Facility layout problems: A survey

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Abstract

Layout problems are found in several types of manufacturing systems. Typically, layout problems are related to the location of facilities (e.g., machines, departments) in a plant. They are known to greatly impact the system performance. Most of these problems are NP hard. Numerous research works related to facility layout have been published. A few literature reviews exist, but they are not recent or are restricted to certain specific aspects of these problems. The literature analysis given here is recent and not restricted to specific considerations about layout design.

We suggest a general framework to analyze the literature and present existing works using such criteria as: the manufacturing system features, static/dynamic considerations, continual/discrete representation, problem formulation, and resolution approach. Several research directions are pointed out and discussed in our conclusion.

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1. Introduction

The placement of the facilities in the plant area, often referred to as “facility layout problem”, is known to have a significant impact upon manufacturing costs, work in process, lead times and productivity. A good placement of facilities contributes to the overall efficiency of operations and can reduce until 50\% the total operating expenses (Tompkins et al., 1996). Simulation studies are often used to measure the benefits and performance of given layouts (Aleisa & Lin, 2005). Unfortunately, layout problems are known to be complex and are generally NP-Hard (Garey & Johnson, 1979). As a consequence, a tremendous amount of research has been carried out in this area during the last decades. A few surveys have been published to review the different trends and research directions in this area. However, these surveys are either not recent (Hassan, 1994; Kusiak & Heragu, 1987; Levary & Kalchik, 1985), or focus on a very specific aspect of layout design, such as loop layouts (Asef-Vaziri & Laporte, 2005), dynamic problems (Balakrishnan & Cheng, 1998) and design through evolutionary approaches (Pierreval, Caux, Paris, & Viguier, 2003). Benjaafar, Heragu, and Irani (2002) conducted a prospective analysis and suggested research directions. Our conclusion will show that several of their research propositions remain valid but other issues can also be raised.

In this article, we present a recent survey about layout problems based on numerous literature references. First, in Section 2, we consider several possible definitions of layout problems. Then, we propose a general framework that can be used to analyze the current literature. Section 3 distinguishes the major features of the workshops that can be found. In Section 4, emphasis is put on so called dynamic problems. Section 5 discusses how facility layout problems can be formulated. In Section 6, we are interested in the approaches that are used to solve these problems. Although this review cannot be exhaustive, it has been conducted from a large number of literature references.

2. Definition of layout problems

A facility layout is an arrangement of everything needed for production of goods or delivery of services. A facility is an entity that facilitates the performance of any job. It may be a
3. Workshop characteristics impacting the layout

Several types of workshop are addressed in the literature. In fact, the layout problems addressed are strongly dependent on the specific features of manufacturing systems studied. Several factors and design issues clearly differentiate the nature of the problems to be addressed, in particular: the production variety and volume, the material handling system chosen, the different possible flows allowed for parts, the number of floors on which the machines can be assigned, the facility shapes and the pick-up and drop-off locations. Due to their importance, these factors are detailed below.

3.1. Products variety and volume

The layout design generally depends on the products variety and the production volumes. Four types of organization are referred to in existing articles, namely fixed product layout, process layout, product layout and cellular layout (Dilworth, 1996). These key organizations are sometimes discussed differently according to the authors.

In Fixed product layout, the products generally circulate within the production facilities (machines, workers, etc.); in this particular type of layout, the product does not move, it is the different resources that are moved to perform the operations on the product. This type of layout is commonly found in industries that manufacture large size products, such as ships or aircrafts. Process layout groups facilities with similar functions together (resources of the same type). This organization is often reported to be suited when there is a wide variety of product. Product layout is used for systems with high production volumes and a low variety of products. Facilities are organized according to the sequence of the successive manufacturing operations. In Cellular layout, machines are grouped into cells, to process families of similar parts. These cells also need to be placed on the factory floor. Therefore, one is also generally concerned with so called intra cells machine layout problems, as mentioned for example in (Proth, 1992, ch. 3) and (Hamann & Vernadat, 1992). Here, one is concerned with finding the best arrangement of machines in each cell.

