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Study of Facility Layout Planning Algorithms and Approaches

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Abstract

Facility Layout Planning problem (FLP) concerns with the design of plan or layout for different operations within the enterprise for enhanced productivity and improved efficiency of a production system. The aim of FLP problem is concerned with optimum layout design and arrangement/positioning of personnel, machines, tools and equipments within a factory environment. In a manufacturing firm, cost entailed for facilities layout corresponds to 20-50% of the total cost, which can be reduced to 20-30% with better FLP. In the last 5 decades, many researchers have proposed several mathematical, classical and heuristic approaches to solve FLP problem, due to its combinatorial NP-hard nature. A research direction on FLP design using several approaches has been described in this review article. The objective of review is to show the merits and demerits in many robust intelligent approaches to solve FLP.

Keywords: AHP, DEMATEL, Fuzzy DEMATEL, Facility Layout, Fuzzy AHP, Fuzzy TOPSIS, TOPSIS, Rough AHP

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1. Introduction

FLP is an optimization problem which seeks to optimize some objectives by placements of man, machine, tools, support stations, equipments, inventory stores etc.,[29,72] within the factory floor space, workstations or architectural layouts such as hospitals, offices, schools, buildings according to the relationship that exists between them (Tompkins et al., 2003; [50,91]. Layout Planning is an important area of research which branches to Industrial Engineering and Optimization (Singh and Sharma, 2006). Many researchers and industrial experts are working on FLP problem to manufacture higher quality, flexible and reliable products, so as to achieve superior results and to survive the pressure incurred due to globalization and increased market competition[1,79]. Due to the latest trend of customized & cost-effective products, and less product lifetime, future manufacturing system needs to be dynamic and flexible enough to mould them to adapt to these market changes (Tompkins, 2010). The ability to reconfigure an existing factory layout is an important constraint to withstand competition in production world. FLP is an inherently NP hard problem, its solution approach is of combinatorial nature which is difficult to solve, but curiosity to find the best optimum solution through various approaches such as heuristics, meta-heuristics, and exact approaches is the need of the hour and makes FLP an important research field. The efficiency of a layout if governed by its Material Handling Cost (MHC) and it is anticipated that 20-50 % of the total manufacturing costs are subjected to MHC and it is estimated that an effective layout plan can reduce this cost up to 30%[82,4].

FLP problem considers quantitative as well as qualitative factors[55] so as to boost performance and efficiency ratings in a manufacturing enterprise even though, determination of factors for a layout design is a challenging yet beneficial. From literature it could be concluded that many existing facility layout design gets entrapped into local optima solution because of using a substitute function for calculating the material and information flow distance or for considering basic objective functions; consequently this causes a poor layout design with lot of inefficiencies and scope of improvement. The present study explores the review of intelligent approaches and Soft Computing Techniques used for solving FLP problem. Figure 1 shows the various approaches to solve FLP problem and on which approach we are focusing in this literature review.

The following survey is intended on popularly used MCDM approaches in FLP analysis, such as AHP, TOPSIS, DEMATEL, Rough AHP, Fuzzy AHP, Fuzzy TOPSIS, and Fuzzy DEMATEL.

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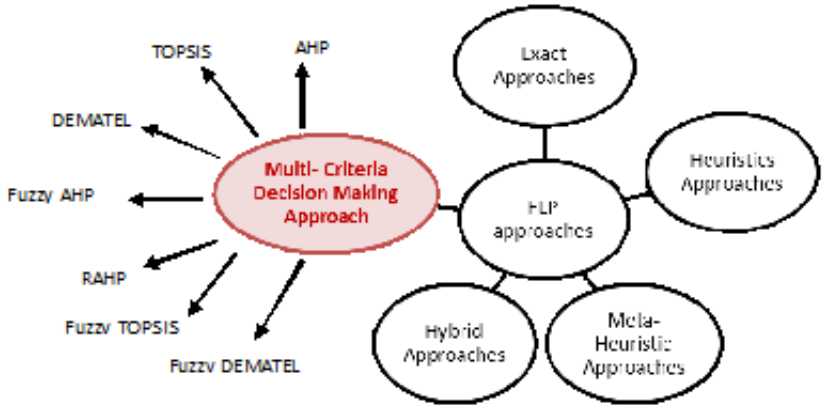

Figure 1. Focus of FLP approach in this Literature Review.

This article draws a recent survey about various approaches applied to solve FLP problems. Section 2, gives a brief introduction and background of a facility layout problem. Section 3 considers the tabular comparison of numerous works done by researchers on facility layout planning based on several MCDM approaches. Section 4, emphasizes on facility layout criterions which serve as constraint to achieve optimal facility layout, and importance of few criterions for FLP problem. Conclusion from the text and literature survey along with the future scope of research in FLP problem domain is given in Section 5. This review is based on numerous literature surveys, hence it cannot be considered exhaustive.

