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The Unequal-Area Facility Layout Problem: A Review

Sebastián Cáceres-Gelvez[1], Martín Darío Arango-Serna[1],
Julián Andrés Zapata-Cortés[2]

[1] Universidad Nacional de Colombia,
Colombia

[2] Institución Universitaria CEIPA,
Colombia

{scaceresg, mdarango}@unal.edu.co,
julian.zapata@ceipa.edu.co

Abstract. The facility layout problem is one of the important and complex problems in operations management literature. When area requirements of departments are different, the problem is known as the unequal-area facility layout problem (UAFLP) and consists of locating a number of departments within a facility plan, in order to minimize the total material handling cost, which is the most addressed criteria for the facility layout problems. In this paper, a review for the UAFLP is presented as well as the explanation of how this kind of problem can be solved.

Keywords: Facility layout, unequal-area, material handling, solution techniques.

1 Introduction

The facility layout optimization is considered as an important and complex decision in operations management. The facility layout problem (FLP) consists of determining the location of the facilities (i.e. machines, workstations, departments, etc.) of a manufacturing or service company within a floor plan in order to optimize qualitative and/or quantitative criteria (Armour & Buffa, 1963; Drira et al., 2007; Meller & Gau, 1996). When facilities have unequal area requirements, that is, the dimensions of their widths and lengths are different, the problem is known as the unequal-area facility layout problem (UAFLP), and it is one of the most important problems in FLP literature (Armour & Buffa, 1963; Kulturel-Konak et al., 2004; Meller & Gau, 1996; Wong & Komarudin, 2010). The UAFLP was first presented by Armour & Buffa (1963) and considers a continuous arrangement of the facilities within a rectangular region subject to a) department and floor area requirements, b) department non-overlapping constraints, and c) department maximum aspect ratio constraints (Komarudin & Wong, 2010; Kulturel-Konak et al., 2004).

The solution of the UAFLP is a block layout which specifies the location and dimension of the departments (Jankovits et al., 2011; Kulturel-Konak & Konak, 2011a). The UAFLP is frequently addressed in the research literature, since its characteristics are similar to real-life layout problems (Balamurugan et al., 2006). In general, the facility layout optimization is known to have an impact on manufacturing costs, work-in-process inventory, lead times and productivity (Drira et al., 2007; García-Hernández et al., 2015). In order to achieve this impact, the UAFLP is usually optimized by minimizing the total material handling costs (MHC) of a layout alternative, which is considered as a major operational cost for an organization (Tompkins, 2010). However, other qualitative criteria, such as the closeness relationship between departments, has also been applied for optimizing the UAFLP (Aiello et al., 2013; García-Hernández et al., 2014; Ripon et al., 2011).

Due to the existence of non-linear area constraints, the UAFLP is recognized as a complex NP-hard class problem. For this reason, a wide variety of exact non-linear and relaxed linear programming models have been proposed for addressing the UAFLP (Armour & Buffa, 1963; Castillo et al., 2005; Meller et al., 2007; Meller & Gau, 1996; Sherali et al., 2003). In the same sense, a large amount of heuristic, metaheuristic, and even matheuristic algorithms have been presented for obtaining good solutions in short computational times for the problem (García-Hernández et al., 2019; Komarudin & Wong, 2010; Kulturel-Konak & Konak, 2011a; Paes et al., 2017; Palomo-Romero et al., 2017; Ulutas & Kulturel-Konak, 2012).

2 Background

As mentioned before, the FLP has been a widely addressed problem in operations management literature. A large amount of documents have been published regarding the different variants of the problem, as well as reviews about the proposed construction algorithms, metaheuristic approaches and mathematical formulations for the problem (see for example Kusiak & Heragu (1987), Drira et al. (2007), Singh & Sharma (2006), Meller & Gau (1996), Kundu & Dan (2012), Anjos & Vieira (2017), Hosseini-Nasab et al. (2018) and Kikolski & Ko (2018)).