3.2. Facility shapes and dimensions

Two different facility shapes are often distinguished (Fig. 2): regular, i.e., generally rectangular (Kim & Kim, 2000) and irregular, i.e., generally polygons containing at least a 270° angle (Lee & Kim, 2000). As mentioned by Chwif, Pereira Barretto, and Moscato (1998) a facility can have given dimensions, defined by a fixed length (L) and a fixed width (W). In this case, the facilities are called fixed or rigid blocks. According to the same authors, a facility can also be defined by its area, its aspect ratio: a1 = L/W, an upper bound a1 and a lower bound a2 such that a1 ≤ a ≤ a2. The aspect ratio was also used by Meller et al. (1999). If a1 = a = a2, this corresponds to the fixed shape blocks case (Chwif et al., 1998).

3.3. Material handling systems

A material handling system ensures the delivery of material to the appropriate locations. Material handling equipment can be conveyors (belt, roller, wheel), automated guided vehicles (AGV), robots, etc. (El-Baz, 2004). Tompkins et al. (1996) estimated that 20–50% of the manufacturing costs are due to the handling of parts and then a good arrangement of handling devices might to reduce them for 10–30%.

When dealing with a material handling system, the problem consists in arranging facilities along the material handling path. Two dependent design problems are considered: finding the facility layout and selecting the handling equipment. The type of material-handling device determines the pattern to be used.
Fig. 1. Tree representation of the layout problems.
for the layout of machine (Deviye & Pierreval, 2000; Heragu & Kusiak, 1988). Co, Wu, & Reisman (1989) also pointed out that the facility layout impacts the selection of the handling device. Given the difficulty of solving both problems jointly, they are mainly solved sequentially (Hassan, 1994). Among the major types of layout arrangement based on the type of material handling, one can distinguish, as depicted in Fig. 3: single row layout, multi-rows layout, loop layout and open-field layout (Yang, Peters, & Tu, 2005).

The single row layout problem occurs when facilities have to be placed along a line (Djellab & Gourgand, 2001; Ficko, Brezocnick, & Balic, 2004; Kim, Kim, & Bobbie, 1996; Kumar, Hadjinicola, & Lin, 1995). Several shapes may be considered from this basic situation, such as straight line, semi-circular or U-shape (Hassan, 1994). The loop layout problem deals with the assignment of m facilities to candidate locations 1, ..., m, in a closed ring network, around which parts are transported in one direction (Chaieb, 2002; Cheng & Gen, 1998; Cheng, Gen, & Tosawa, 1996; Nearchou, 2006; Potts & Whitehead, 2001). The loop layout incorporates a Load/Unload (L/U) station, i.e., location from which a part enters and leaves the loop. This station is unique and it is assumed to be located between position m and 1. The multi-rows layout involves several rows of facilities (Hassan, 1994). The movements of parts occur between facilities from the same row and from different rows (Chen, Wang, & Chen, 2001; Ficko et al., 2004; Kim et al., 1996). The open field layout corresponds to situations where facilities can be placed without the restrictions or constraints that would be induced by such arrangements as single row or loop layout (Yang et al., 2005).

3.4. Multi-floor layout

Nowadays, when it comes to construct a factory in urban area, land supply is generally insufficient and expensive. The limitation of available horizontal space creates a need to use a vertical dimension of the workshop. Then, it can be relevant to locate the facilities on several floors, as depicted in Fig. 4. This figure shows that parts can move horizontally on a given floor (horizontal flow direction), but also from one floor to another floors located at a different level (vertical flow direction). The vertical movement of parts requires a vertical transportation device: elevator. In such situations, both the position on the floor and the levels have to be determined for each facility, so that the related problems are referred to as multi-floor layout problems (Kochhar & Heragu, 1998).