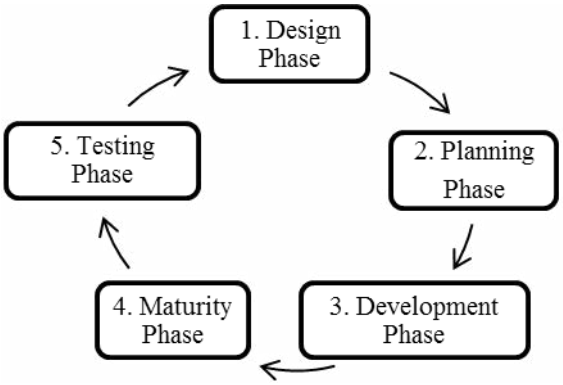

Figure 2. Facility Layout Life Cycle (source author).

2. Background

Since the past three decades, different aspects of facility layout design- its need, benefits and future scope has been intensely studied by many research scholars. But, it was found that the research was more qualitative as compared to quantitative nature. Plant Layout of any manufacturing organization incorporates optimized allocation of factory space and machines or equipments, so as to minimize the overall operating cost (Lim and Nobel, 2006; Ariafar et. al., 2011; [81]. Purpose of Facility Layout is to formulate a significant arrangement of facilities within the factory floor space to economically meet the desired results to generate huge profits[6]; Tasadduq et. al., 2011). The selection of an optimal layout that satisfies the present needs as well as meets the future demands is a complicated and iterative procedure. Therefore production managers and design engineers should be creative and capable enough to select the best alternative amongst the options so that the industrialists don't face any complications for selecting the optimal layout design. Figure 2 shows the life cycle of a FLP problem.

FLP problem (Krishnan et. al., 2006 and 2008)[51] is wide research area, much work has already been done on it through various mathematical approaches and still the scope of this topic is never ending from the research point of view and quest to achieve better optimized result. The earlier approaches seemed inaccurate and vague because they didn't take into account the flexibility factor, multiple objectives and customer oriented approach. For example, in case of exact approaches, most of the research scholars considered small size of the problem for its ease due to its computational intractability[26]. Many research scholars and work has been done to review FLP problem, few of this works were done by Drira et. al (2007) presented a survey of resolution approaches for solving FLP. Meller and Gau (1996)[63] presented a survey of various layout models and algorithms to solve layout problems. Singh and Sharma (2006) presented a survey of several formulations, software packages and solution methodologies/ approaches to FLP.

For mass production, arrangement of facilities and services remains constant due to the long product life whereas for mid-

variety and mid-volume production (Batch production), the arrangement of facilities and services do not remain constant due to short product life. Due to the latest trend of customized products, product varieties, rapid market changes, technology improvement and short product life, it is desirable to plan for re-layout and develop flexible layout which is adaptable to recent market changes[3]; Tompkins, 2010). It is believed that every two years, in developed nations, major dislocation of facilities and services occur (Yang, et. al., 2012)[92]. Poor facility design is categorized by meager quality parts or products, reduced labor productivity, dissatisfaction among customers, and reduced market reputation, thus efficient and optimal layout design is a must for manufacturing enterprises[46,74].

In case of FLP obtaining an excellent initial solution results in good final solution, one such research in this area was done by Sangchooli and Jokar (2013) with an objective to develop a good initial solution using Maximal Planar graph (MPG) approach. Although, the approach resulted in cost reduction and was efficient on large size problem, but the scope of this approach could be improved using metaheuristic approaches such as GRASP and Tabu Search (Sangchooli and Jokar, 2013). FLP problem is important to maintain sustainability in manufacturing enterprises because efficient utilization of resources or facilities will entitle for sustainable growth of the enterprise[42,52,58]. Moreover, sustainability is the need of the hour in order to safeguard resources against exploitation, in the name of productivity and competitiveness, by manufacturing and service organizations. Reducing factors such as unnecessary transportation or material handling cost, rework, and wastage will aid in achieving sustainability (Luthra et. al., 2016). Several internal and external disturbances lead to the redesign of facility layout. Reasons for internal disturbances within a manufacturing unit could be equipment breakdown, bottlenecks, rework time, and plant shutdown etc., and the reasons for external disturbances are rapid market changes, customized product demand, low-product life etc. Every layout problem has mainly four inputs viz a viz Cost of travelling between facilities- C_{ij}, Length of workstations- L_i, Width of Workstations- W_j and, To/ Flow matrix – F_{ij}.

