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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.

Keywords: Manufacturing facility; Facility layout; Material handling; Dynamic layout; Optimization methods

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

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machine tool, a work centre, a manufacturing cell, a machine shop, a department, a warehouse, etc. (Heragu, 1997).

Due to the variety of considerations found in the articles, researchers do not agree about a common and exact definition of *layout problems*. The most encountered formulations are related to *static layout problems* (in opposition to the *dynamic layout problems* that will be specifically discussed in Section 3). Koopmans and Beckmann (1957) were among the first to consider this class of problems, and they defined the facility layout problem as a common industrial problem in which the objective is to configure facilities, so as to minimize the cost of transporting materials between them. Meller, Narayanan, and Vance (1999) considered that the facility layout problem consists in finding a non-overlapping planar orthogonal arrangement of n rectangular facilities within a given rectangular plan site so as to minimize the distance based measure. Azadivar and Wang (2000) defined that the facility layout problem as the determination of the relative locations for, and allocation of, the available space among a given number of facilities. Lee and Lee (2002) reported that the facility layout problem consists in arranging n unequal-area facilities of different sizes within a given total space, which can be bounded to the length or width of site area in a way to minimize the total material handling cost and slack area cost. Shayan and Chittilappilly (2004) defined the facility layout problem as an optimization problem that tries to make layouts more efficient by taking into account various interactions between facilities and material handling systems while designing layouts.

Numerous articles have been published in this area. In order to highlight what seems to constitute essential features to characterize layout problems, we propose in Fig. 1, a first possible rough tree representation of the different factors taken into account in the literature. In fact, the problems addressed in research works differ, depending on such factors as: the workshop characteristics (e.g. a_{il}, specificities of the manufacturing systems, the facility shapes, the material handling system, and the layout evolution), what is the problem addressed (e.g., problem formulation, objectives and constraints) and the approaches used to solve it (Resolution approaches). Although this tree representation can probably be improved in future research works, we have found it helpful in characterizing existing research works. Consequently, the rest of this article is organized in accordance with this representation and with the most important features identified.

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_i) and a fixed width (W_i). 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:* $a_i = L_i/W_i$, an upper bound a_{iu} and a lower bound a_{il} such that $a_{il} \leq a_i \leq a_{iu}$. The aspect ratio was also used by Meller et al. (1999). If $a_i = a_{il} = a_{iu}$, 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