Johnson (1982) seems to be among the firsts to address a multiple-floor layout problem. He dealt with the problem of defining relative locations of facilities in a multiple-floor building. Later, other researchers focused on taking into consideration vertical movements of parts from one floor to another (Bozer, Meller, & Erlebacher, 1994; Meller & Bozer, 1996, 1997). Elevators are often the material handling system reported (Lee, Roh, & Jeong, 2005). Their number and location are either known (Lee et al., 2005) or to be determined through optimization (Matsuzaki, Takashi, & Yoshimoto, 1999). In (Matsuzaki et al., 1999), the capacity of each elevator was considered as a constraint. The number of floors can be known (Lee et al., 2005) or to be determined, depending on each floor area and on the number and dimensions of the facilities (Patsiatzis & Papageorgiou, 2002).

3.5. Backtracking and bypassing

Backtracking and bypassing (see Fig. 5) are two particular movements that can occur in flow-line layouts, which impact the flow of the products. Backtracking is the movement of a part, from one facility to another preceding it in the sequence of facilities in the flow-line arrangement (Braglia, 1996; Kouvelis...
& Chiang, 1992; Zhou, 1998). The number of these movements has to be minimized. Zhou (1998) called this problem Production Line Formation Problem (PLFP), which consists in determining the orders (partial or total) of machines so as to minimize the weighted sum of arrows whose direction is contrary to the global flow of products, while taking into account constraints on the rank of machines.

Bypassing occurs when a part skips some facilities during its moving towards the flow line arrangement (Chen et al., 2001). Hassan (1994) noticed that several procedures were presented for dealing with and minimizing backtracking but no procedure was suggested in the literature for addressing bypassing.

### 3.6. Pick-up and drop-off locations

It is often necessary to determine the location from which parts enter and leave facilities, called Pick-up and Drop-off (P/D) points. Although they can potentially be located at various places (Kim & Kim, 2000), several researchers restricted their possible position to reduce the complexity (Das, 1993; Rajasekharan, Peters, & Yang, 1998; Welgama & Gibson, 1993). An example is given in Fig. 6.

### 4. Static vs. dynamic layout problems

We have seen that the workshop characteristics introduce differences in the way to design the layout. In addition, it is well known that nowadays, manufacturing plants must be able to respond quickly to changes in demand, production volume and product mix. Page (1991) reported that, on average, 40% of a company’s sales come from new products. However, the change in product mix yields to modify the production flow and thus affects the layout. Gupta and Seifoddini (1990) stated that 1/3 of USA companies undergo major reorganization of the production facilities every 2 years. A good number of authors have tried to take such an important issue into account when designing the layout. Most articles dealing with layout problems are implicitly considered as static; in other words they assume that the key data about the workshop and what it is intended to produce will remain constant enough over a long period of time. Recently the idea of dynamic layout problems has been introduced by several researchers. Dynamic layout problems take into account possible changes in the material handling flow over multiple periods (Balakrishnan, Cheng, Conway, et al., 2003; Baykasoglu, Dereli, & Sabuncu, 2006). Rearrangement costs have to be considered when facilities need to be moved from one location to another (Baykasoglu & Gindy, 2001).

### 5. Formulation of layout problems

The workshop characteristics and the static or dynamic issues being raised, there are several ways of formulating mathematically the layout problems so that they can be solved. This formulation of static and dynamic layout problems can be based on several types of models, which allow the complex relationships between the different elements involved in a layout problem to be expressed. Such models can rely on different principles, which include graph theory (Kim & Kim, 1995; Leung, 1992; Proth, 1992) or neural network (Tsuchiya, Bharitkar, & Takefuji, 1996). These models are generally used to suggest solutions to the layout problems, which most researchers consider as optimization problems, with either single or multiple objectives. Depending on the manner in which the problem is formulated, that is, discrete or continuous, the formulations found in the literature can lead to Quadratic Assignment Problems (QAP) or Mixed Integer Programmin (MIP), which are the most commonly encountered. In each case, a few authors have argued that the available data could not be perfectly known and have suggested fuzzy formulation. These approaches are discussed in the following.

#### 5.1. Discrete formulation

The layout is sometimes considered as discrete (Fig. 8a). In such a case, the associated optimization problem is sometimes addressed as QAP. The plant site is divided into rectangular blocks with the same area and shape, and each block is assigned...
to a facility (Fruggiero, Lambiasi, & Negri, 2006). If facilities have unequal areas, they can occupy different blocks (Wang, Hu, & Ku, 2005).