3. Comparative Analysis of Approaches to Solve FLP Problem

Facility layout can be classified on the basis of various sub-factors such as: on the basis of area we have equal (where factory area is equally divided among cells or departments) and unequal area facility assignment problem[80]. The later can further be classified into soft module (pre-defined area but the dimensions are not fixed) and hard (it has rigid dimensions) unequal area module. On the basis of facility placement are, FLPs can be classified into open space module (where, there is no constraint on the enclosing area) and closed space module (where, there are constraints to obtain optimal layouts within a given enclosing area (Tak and Yadav, 2012). On the basis of rows, we have single row and multiple row FLP problems. In case of single row FLP, all the facilities are arranges in a straight line fashion whereas in multiple row FLP, the facilities are arranged in several rows so as to reduce the material handling distance within departments (Drira, et. al., 2007). Azadeh et. al., (2014)[10] have demonstrated in their paper that in practical situations it is difficult to deal with crisp values data, due to its inadequacy and uncertainty[40]. Data taken from human experts is often biased and uncertain, (Govindan et. al., 2015c) so it is difficult to rate them as exact numerical values. Therefore, techniques are often implemented using fuzzy logic given by Zadeh in 1965 resulting in hybrid or improved approached fuzzified approaches[98] such as Fuzzy AHP (Chang, 1996), Fuzzy TOPSIS (Chen, 2000), Fuzzy DEMATEL (Baykasog˘lu et. al., 2013 and Altuntas et. al., 2014)[5] etc. Onut and Soner (2008)[66] implemented AHP for the calculation of the weights of fuzzy TOPSIS as a method for the selection of locations for waste disposal. Dagdeviren et al. (2009) implemented a similar method for the selection of weapons; and Torfi et al. (2010)[83] to rank alternatives. In this review article, the literature of FLP is classified based on optimization methodology, specially focused on MCDM methods. In this review article, seven major MCDM based solution methods, namely AHP, TOPSIS, Rough AHP, Fuzzy AHP, Fuzzy TOPSIS, DEMATEL, and Fuzzy DEMATEL are reviewed.

A detailed author wise review of MCDM approaches to solve FLP problem is discussed in Table 1. This review comprises of the proposed methodologies and approaches followed by varied researchers and their research findings for FLP problem.

At present research scholars are focusing on to devise new techniques as well as to use available heuristics, meta-heuristics approach and integrated approaches to get superior solution. Approaches to solve FLP problems are:

3.1 Exact methods

In case of exact approaches, most of the research scholars considered small size of the problem for its ease, due to its computational intractability (Drira, et. al., 2007).

3.2 Heuristics

To overcome the exhaustive complexity of exact methods, heuristics approach was incorporated. For e.g. Steepest-decent method was implemented to solve FLP problem by pair-wise-interchange of departments (Drira, et. al., 2007). But the disadvantage of this approach is that it is not suitable for complex problems.

3.3 Meta-heuristics

(Kundu and Dan, 2012) - Examples of some Meta-heuristic approaches are: Simulated Annealing (SA)[86,89], Particle Swarm Optimization (PSO)[41], Ant Colony Optimization (ACO) (Grobeiny, 1987a), Genetic algorithms[30,78], Tabu Search (TS), and Fire Fly etc (Drira et.al., 2007). The advantage of such approach is that it is suitable for complex FLP problem with multi-objective functions, subject to constraints of multiple criteria.

3.4 Hybrid approaches

Hybrid approaches are the combinations of two or more approaches, which are integrated to solve complex problems for e.g. hybrid assembly lines[43].

3.5 Multiple Criteria Decision Making (MCDA)

Methods to solve FLP problem, some of its examples are AHP, TOPSIS, Analytical Network Process (ANP), Data Envelope Analysis (DEA) etc.

3.5.1 Analytical Hierarchical Process

AHP (Saaty 199069, 70; Ju et.al, 2012; Govindan, 2015c; Mangla et al., 2015)[60]

A Hierarchical decision making approach proposed by T.L. Satty, which provides problem formulating platform and organized approach for representing a problem[71]. It aids in decomposing, composing, organizing and analysing a complex problem and is suggested as a better tool in comparison to others due to its wide applicability and ease in use (Luthra et. al., 2016). In this Multiple Criteria approach problem is sub-divided into hierarchies such that 1st level comprises of objective function, 2nd level comprises of criterion within which objective function is to be validated, 3rd level comprises of sub-criterion. Finally all alternatives are joined with the sub-criteria, to be ranked on its basis. The advantage of AHP is to assign weights to criterions randomly. Moreover it is suitable for considering large no. of criteria and alternatives. AHP though is one of the simplest and easiest MCDA approach, but some quantitative factors don't satisfy its 9-point scale. The disadvantage of AHP is that it shows the bias nature of the experts[38] and hence is, sometimes inefficient for evaluating many alternatives at the same time i.e. it is not suitable for complex problems. AHP proves to be inefficient for certain problems while performing pair-wise comparison (that has the advantage of being simple), when there is uncertainty, vagueness or fuzziness in expert decisions (Govindan et. al., 2015c; Gandhi et. al., 2016). This happens due to incomplete information or differences in the perception of the problem among the experts. For this problem, the solution is the fuzzy assessment of the problem (Ju, et.al., 2012[48]; Mangla et. al., 2015; Luthra et. al., 2016).

