Facility Planning in the Context of Industry 4.0 - A Review

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Abstract

The main objective of Facility planning techniques is to achieve supply chain excellence. Supply chain excellence would ensure excellence among all elements of the supply chain. This would include manufacturing companies, suppliers, etc. Thus, facility planning design has assumed special significance. Many researchers have proposed tools and techniques for solving Facilities layout problems. The present research critically reviews various facility planning tools proposed by many researchers. Also, the paper would give research directions, which would help researchers, academicians, and practitioners, interested in pursuing further research in this field. As of today facility planning study in the context of Industry 4.0, has not been done. In this context, the proposed method assumes special significance.

1. Introduction

Facility layout planning or shortly layout planning (LP) is the technique of arranging machines and other facilities of a manufacturing company or organization in order to help deliver quality product to the customer, on-time and in the most efficient way without sacrificing the employee comfort and safety (Deshpande 2016). Facility layout would help a company in achieving productivity and delivering quality product to the customer. Well-designed facility layout would help in achieving supply chain excellence. Many research works in the area of facility planning are proposed and many techniques for addressing the issues related to facility planning. Layout planning (LP) is considered very challenging, because of multiple dimensions. LP should address issues not only related to the current but also the future expectations. LP would also help a company achieve its long-term strategies. Thus, LP is attracting many researchers. LP will also help a manufacturing company in meeting production schedules in the short-term as well as long-term basis. A well laid LP would also help in re-lay outing in the future. Thus, the team engaged in the design of company's layout will have to consider many factors such as the type of product to be made, volume of production, the type of material to be transported, quantity of material to be transported etc. This clearly shows the importance of layout planning. Author strongly feels, a comprehensive review work, in the area of layout planning in the context of Industry 4.0, is very much required for not only practitioners but also academicians and researchers.

Many of the techniques for solving the facility layout problems can be broadly classified into - facility location and facility design problems. Facility location problems consist of supply-pushed or demand-pulled. For solving facility location problems, researchers have proposed many techniques such as single facility and multi-facility problems. Researchers have used both rectilinear and Euclidean distance measures while solving location problems. Facility design problems, on the other hand, can be further classified into structural design, layout design, and handling system design. Structural design includes the building requirements required for the manufacturing company. That is whether a single building or multiple buildings are required for the manufacturing facility. Floor space and cubic space utilization are also considered, while planning for buildings. This may include single floor or multi-floor design. Layout design problem includes the design of the different departments required for the manufacturing company. This will also include determining both the shape and area of the departments. The length and width of the department may be fixed or variable. Material handling system design include positioning equipment, unit load formation equipment, Storage equipment, identification, and control equipment. For guiding the design of material handling equipment, several principles are being followed in many research works reported in the literature, such as planning principle, standardization principle, work principle, ergonomic principle, Unit load principle, space utilization, system principle, automation principle, environmental principle, life cycle cost principle and Unit load principle.

Transportation equipment helps move material from the source to the destination. Conveyors, cranes, and industrial trucks come under this category. Positioning equipment is used for handling material in one location or work machine so that it becomes easy for handling, machining, and subsequent storage of raw materials. Unit load formation equipment would help in maintaining the integrity of the materials when handled as a single unit while transportation or storage. Storage equipment is used for storing the materials over a while. AS/RS will come under this category. Identification and control equipment is used for effective communication that is required for the proper flow of materials in the manufacturing line. These devices would also help in the proper flow of materials between the supplier and the manufacturing facility or between the manufacturing facility and the customer. This paper would not only do a critical review of existing facility planning techniques but also would provide future directions for helping both researchers and practitioners.

2. Literature review.

Literature review is performed by using technical articles published in reputed journals of the last ten years, indexed in SCOPUS and Science Citation Index Expanded (SCIE) of Web of science. While doing Literature review, the focus was on Tools used, Technologies used, Systems under consideration, Safety, Ergonomic analysis, and Quality factors. Proper layout design will ensure increased productivity in product manufacturing (Altuntas and Selim 2012, Navidi 2012; Ku 2011). If a layout is not designed properly, it would lead to improper utilization of available space, formation of bottle necks and injuries/or accidents due to accidents (Pérez-Gosende et al. 2016). Researchers have demonstrated that as the number of machines, departments, manufacturing cells increases, the complexity of the layout problem also increases.