A typical formulation, when determining the relative locations of facilities so as to minimize the total material handling cost, is as follows (Balakrishnan, Cheng, & Wong, 2003):

\[
\min \sum_{i=1}^{N} \sum_{j=1}^{N} \sum_{k=1}^{N} f_{ik} d_{ij} x_{ij} x_{kl}
\]

subject to

\[
\sum_{j=1}^{N} x_{ij} = 1, \quad j = 1, \ldots, N
\]

\[
\sum_{i=1}^{N} x_{ij} = 1, \quad i = 1, \ldots, N
\]

where \(N\) is the number of facilities in the layout, \(f_{ik}\) the flow cost from facility \(i\) to \(k\), \(d_{ij}\) the distance from location \(j\) to \(l\) and \(x_{ij}\) the 0, 1 variable for locating facility \(i\) at location \(j\). The objective function (1) represents the sum of the flow costs over every pair of facilities. Eq. (2) ensures that each location contains only one facility and Eq. (3) guarantees that each facility is placed only in one location.

Discrete formulations are suggested, for example, by Kouvelis and Chiang (1992) and Braglia (1996) to minimize part backtrack in single row layouts. The same type of approach is also used by Afentakis (1989), to design a loop layout, so as to backtrack in single row layouts. The same type of approach is also used by Afentakis (1989), to design a loop layout, so as to backtrack in single row layouts. The same type of approach is also used by Afentakis (1989), to design a loop layout, so as to backtrack in single row layouts.

5.2. Continual formulation

In many articles, the layout representation is continual (Fig. 8b). It is often addressed as Mixed Integer Programming Problems (Das, 1993). All the facilities are placed anywhere within the planar site and must not overlap each other (Das, 1993; Dunker et al., 2005; Meller et al., 1999).

The facilities in the plant site are located either by their centroid coordinates \((x_i, y_i)\), half length \(l_i\) and half width \(w_i\) or by the coordinates of bottom-left corner, length \(L_i\) and width \(W_i\) of the facility. The distance between two facilities can be, for example, expressed through the rectilinear norm (Chwif et al., 1998):

\[
d_{ij}(x_i, y_i, (x_j, y_j)) = |x_i - x_j| + |y_i - y_j|
\]

The pick-up and drop-off points can generate constraints in the layout problem formulation (Kim & Kim, 2000; Welgama & Gibson, 1993; Yang et al., 2005). In this case, the distance traveled by a part from the drop-off of facility \(i\) to the pick-up of facility \(j\), can for example, be given by Eq. (5) (Kim & Kim, 2000).

\[
d_{ij} = |x_i^O - x_j^l| + |y_i^O - y_j^l|
\]

where \((x_i^O, y_i^O)\) designate the coordinates of the drop-off point of facility \(i\), and \((x_j^l, y_j^l)\) the coordinates of the pick-up point of facility \(j\).

The determination of the best locations of the P/D stations is a specific problem, addressed for example by Chitrataanawat and Noble (1999), Kim and Kim (1999), and Aiello, Enea, and Galante (2002).

Obviously, area constraints on the plant site exist, which require the total area available to be superior or equal to the sum of all the facility areas. The area allocated to each machine on the floor plan must also take into account the space of other resources or buffers, which are needed to operate the machine (Lacksonen, 1997). The clearance between facilities can be included or not in the facility surface (Braglia, 1996; Heragu & Kusiak, 1988, 1991).

Another very important constraint is that facilities must not overlap. Welgama and Gibson (1993) set two conditions for the non-overlapping of facilities: condition of X-projection non-overlapping and condition of Y-projection non-overlapping:

\[
(x_{ij} - x_{ib})(x_{ib} - x_a) \geq 0
\]

\[
(y_{ij} - y_{ib})(y_{ib} - y_a) \geq 0
\]

where \((x_{ib}, y_{ib})\) are the top-left and the bottom right corners of the facility \(i\) and \((x_{ib}, y_{ib})\) and \((x_{ib}, y_{ib})\) are the top-left and the bottom right corners of the facility \(j\). Mir and Imam (2001) defined an overlap area \(A_{ij}\) between two facilities to formulate this constraint. The layout optimization problem is expressed as follows:

Minimize objective function

Subject to \(A_{ij} \leq 0\)
where

\[
\begin{align*}
A_{ij} &= \lambda_{ij}(\Delta x_{ij})(\Delta y_{ij}); \\
\Delta x_{ij} &= \lambda_{ij}\left(\frac{L_i + L_j}{2}\right) - |x_i - x_j|; \\
\Delta y_{ij} &= \lambda_{ij}\left(\frac{W_i + W_j}{2}\right) - |y_i - y_j|; \\
\lambda_{ij} &= \begin{cases} 
-1 & \text{for } \Delta x_{ij} \leq 0 \text{ and } \Delta y_{ij} \leq 0 \\
+1 & \text{otherwise}
\end{cases}
\end{align*}
\]

\[(L_i, W_i)\] are the length and width of facility \(i\), and \((x_i, y_i)\) are coordinates of facility \(i\).

Other constraints can also be considered in the layout formulation, such as a pre-defined orientation of certain facilities (Dunker et al., 2005). Given such constraints, a typical formulation of the optimization problem can be as follows:

Minimize \(C = \sum_{i=1}^{N} \sum_{j=1}^{N} f_{ij}(|x_i^d - x_j^o| + |y_j^d - y_i^o|)\) \hspace{1cm} (9)

where \(N\) is the number of facilities, \(f_{ij}\) the amount/cost of material flow from drop-off point of facility \(i\) to pick-up point of facility \(j\), \((x_j^o, y_j^o)\) the coordinates of drop-off point of facility \(i\) and \((x_i^d, y_i^d)\) are the coordinates of pick-up point of facility \(j\).

Very few works seem to deal with dynamic layout problems with a continuous representation. Dunker et al. (2005) addressed unequal size layout problems in a dynamic environment and assumed that the facility sizes vary from one period to another.

5.3. Fuzzy formulation

In many concrete cases, data affecting layout problems are not exactly known. Stochastic approaches, such as the use of queuing networks (Meng et al., 2004) are seldom seen. Fuzzy logic has been proposed to handle the imprecision or uncertainty that is often encountered (Evans, Wilhelms, & Karwowsky, 1987; Grobelsky, 1987a; Raoot & Rakshit, 1991). A few approaches based on fuzzy concepts exist to design layouts.

Evans et al. (1987) addressed the placement of unequal size facilities on the plant area. They expressed relations between every pair of facilities by fuzzy relations describing closeness and importance. These relations allow the analyst to specify the importance associated with each pair of facilities to be located at any distance from each other. The authors proposed a fuzzy formulation of the problem through linguistic variables and propose a heuristic. Grobelsky (1987a, 1987b) tackled the problem of locating \(n\) facilities to \(n\) fixed locations so as to minimize the total material handling cost. The data impacting the layout, such as closeness links and traffic intensity, are fuzzy and modeled with linguistic variables and fuzzy implications. A heuristic procedure, based on binary fuzzy relations, is developed for the selection and the placement of facilities in the available locations. Several principles of this approach are also used by Raoot and Rakshit (1991), who considered the problem of finding the best arrangement on the plant site of facilities based on specifications about their inter-relationship, which are characterized through linguistic variables. Gen, Ida, and Cheng (1995) addressed a multi-objective multi-rows layout problem with unequal area. They are interested in situations where the clearance cannot be precisely defined, and is therefore considered as fuzzy. In Dweiri and Meier (1996), who dealt with a discrete facility layout problem, the amount of parts circulating between facilities, the amount of communications between facilities (information flow) and the number of material handling equipments used to transfer parts between facilities are considered as fuzzy factors. The authors developed an Activity Relationship Chart (ARC) based on the judgment of experts that is used to specify relationships between each pair of facilities. ARC is then integrated in the well known heuristic ‘CORELAP’ to find the best placement of facilities. Aiello and Enea (2001) argued that the product market demands are uncertain data that can be defined as fuzzy numbers. They minimize the total material handling cost, along a single row configuration, under the constraints that the capacity of production for each department is limited. To solve a single row layout problem, they split the fuzzy demands in \(\alpha\)-cuts and determine the \(\alpha\)-level fuzzy cost for each possible layout. Deb and Bhattacharyya (2005) addressed the placement of facilities with pick-up and drop-off points in a continual plane, so as to minimize the total material handling cost. The position of facilities depends on such factors as: the personal flow, the supervision relationships, the environmental relationships and the information relationships, which are rate using linguistic variables (e.g., high, medium, low). The authors developed a fuzzy decision support system based on a set of fuzzy IF–THEN rules. A construction heuristic is then used do determine the placement of facilities in the plant site.