3.5.2 Technique for Order Preference by Similarity to Ideal Solution

TOPSIS (Tompkins, 2010; Aydogan, 2011[9]; Behzadian, et. al., 2012; Baykasogˇlu, et. al., 2013; Falatoonitoosi et. al., 2013 and 2014)[34,35]

It is amongst the best MCDA approach which evaluates real-world or genuine problems[15,16]. Proposed by Yoon and Hwang (1985)[96], in accordance to this approach, alternative which is closest to Positive Ideal Solution (PIS) is considered best and alternative closest to Negative Ideal Solution (NIS) is considered worst (Benitez, et. al, 2007; Behzadian, et. al, 2012). TOPSIS calculation is done by evaluating the Euclidean distance to find PIS and NIS for selecting the best alternative. NIS maximizes cost and minimizes benefit while PIS minimizes cost and maximizes benefit (Mangla et. al., 2015). In case of TOPSIS[84], decision table comprises of specific values to evaluate the ranking whereas in case of Fuzzy TOPS[62] fuzzy and vague values are also taken into consideration to enhance the performance objective and efficiency of the result. Solution of Fuzzy AHP and Fuzzy TOPSIS (Mehdizadeh et. al., 2014) requires formulation of fuzzy membership function which is based on simple arithmetic operations, out of which only few are computationally manageable (Baykasogˇlu et. al., 2013; Zarook et. al., 2015).

3.5.3 Decision Making Trial and Evaluation Laboratory

DEMATEL (Baykasogˇlu, et. al., 2013; Altuntas et. al., 2014; Lin, and Tzeng, 2009)

Battelle Memorial Institute of Geneva developed this analytic technique to evaluate critical criterion for complex problems in 1973 (Lin, and Tzeng, 2009; Baykasoglu et. al., 2013)[14]. It is a digraph based technique which divides the judgmental criteria into cause-effect group. It demonstrates relationship among criterion, clarifies which criteria has what effect on the problem or other criteria, uncovers the main criteria to represent its effectiveness over other criteria and avoids "over fitting". DEMATEL method is used to develop mutual relationships of criteria and their interdependencies (Govindan et. al., 2015c). This method does not need voluminous information and can easily propose the most important criteria which affect other criteria. These benefits result in the use of DEMATEL to find out the cause and effect criteria (Lin et. al., 2008[56]; Lin and Tzeng, 2009). DEMATEL approach was successfully utilized in many areas like hotel service quality, supplier selection, e-learning evaluation, and cause analysis to solve complicated problems (Altuntas et.

al., 2015; Govindan et. al., 2015c). Fuzzy DEMATEL will give better results as it considers all aspects as per human perception, thus giving us a intelligible structural model of the system[23,57,19]; Baykasog˘lu, et. al., 2013; Altuntas et. al., 2014; Falatoonitoosi et.al., 2014; Govindan et. al., 2015). Figure 4 (a) and Figure 4(b) illustrates the pictorial representation of the timeline of a FLP problem.

Table 1. Author wise key findings for MCDM approaches used in FLP problem (Source Author)