2.1 Layout construction and improvement tools

Many layout planning decisions involves either construction of a new layout or improving an existing layout. Plant layout may be generated by mathematical modeling, guidance from experts and by using software. Layout planning involves two stages- overall design (Saraswat 2015; Asef-Vaziri 2018) and the detailed design. Every layout will have a planning horizon. Companies may generate an optimum layout for a specified time horizon by minimizing the material handling costs as well as minimizing re-layout requirements. During overall design different departments are allocated to the building. Whereas, during the detailed design, the internal arrangements of machines within each department will be considered. While generating a layout of manufacturing companies, number of departments is a vital input required. The layout planning engineer will have to decide whether the material flow remains the same between the departments throughout the planning period or not. This is a vital input for further layout planning. Layout planning not only mean the arrangement of facilities at the enterprise level but it does include arrangement of individual departments and the arrangement of machines or workspace within each and every department. The shape of the department in a company may be rectangular may have any other shape. Both size of the department and the area of the department are very much required in the layout planning. The size of a department not only depends upon the volume of production, but also depends upon the type of machines and the number of machines. The material handling is another factor that would add up to the complexity of the layout planning. The type of material handling to be used depends upon the nature of material being moved, quantity of material to be moved and the size of the unit load. The different departments in a manufacturing company may be arranged in (i) Single row (Figure 1) (ii) parallel row (iii) loop configuration (Figure 2).

The objective in transporting materials is to reduce ensure availability of right type of materials at the right time. Also, to reduce the material handling cost. Material handling should also focus on the safety of operators and the condition of the raw material or material should be moved carefully, without causing any damage to the material. Sometimes, while transporting the material, care should be taken not to disturb the orientation of the material. This is true in some pharma and automobile companies.

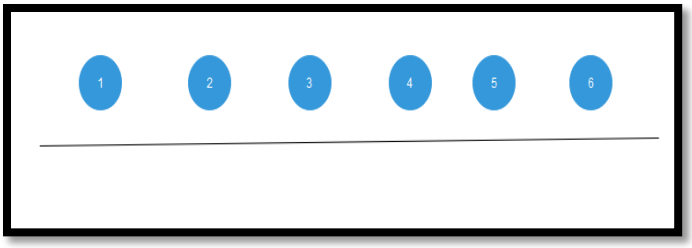

Fig. 1 Single row of departments

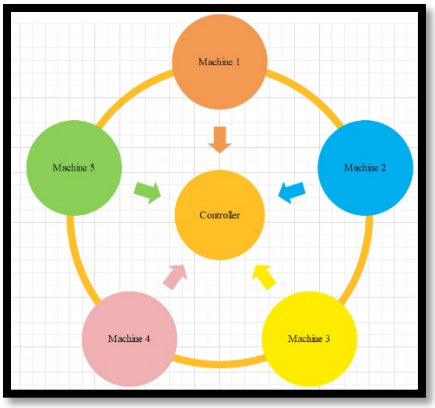

Fig. 2 Loop configuration

Literature has reported the use of multiple tools- CRAFT (Armour et al. 1963), ALDEP (Seehof et al. 1966), CORELAP, etc. It is reported in literature that design of a layout should include the consideration of the factors such as information integration, safety, ergonomics, quality and economics. The traditional layout planning technique is Quadratic assignment problem (QAP) (Bazaraa, 1975). This technique assumes that all the departments in a facility have equal areas and their locations are also fixed as well as priorities. QAP is being used not only in manufacturing but also in urban planning as well. The techniques such as CORELAP (Computerized Relationship Layout Planning) and ALDEP (Automated Layout Design Program) do not require any initial layout as they are layout construction techniques. On the other hand, CRAFT (Computerized Relative Allocation of Facilities Technique) and COFAD (Computerized Facilities Design) techniques do require initial layout as they are layout improvement techniques. Researchers have also started Hybrid techniques such as using Genetic algorithm and Quadratic assignment problem for optimizing the material handling cost in layout planning. Minimizing material handling cost is the most commonly used objective function while evaluating layouts by many researchers (Singh and Ingole 2019). Single objective function sometimes may not yield feasible solutions qualitative factors such as safety and flexibility will also have to be considered. It is not reasonable to expect a single optimum solution to fulfill all the objectives. Many researchers have tried to solve such multi objective optimization techniques (Aiello et al. 2013, Ripon et al. 2013;).