5.4. Multi-objective layout problems

In most articles about layout problems, the main objective is to minimize a function related to the travel of parts (the total material handling cost, the travel time, the travel distance, etc.). To be more realistic, some researchers have considered more than a single objective. For example, Dweiri and Meier (1996) aimed at minimizing simultaneously the material handling flow and the equipment flow and the information flow. Most authors combine the different objectives into a single one either by means of Analytic Hierarchy Process (AHP) methodology (Harmonsky & Tothero, 1992; Yang & Kuo, 2003) or using a linear combination of the different objectives (Chen & Sha, 2005).

Few researchers used a Pareto approach to generate a set of non-dominated solutions. Aiello, Enea, and Galante (2006) dealt with a layout problem related to the minimization of the material handling cost and the maximization of an adjacency function (assessment of the proximity requests between two departments). The set of non-dominated solutions is then found and a “best” solution is then selected from this set using the well known ‘Electre method’.
5.5. Simultaneous solving of different problems

It is common that other problems have to be solved together with the layout design. For example, this occurs when designing cellular manufacturing systems, where one has both to assign machines to cells (cell formation problems) and to determine the position of each machine in the cell (intra cell layout). The position of each cell in the floor plant has also to be determined. Instead of formulating and solving these problems sequentially, it is sometimes possible to address these two issues as a same problem (Gupta, Gupta, Kumar, & Sundaram, 1996).

6. Resolution approaches

Several approaches exist to address the different types of problems that are formulated in the literature. They aim either at finding good solutions, which satisfies certain constraints given by the decision maker or at searching for an global or local optimum solutions given one or several performance objectives. This has yield heuristic based methods or optimization algorithms, as explained in the following of this section.

Some attempts of using artificial intelligent approaches have been made to address layout problems. Expert systems were, for example, proposed in (Heragu & Kusiak, 1990). Hamann and Vernadat (1992) also used this approach for intra-cell problems. More recently, an expert system based on artificial neural networks was implemented for facility layout construction in a manufacturing system (Chung, 1999).

Several types of optimization approaches have been proposed in the literature. In the following, we distinguish: exact methods, such as branch and bound, and approximated approaches, such as heuristics and metaheuristics.

6.1. Exact approaches

Among articles that dealt with exact methods, Kouvelis and Kim (1992) developed a branch and bound algorithm for the unidirectional loop layout problem. Meller et al. (1999) also used this approach to solve the problem of placing \( n \) rectangular facilities within a given rectangular available area. They proposed general classes of valid inequalities, based on an acyclic sub-graph structure, to increase the range of solvable problems and use them in a branch-and-bound algorithm. Kim and Kim (1999) addressed the problem of finding P/D locations on fixed size facilities for a given layout. The objective of the problem is to minimize the total distance of material flows between the P/D points. Authors suggested a branch and bound algorithm to find an optimal location of the P/D points of each facility. Rosenblatt (1986) used a dynamic programming method to solve a dynamic layout problem with equal size facilities. However, only small problem instances have been solved optimally (six facilities and five time periods).

6.2. Approximated approaches

Since exact approaches are often found not to be suited for large size problems, numerous researchers have developed heuristics and metaheuristics.