Name of the Authors	Proposed Methodology & Approach	Findings
Buckley, 1985[18]	**Approach:** Fuzzy AHP **Methodology:** Employ fuzzy ratios instead of exact ratios	Fuzzy weights criteria is calculated and evaluated which then determines alternative weights
Evans, et. al., 1987[33]	**Approach:** Fuzzy Approach **Methodology:** Employed fuzzy approach to solve block layout problem.	Modeled linguistic closeness relationship among departments
Grobelny 1987a	**Approach:** Fuzzy set theory **Methodology:** Applied Fuzzy approach to solve FLP problem.	Closeness relationship values among departments
Cambron and Evans, 1991[20]	**Approach:** Fuzzy AHP, Fuzzy TOPSIS **Methodology:** AHP was used for evaluation of criteria	Modeled unstructured FLP problem
Raoot and Rakshit, 1991[67]	**Approach:** Heuristics & Fuzzy set theory **Methodology:** Proposed a construction-type layout design using qualitative design criteria	Solved the problem of uncertainty due to fuzziness
Abdou and Dutta, 1990	**Approach:** Expert System Methodology: Knowledge base was manipulated incorporating 6 factors to define appropriate layouts.	Optimized selection of materials handling equipment, obtained appropriate layouts
Harmonosky and Tothero, 1992[44]	**Approach:** Simulated Annealing and Tabu Search **Methodology:** To solve plant layout considering multiple factors	Found closeness relationship values between facilities.
Raoot and Rakshit, 1993[68]	**Approach:** Fuzzy set theory **Methodology:** Presented an algorithm for layout evaluation	Fuzzy linguistic variables were used to solve FLP problem
Badiru and Arif, 1996[12]	**Approach:** Fuzzy set theory, BLOCPLAN & expert system. **Methodology:** Proposed integrated approach considering knowledge-based rules.	Improved computational efficiency and fuzzy linguistic modeling capability
Dweri and Meier, 1996[28]	**Approach:** Fuzzy AHP **Methodology:** Vagueness in weights of decision criteria is countered using Fuzzy AHP approach.	Closeness rating is determined between facilities within a department based on qualitative & quantitative location factors.
Meller and Gau, 1996	**Approach:** Fuzzy Set Theory along with decision making algorithm **Methodology:** Solve block layout design problem.	Fuzzy closeness relationship determined order of entry of departments within layout.
Weck, et. al, 1997[90]	**Approach:** Extended Fuzzy AHP **Methodology:** Extended Fuzzy AHP concept determines criteria & evaluates alternatives.	Solved multiple attribute decision making FLP problems for a case study.
Foulds and Partovi, 1998[37]	**Approach:** AHP & Graph theory **Methodology:** AHP & Graph theory was evaluated among departments	Computer software BLOCPLAN generated alternatives and optimal layout was selected from proposed alternatives.
Dweiri, 1999[27]	**Approach:** AHP **Methodology:** AHP was implemented using qualitative and quantitative criteria.	Crisp activity relationship chart was developed to solve FLP problem
Karray, et. al, 2000[49]	**Approach:** Fuzzy set theory & GA **Methodology:** To investigate temporary facility layout.	Closeness relationship values among facilities

Yang, et. al, 2000[95]	**Approach:** AHP **Methodology:** To design a systematic layout for a semiconductor wafer fabrication facilities	Muther's systematic FLP was implemented to generate design alternatives, which were evaluated by AHP based on certain criteria.
Aiello and Enea, 2001[2]	**Approach:** Fuzzy set theory **Methodology**: Proposed technique solves FLP using fuzzy approach.	Optimal layout generated minimizes the MHC.
Monitto, et.al, 2002[65]	**Approach:** Fuzzy AHP **Methodology:** Précised, accurate and value driven FAHP approach is proposed subject to constraint of productivity & flexibility issues	Problem is evaluated using FAHP to administer vagueness,
Deb and Bhattacharyya, 2003[24]	**Approach:** Fuzzy set theory **Methodology:** This paper proposed a diverse methodology for FLP problem using fuzzy approach for handling uncertain, fuzzy or vague data.	Two-tier fuzzy inference system is proposed which evaluates proposed methodology in regard to conventional methodology.
Yang and Kuo, 2003	**Approach:** AHP & DEA **Methodology:** Techniques were applied to take into account qualitative as well as quantitative criteria	Each Decision Making Unit consumed different inputs to generate outputs accordingly.
Deb and Bhattacharyya, 2005[25]	**Approach:** Fuzzy decision support system **Methodology:** Fuzzy theory was employed to solve FLP in a case study	Presented fuzzy linguistic relations to criteria for manufacturing facilities layout planning.
Enea, et. al, 2005	**Approach:** Fuzzy set theory and GA **Methodology:** Uncertainty of production demand is modeled using fuzzy linguistic variables.	Evaluation of the efficiency of approaches is done in terms of deterministic situation.
Ertay, et. al, 2006[31]	**Approach:** DEA and AHP **Methodology:** Both AHP and DEA approach was used to generate outputs with potential benefits.	This approach is considerable especially when the size of the problem increases.
Chakraborty and Banik, 2007[21]	**Approach:** AHP **Methodology:** Pairwise comparison analysis was done to evaluate the multiple criteria.	Evaluated the criteria and optimal layout was selected.
Yang and Hung, 2007	**Approach:** TOPSIS and fuzzy TOPSIS **Methodology:** MCDA approach was implemented to select design alternatives.	Optimal layout design was obtained which was evaluated for multiple attributes
Azadeh, et. al, 2008[11]	**Approach:** AHP & DEA **Methodology:** Integrated approach was implemented to select most favorable alternatives under the constraints of multiple quantitative and qualitative factors	In the proposed layout, there was more reliability; lesser material handling time & better safety conditions at lesser cost was achieved.
Ertugrul and Karakaşoğlu, 2008[32]	**Approach:** Fuzzy AHP – Fuzzy TOPSIS **Methodology:** To use FAHP and FTOPSIS techniques to obtain optimal Facility layout.	Optimal layout was selected for the case study of the textile company in Turkey.
Kuo, et. al, 2008[53]	**Approach:** Intuitionistic fuzzy set theory **Methodology:** MCDA approach along with Intuitionistic fuzzy information	The FLP problem of the case study was solved and the optimal layout was generated and validated.
Lee, et. al, 2008[54]	**Approach:** Fuzzy AHP and BSC **Methodology:** Balance Score Card concept defines the hierarchy; for every alternative performance indicators are chosen.	This layout design is a good tool for evaluating MCDA problems.
Lin and Wu, 2008	**Approach:** Fuzzy DEMATEL **Methodology:** Fuzzy DEMATEL method was proposed to inspect the cause-effect relationship of FLP	This methodology helped experts to concentrate more on location criteria that were of more significance.