While planning for facilities, certain researchers have assumed that the material flow among departments is constant during the timeframe (Alsyouf 2012, Aiello 2012, Aiello 2013, Xiao 2017, Datta Dilip 2011, Bernardi 2013, Meller 1996, Eben-Chaime 2011). This may not be true in many industries because of variation in product demand is bound to be there over a period of time (Moslemipour 2017, Peng et al. 2018). Peng et al. 2018 used simulation for modeling variation in product demand. Jithavech et al. (2010) developed demand uncertainty models using uniform continuous probability distribution. Zhao et al. (2014) have developed demand uncertainty models using beta distribution. Moslemipouret al. (2017) proposed demand uncertainty models using normal distribution. Vitayasak et al. (2017) proposed demand uncertainty models using exponential distribution. Making changes to the existing layout for

improvement is even more difficult than planning for a fresh or new layout. This is because, the improvements to the existing layout would require consideration of additional constraints and additional objective functions. Another bigger problem is that improving an existing layout would require stopping of the entire production till the improved layout becomes functional. Layout improvements might require additional investments with regard to buying new equipment or machinery and tools. Many research works reported about facility planning so far have focused only on one building and one floor. In reality, however, a manufacturing company may exist in multiple buildings and multiple floors. Thus, much research is expected from researchers in this direction.

Very few researchers have been working on objective assessments of re-lay outing requirements. There is a huge scope for determining procedures required for the objective assessment of re-layout requirements.
Many of the researchers have been proposed techniques which involve 2D and no researcher has ever proposed a technique on 3D technique. Though, space utilization in three dimensions should be considered.

2.2 Layout evaluation techniques

Layout evaluation is a technique used by organizations for determining the suitability of the layout with regard to meeting organizational objectives. A manufacturing company may have multiple objectives. One of the objectives might be to reduce the handling cost. The objectives may be conflicting in nature. In this scenario, it may not be possible to arrive at a single layout which meets all the objectives of the organization. To overcome this scenario, researchers have proposed multi objective optimization (MOO) technique. MOO would help companies in arriving at an optimum layout for meeting multiple objectives. This will not ensure a best layout but the most suitable layout for meeting the set of objectives. Researchers have also proposed another technique based on linear programming. The technique will determine the ranking of the alternate layouts, based on efficiency, as for as meeting of the organizational objectives are concerned. Table 1 shows the different layout evaluation techniques. MOO will only help in assessing relative performance of alternate layouts. However, it cannot be used for assessing the performance of existing layout. They will not help determine the re-layout requirements for the facility or manufacturing company.

Many layout evaluating methods use single objective function such as minimizing material handling cost. However, combining both qualitative and quantitative methods may be very useful for meeting specific industry requirement. For example, qualitative features may include flexibility in meeting future requirements, operator safety and ergonomics.

Table 1. Layout evaluation techniques.

Method	**Basis of evaluation**	**Authors**
Multi criteria method/ or multi objective optimization method	Ranking of alternate layouts will be done based on the suitability of a layout for meeting set criteria	Alsyouf, I.,O. Al-Araidah,M. Tates, and R. Ciganovic. 2012 Aiello, Giuseppe, Giada La Scalia, and Mario Enea. 2012. Aiello, Giuseppe, Giada La Scalia, and Mario Enea. 2013.
Data envelopment analysis	Efficiency of alternate layouts in meeting the organizational objectives are determined by using the technique of linear programming	Xiao, Yiyong, Yue Xie, Sadan Kulturel-Konak, and Abdullah Konak. 2017. Datta, Dilip, André R.S. Amaral, and José Rui Figueira. 2011. Bernardi, S., and M. F. Anjos. 2013. Meller, R. D., and K. Y. Gau. 1996 Eben-Chaime, Moshe, Avital Bechar, and Ana Baron. 2011.
Simulation method	Layout performance assessment indicators are measured for the alternate layouts through simulation and the best layout will be considered	Lee, Hsin-Yun. 2012 Datta, Dilip, André R.S. Amaral, and José Rui Figueira. 2011.
Non-linear programming method	This technique makes use of non-linear programing optimization models for assessing the alternate layouts.	Hadi-Vencheh, A., and A. Mohamadghasemi. 2013.
Fuzzy constraint method	In this technique the objective functions and the constraints with uncertainty are determined and the alternate layout evaluations are done.	Hernández Gress, E. S., J. Mora-Vargas, L. E. Herrera del Canto, and E. Díaz-Santillán. 2011. Jung, Seungho, Dedy Ng, Jin-Han Lee, Richart Vazquez-

		Roman, and M. Sam Mannan. 2010. “

Simulation technique (Table 1) would help in analyzing different scenarios, which would be difficult to solve by using analytical methods. Many complicated problems can be solved by using this technique. Though simulation is very efficient in terms of achieving quick results, the method fails to consider factors such as worker comfort and safety, which are also equally important, in enhancing productivity (Li 2018).

Many companies have adopted Group technology layouts for achieving the flexibility with regard to both volume and variety. Group technology layouts are also known as Cellular layouts.

2.3 Future directions.

Many research works reported about facility planning so far have focused only on one building and one floor. In reality, however, a manufacturing company may exist in multiple buildings and multiple floors. Thus, much research is expected from researchers in this direction.

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