Construction approaches build progressively the sequence of the facilities until the complete layout is obtained whereas improvement methods start from one initial solution and they try to improve the solution with producing new solution. Construction heuristics include: CORELAP (Lee & Moore, 1967), ALDEP (Seehof & Evans, 1967) and COFAD (Tompkins & Reed, 1976), SHAPE (Hassan, Hogg, & Smith, 1986). Example of improvement heuristics are: CRAFT (Armour & Buffa, 1963), FRAT (Khalil, 1973) and DISCON (Drezner, 1987).

Among the approaches based on metaheuristics, one can distinguish global search methods (Tabu search and simulated annealing) and evolutionary approaches (genetic and ant colony algorithms).

Chiang and Kouvelis (1996) developed a tabu search algorithm to solve a facility layout problem. They used a neighborhood based on the exchange of two locations of facilities and included a long term memory structure, a dynamic tabu list size, an intensification criteria and diversification strategies.

Chwif et al. (1998) used a simulated annealing algorithm to solve the layout problem with aspect ratio facilities sizes. Two neighborhood procedures are proposed: a pairwise exchange between facilities and random moves on the planar site in the four main directions (upwards, downwards, leftwards and rightward). McKendall et al. (2006) suggested two simulated annealing approaches for a dynamic layout problem with equal size facilities. The first simulated annealing approach used a neighborhood based on a descent pairwise exchange method, which consists in randomly changing the location of two facilities while the solution is improved. The second approach combines the first simulated annealing algorithm and improvement strategy called “look-ahead and look-back strategy”.


A very important problem when developing a genetic algorithm is related to the coding of a candidate floor plan. A popular representation of the continual layout is the slicing tree (Shayan & Chitlappilly, 2004). A slicing tree is composed of internal nodes partitioning the floor plan and of external nodes representing the facilities. Each internal node can be labeled either h (horizontal) or v (vertical), indicating whether it is a horizontal or vertical slice whereas external nodes label the facility index (1, 2, 3, ... \( n \) for \( n \) facilities). Each rectangular partition corresponds to a space allocated to a facility. Fig. 9 shows a particular layout and the corresponding slicing tree.
When authors addressed discrete layout problems, the coding scheme differs from continual representation. For discrete representation, a popular solution for coding layouts is based on Space Filling Curves (SFC) (Wang et al., 2005). The plant area being divided into grids, a space filling curve defines a continuous sequence through all neighbor squares in the underlying layout (Fig. 10). Space-filling curves ensure that a facility is never split (Bock & Hoberg, 2007). Nevertheless, this technique requires many rules to verify the connection of all positions of a layout as for example using expert rules (Wang et al., 2005).

When a space filling strategy is defined, solutions have to be coded. Islier (1998) decomposed strings into three segments, encoding the sequence of facilities, the area required for each facility and the width of each sweeping band. Recently, Wang et al. (2005) encoded the chromosome's genes through five segments strings. The first segment shows the department placement sequence. The second gives the required areas of each department. The third segment indicates the site size (length and width). The fourth segment shows the sweeping direction (1: horizontal, 2: vertical) and the fifth segment indicates the sweeping bands. An example is illustrated in Fig. 10.

The objective function used in evolutionary methods is generally expressed as a mathematical cost function, which is derived from the problem formulation under consideration. To take into account in a more realistic way the system performance, simulation models have been connected to evolutionary methods to evaluate the candidate solutions (Azadivar & Wang, 2000). Hamamoto, Yih, and Salvendy (1999) addressed a real problem of pharmaceutical industry. The chromosome evaluation is performed through the simulation of a 4 months production.