Bashiri and Hosseininezhad, 2009[13]	**Approach:** Fuzzy AHP **Methodology:** To solve multi-FLP by taking into consideration several location factors.	All alternatives are illustrated and sensitivity analysis is done to generate different optimal solutions based on expert's opinion.
Singh, 2009[77]	**Approach:** Approximate algorithm **Methodology:** FLP is devised as linear assignment problem and evaluated for polynomial time.	Performance evaluation done by comparing the performances between optimal and heuristic solution.
Fazlollahtabar, et. al, 2010[36]	**Approach:** Fuzzy AHP **Methodology**: Alternatives in the FLP problem are evaluated using FAHP.	The alternatives were analyzed & prioritized using FAHP and the best alternative was proposed.
Sangwan, 2010[73]	**Approach:** Fuzzy AHP **Methodology:** Proposed MCDA technique to solve FLP problem subject to criterion that influence layout problem in fuzzy environment.	A practical model was designed by taking into consideration several factors.
Torfi, et. al, 2010	**Approach:** Fuzzy AHP - Fuzzy TOPSIS **Methodology:** Objective is to evaluate alternatives in priority order.	Weights of criteria are calculated using Fuzzy AHP and alternatives are ranked using Fuzzy TOPSIS.
Guo-feng, and Li-wen, 2010	**Approach:** Rough set theory, AHP & TOPSIS **Methodology:** Criteria weights are calculated using Rough set–AHP approach and ranking is done using TOPSIS.	Sensitivity analysis of criteria weights is studied to find their influence on ranking results. Results obtained by MCDA approaches are compared.
Bozorgia and Abedzadeh, 2011[17]	**Approach:** Tabu search, Minmax DEA **Methodology:** To generate a set of feasible solutions and measure criteria for each solution.	Optimized and efficient unit was chosen
Ghaseminejad, et. al, 2011[39]	**Approach:** TOPSIS, DEA **Methodology:** Proposed approach use2-optalgorithm to obtain best layout.	TOPSIS and DEA approach result was tested by ranking the best answer of each DEA iteration.
Maniya and Bhatt, 2011[61]	**Approach:** Preference selection index method **Methodology:** An alternative MADM methodology is presented	FLP problems are inspected to demonstrate, authenticate, and to ensure the consistency of proposed methodology.
Shahin and Poormostafa, 2011[75]	**Approach:** Fuzzy AHP, QFD and TOPSIS **Methodology:** Proposed methodology considers both qualitative and quantitative objectives.	Most efficient optimal solution was ranked using TOPSIS successfully for a plastic profile production company.
Yang et. al, 2012	**Approach:** Rough AHP and TOPSIS **Methodology:** Proposed methodology considers layout criteria and energy relevant factors	Rough AHP is used to generate weights while priority order is decided by TOPSIS. Sensitivity analysis of the result is done to select the optimal layout.
Altuntas, et. al, 2013	**Approach:** Fuzzy approach **Methodology:** Three solution approaches named fuzzy, Gyenesei's and normalized weighted association rule mining approaches were proposed.	Case study is considered to exhibit the utility & worth of proposed approaches.
Ataei, 2013[7]	**Approach:** TOPSIS, Fuzzy TOPSIS **Methodology:** Explore the implementation of proposed approaches to evaluate FLP for a case study.	Proposed approaches are feasible to evaluate layout design problem
Aydin and Murat, 2013[8]	**Approach:** Particle Swarm Optimization **Methodology:** Presented swarm intelligence approach to evaluate Capacitated Reliable FLP (CR-FLP).	This approach generated optimal solution even with fewer samples, and improved computational efficiency.
Jiang and Nee, 2013[47]	**Approach:** AHP & GA **Methodology:** Augmented Research-based system tailored for FLP	Optimal reconstruction of the existing facility layout.

