departments. Relationship evaluated by closeness rating which is assigned to each pair of workstations based on their functional and spatial relationship. Closeness rating represents order of preference where, A, E, I, O, U or X can be used to represent the relationships, with A indicating a high degree of interaction and X indicating no interaction or workstation placed as far as possible [4, 23].



No.	Reason
1	*direct patient movement*
2	*specimen flow*
3	*infection control*
4	*natural light*
5	*sharing the same services*

Figure 6: Relationship chart (Courtesy: N.Jamali et al., [11])

V. Conclusion:

A systematic review of the Facility Layout Problem has been conducted in two parts. The first part focuses on the bibliometric analysis by using Web of Science data. The second part of the review is carried out on various solution methods used in solving both static and dynamic facility layout problems. From the literature review, it is observed that the study of facility layout has increased and it has adapted to various service organisations, manufacturing industries, and healthcare facilities. The goal of the survey on Facility Layout Problems was to understand the current trends and methods being used in facility layout planning. Also to identify potential areas for further research in facility layout planning.

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