The hybridization of different metaheuristics has also been considered for solving facility layout problems. Mahdi, Amit, and Portman (1998) proposed a hybrid approach for minimizing the material handling cost. They used a simulated annealing algorithm to solve the geometrical aspect of the problem, a genetic algorithm to make decisions about the material handling system and an exact method (Hitchcock’s method) to minimize the total material handling utilization cost. Mir and Imam (2001) presented a hybrid approach for a layout problem with unequal area facilities. Starting from an initial solution given by a simulated annealing algorithm, the optimal positions of facilities are determined by an analytical search technique in a multi-stage optimization process. Lee and Lee (2002) presented a hybrid genetic algorithm for a fixed shape and unequal area facility layout problem. Tabu search and simulated annealing are first used to find global solutions and the genetic algorithm is introduced in the middle of the local search process to search for a global solution. Balakrishnan, Cheng, Conway, et al. (2003) developed a hybrid genetic algorithm to solve the dynamic layout problem previously tackled by Rosenblatt (1986). The initial population is generated with two methods: a random method and an Urban’s procedure (Urban, 1993). The crossover is based on a dynamic programming approach and the mutation is achieved by the CRAFT heuristic (Armour & Buffa, 1963). McKendall and Shang (2006) developed and compare three hybrid ant colony algorithms for a dynamic facility layout problem. They combine an ant colony with three local search procedures: (1) a random descent pairwise exchange procedure, (2) a simulated annealing algorithm and (3) a look-ahead/look-back procedure.

7. Conclusion and research directions

In this article, we have presented a recent comprehensive survey related to facility layout problems. Although this survey cannot be exhaustive, the analysis carried out is based on a large
number of literature references. From this analysis, it appears that articles related to layout design continue to be regularly published in major research journals and that facility layout remains an open research issue. Several current trends and directions seem worth being mentioned.

First of all, recent papers include more and more complex and/or realistic characteristics of the studied manufacturing systems. Typical examples are P/D points, aisles, complex geometrical constraints, several floors, which are taken into account together when formulating the layout design problem. This is indeed an important issue because many articles contain restrictive assumptions that are not adapted to the complexity of many manufacturing system facilities. This is an old trend (Benjaafar et al., 2002). However, research is still needed. The use of a third dimension when designing a plant is a recent consideration that certainly requires more research, for example to select and optimize resources related to the vertical transportation of parts between different floors.

The often unrealistic aspect of static approaches, which consider that the data available are relevant to characterize the future operating conditions of the system, seems to be now well identified by researchers. Dynamic approaches may sometimes be a potential alternative; meanwhile, they often rely on knowledge of the future operating conditions. Fuzzy methods can offer interesting possibilities to include uncertainty. However, as already noted by Benjaafar et al. (2002), research is still needed to suggest or improve methods for designing (1) robust and adaptive layouts, (2) sensitivity measures and analysis of layouts and (3) stochastic models used to evaluate solutions.

In terms of methods used to solve layout problems, one can obviously see that the use of metaheuristics is more and more reported in articles, in order to cope with problems of a larger size and to take into account more realistic constraints. Evolutionary algorithms seem to be among the most popular approaches. Solving methods are also hybridized, either to solve complex problems (e.g., metaheuristics embedding heuristics or connected with exact methods) or to provide more realistic solutions (e.g., connection of evolutionary principles with simulation). Approaches based on artificial intelligence are now seldom published. Given the fact that it is probably difficult to solve everything without using some kind of expert knowledge about the system, there is probably still a need for hybrid methods capable of optimizing the layout while taking into account expert available knowledge.

We have noticed that most published works focus on determining the position of facilities. However, in practice this problem is often consider together with other design problems, such as the choice of the type of manufacturing or transportation resources, the design of cells, the determination of resources capacities, etc. These problems are often not independent (for example, the choice of a conveyor as a material handling device does not induce the same constraints as the choice of automated guided vehicles). Therefore, there is still research needed for solving the different problems involved in the design of the workshop simultaneously instead of sequentially. Such combinations, that start to be addressed, turn out to be promising and would worth being developed and improved. This would lead to favor more global research about workshop design, instead of concentrating on facility layout problems.

The articles studied in this article focus on manufacturing system applications. However, layout design problems also concern other types of systems, such as ports, supermarkets, airports, etc. These constitute interesting areas that could benefit from the advances made in the specific area of manufacturing.

As a final remark, let us note that commercial software tools available on the market to globally assist in the design of manufacturing are currently limited. Therefore, there is probably a need for trying to make the resolution approaches more generic, so that they can be embed as layout procedures in software tools supporting the design of manufacturing systems. The combination with graphical tools would also render such tools more efficient and attractive and a few authors have started to consider possible interfaces with virtual reality systems.

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