Singh and Yilma, 2013[76]	**Approach:** Systematic layout planning (SLP) **Methodology:** SLP technique has been employed to design the two alternative production shop floor layouts	Performance between new and existing layout was compared based on certain criteria. The existing production process was inefficient.
Vencheha and Mohamadghasem 2013[85]	**Approach:** Nonlinear programming model & AHP **Methodology:** Integrated approach was implemented to select the best alternative amongst the proposed layouts generated by SPIRAL.	Alternatives generated by SPIRAL are evaluated using AHP & NLP to solve FLP
Altuntas, et. al, 2014	**Approach:** Fuzzy DEMATEL **Methodology:** Proposed methodology considered six qualitative and quantitative location factors	Viability of proposed alternative was checked and tested for a case study problem in a manufacturing industry firm.
Mehdizadeh, et. al, 2014	**Approach:** TOPSIS **Methodology:** MCDA based approach to choose most favorable alternative.	The design alternatives are generated by design engineers which are then ranked in priority order
Yu, et. al, 2014[97]	**Approach:** Tabu search & Heuristics technique **Methodology:** Single row layout problem was considered to solve problems of realistic size.	Within the limited time constraint they found optimal facilities sequence, determined additional clearance for each facility

4. Facility Layout Criteria Description

Performance of a layout plan can be evaluated by taking into account certain criteria or factors (Buyukozkan, and Cifci, 2012; Altuntas, et. al., 2014). Criterion is a bigger term which can further be based on the conception of attributes and objectives (Malakooti and D'souza, 1987[59]; Karray, et. al., 2000). The former is a measurable parameter which replicates the extent to which an objective can be reached whereas later is the general account of the preferred state of the system concerned (Yang and Hung, 2007). A brief review of various criterion considered by several research scholars is illustrated in Table 2. From the table we can draw a conclusion that the following criteria are very fundamental for any FLP problem. The brief descriptions of these criterions are discussed below:

4.1 Quality Factor

Quality is a very more important factor in FLP (Buyukozkan, and Cifci, 2012). Quality no longer simply applies to the product itself but also applies to the service and other aspects. The quality factor is measured via inspection and testing unit in the production or manufacturing sector (Bozorgia and Abedzadeh, 2011; Buyukozkan, and Cifci, 2012)). Important sub-criteria for Quality are: Product durability (i.e. Lifespan), Product reliability (i.e. Consistency), Quality systems and percent rejection, Reputation and position in the market, and Periodicity of internal quality audits to verify effectiveness of quality system.

4.2 Man-Power Factor

Human issues, such as ease of supervision and control as well as safety and housekeeping must be considered in the evaluation of any manufacturing layout because of its direct impact on productivity. An effective employee is a combination of a good skill set and a productive work environment. Many factors affect employee performance that managers need to be aware of and should work to improve at all times. Its sub- criteria are: Safe and improved conditions at workplace, Manpower requirements, (training, education, etc.), Optimum Utilization of manpower, Wages and incentives, and Medical facilities and reimbursements. (Jiang and Nee, 2013; Altuntas, et. al., 2014))

4.3 Information Flow

An information flow diagram (IFD) is an illustration of information flow throughout an organization. An IFD shows the relationship between external and internal information flows between organizations. Lines indicate how the information travels from one system to another. Its sub criteria are: Mutual Confidence and trust among personnel, Knowledge transfer and value addition, User friendly (user interface design), Easily accessible (Ease of use), and Collection of data of product demand, amount or shape changes. (Dweri and Meier, 1996; Maniya and Bhatt, 2011; Altuntas, et. al., 2014)

4.4 Flexibility

Flexibility is defined as the ease by which departments/facilities can be arranged and rear- ranged, and measured flexibility in

terms of flow volume based upon the relative proximity among the departments/ facilities. Its sub- criteria are: Considerations for varied product mix, Reduction in price, order frequency etc., Considerations for alternate routings, Scope for future expansion, and Effective and optimum utilization of knowledge, resources, machinery and manpower. (Malakooti and D'souza, 1987; Maniya and Bhatt, 2011; Vencheha and Mohamadghasem, 2013)

4.5 Material Flow

Material flow (MF) is the description of the transportation of raw materials, assemblies, sub-assemblies, and tools etc. Material Flow system is a model of a process, industry sector or region of concern. Material Flow system consists of the system boundary, processes, flows, and stocks. Industrial material flow is a very complex and important criteria. Its sub criteria are: Design,

Table 2. Criterion considered by various authors to evaluate Facility Layout Problem (source author)

Author's Name	Decision criterions implemented	Mathematical Tool/ Technique
Malakooti and D'souza, 1987	Flexibility, Production rate, and MHC	Heuristics algorithm
Dweri and Meier, 1996	Material Flow, Information Flow and Equipment Flow	AHP, fuzzy decision-making system (FDMS)
Wang, et. al., 1998	Cost, time	Improved simulated annealing algorithm
Karray, et. al., 2000	Material Flow, Information Flow and Equipment flow	Fuzzy set theory and GA
Chan, et. al., 2003[22]	Part Flow, No. of Machines, Part-Handling Factor, Quantity, and Travelling Distance.	Heuristics algorithm
Yang and Kuo, 2003[94]	Distance, Adjacency, Shape ratio, Flexibility, Accessibility and Maintenance	AHP and Data Envelopment Analysis (DEA)
Yang and Hung, 2007[93]	Material Handling Cost, Adjacency Score, Space Ratio, Flexibility, Accessibility and Maintenance	TOPSIS and fuzzy TOPSIS
Bozorgia and Abedzadeh, 2011	Quality and Quantity Factors Such As Cost, Adjacency and Separation (Distance Request)	Tabu search, DEA technique
Maniya and Bhatt, 2011	Material flow, Information flow, Equipment flow, Maintenance, Flexibility and Adjacency.	Alternative MADM methodology i.e. Preference selection index PSI)
Yang, et. al., 2012	Energy Saving (ES), Space requirement (SR), Investment (Inv.), Transport Performance (TP), Distance Request (DR),	Rough set theory is integrated with AHP and TOPSIS
Buyukozkan, and Cifci, 2012	Quality, Cost, Time And Flexibility	DEMATEL, ANP, and TOPSIS in a fuzzy context.
Mohamadghasemi and Hadi-Vencheh, 2012[64]	Flexibility, Facilitation Of Handling , Accessibility, Speed Of Helping, Total Cost Of Handling Material and Construction Cost Of Width Walls	Fuzzy set theory and NLP
Jiang and Nee, 2013	Material Handling Cost, Personnel Flow, and Space between Facilities	AHP & GA based optimization scheme
Vencheha and Mohamadghasem, 2013	Distance, Adjacency Score, Accessibility, Shape ratio, Maintenance, and Flexibility.	NLP and AHP
Altuntas, et. al., 2014	Material Flow, Information Flow, Personnel Flow, Equipment Flow, Environmental Condition, and Supervision Of Personnel	Fuzzy DEMATEL
Azadeh, et. al., 2014	Queue Length, Machine Utilization and Time In System	Novel Computer Simulation–Stochastic DEA algorithm
Hawari, et. al.,'2014[45]	Closeness Gap Value, Expansion Flexibility, Routing Flexibility, Productive Area Utilization, Volume Flexibility, Human Issues	Analytic Network Process (ANP) method

drawing and specification of final product(s), Materials used in Defected and Rework assemblies, Quantity, quality and product-mix of product(s), Space requirements for the finished & unfinished assemblies and raw material (Inventory), and Raw materials, and other materials used for manufacturing. (Dweri and Meier, 1996; Karray, et. al., 2000; Maniya and Bhatt, 2011; Altuntas, et. al., 2014)

4.6 Movement Factor

Movement is an important factor in Indian manufacturing companies. Though movement factor is an unproductive and inevitable activity in production cycle, even then attempt must be made to minimize through a logical arrangement of all physical facilities and other supporting facilities within the floor area. This is dependent on material handling and placement of facilities in a production unit. Its sub criteria are: Routing and flow pattern, Space requirements for their moves, unwanted and uneconomical moves, Frequency of movement between facilities, Overall utilization of factory floor space (Yang, et. al., 2012).

5. Conclusion and Future Scope

In this research work, we have examined a thorough review of few MCDM approaches (such as AHP, TOPSIS, DEMATEL, ROUGH AHP, FAHP, FDEMATEL, FTOPSIS etc.) popularly applied in FLP problem. We have also discussed the various criterions implemented by research scholars to solve FLP problem. From the aforementioned study the following points can be concluded:

- From the literature it can be seen many research scholars have incorporated AHP approach to solve FLP problem but there is a gap or limitation in AHP approach to give vague and uncertain results due to the biasness in decision making by experts.
- Fuzzy approaches when integrated with MCDM approaches gives better, improved results for real world situations as well as it never neglects uncertainty or biased opinions of experts.
- Various criterions were incorporated by several research scholars but it can be concluded that Quality, Material Flow, Flexibility, Manpower, Movement and Information flow are key criterions to solve any FLP problem.
- From Table1, it can be pointed that DEMATEL, Fuzzy DEMATEL and Rough AHP approaches have not been explored much and in future work can be done using these approaches.
- From pictorial representation of FLP problem timeline, a clear picture of what all approaches have been exploited in this domain and what all approaches have future scope can be cited.
- In future the above MCDM approaches can be implemented to solve a real world facility layout problem and their performance can be analyzed, simulated and validated to explore their effectiveness in a practical problem.

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Annexure-I

Study of facility layout planning algorithms and approaches

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