In relation to the UAFLP, Drira et al. (2007) reviewed some metaheuristic approaches for solving the problem, while Kundu & Dan (2012) and Anjos & Vieira (2017) analyzed and described the different mathematical formulations that have been presented. Ever since its presentation by Armour & Buffa (1963), publications have been focused on solving the UAFLP via exact and heuristic procedures. Exact non-linear formulations for the problem were initially addressed, but due to computational intractability, linearization methods have been a very important issue for the problem. Montreuil (1991), Meller et al. (1998), Sherali et al. (2003) and Castillo & Westerlund (2005) have made contributions to improve the approximation methods for linearizing the non-linear area constraints.

Other very frequently approach has been the implementation of heuristic, metaheuristic and matheuristic procedures. In these approaches, the problem is represented by one of the following most common structures: flexible bay structure (FBS), slicing tree structure (STS) and shape-based block layout structure (SBL). FBS is known to be the easiest and most simple structure to implement, where departments are grouped and located within parallel bays with varying widths in the floor space

(Kulturel-Konak & Konak, 2011b). STS is a more complex structure that divides the facility horizontally and vertically in order to locate the departments (García-Hernández et al., 2020). Finally, SBL also considers bays with varying widths to locate fixed-shaped facilities (Lee & Lee, 2002).

3 The Unequal-Area Facility Layout Problem

The unequal-area facility layout problem (UAFLP) is an important and widely applied problem in both academia and industry (Chae & Regan, 2016; Kulturel-Konak et al., 2004; Meller & Gau, 1996; Wong & Komarudin, 2010). The continuous representation of the departments on the floor plan, as well as the consideration of unequal area requirements for the departments, brings this problem be more realistic for facility planners. In addition, the objective is to minimize MHC, which seeks to decrease the wastes related to transportation and unnecessary material movements inside the facility.

The UAFLP consists of locating a set of n departments within a facility plan, while considering area (a_i) and aspect ratio (β_i) requirements for each department i. Also, for each department i, the coordinates of its centroids (x_i, y_i) and the dimensions of its width (l_i^x) and height (l_i^y) are determined. The distance between a pair of departments (d_{ij}) is computed according to the rectilinear distance norm, for this application, and the flow of materials (f_{ij}) is also considered for determining the MHC, as shown in equation (1). An exact mixed integer non-linear programming formulation for the UAFLP is presented below, adapted from (Kang & Chae, 2017).

Notation and Parameters

n	number of departments
i, j	indexes for the departmetns, $i < j$
L^x, L^y	dimensions of the width and height of the facility, respectively
a_i	area requirements for department i
β_i	maximum aspect ratio requirement for department $i, \beta\_i \geq 1$
f_{ij}	volume of material flow between departments i and j

Decision Variables

d_{ij}	rectilinear distance between departments i and j
l_i^x, l_i^y	dimensions of the width and height of department i, respectively
c_i^x, c_i^y	coordinates of the centroid on the axis x and y for department i, respectively
z_{ij}^x	1, if department i is located to the left of department j. 0, otherwise.
z_{ij}^y	1, if department i is located lower than department j 0, otherwise.

$$\text{Minimize MHC} = \sum_{i=1}^{n} \sum_{j=1, i \neq j}^{n} f_{ij} d_{ij}, \quad (1)$$

subject to:

$$d_{ij} = \left|c_i^x - c_j^x\right| + \left|c_i^y - c_j^y\right|, \forall\, i, j\ (i \neq j), \quad (2)$$

$$a_i = l_i^x * l_i^y, \forall\, i, \quad (3)$$

$$\sum_{i}^{n} a_i \leq L^x * L^y, \quad (4)$$

$$\frac{\max\{l_i^x, l_i^y\}}{\min\{l_i^x, l_i^y\}} \leq \beta_i, \quad (5)$$

$$c_i^x + \frac{l_i^x}{2} \leq c_j^x - \frac{l_j^x}{2} + L^x\left(1 - z_{ij}^x\right), \forall\, i \neq j,$$
$$c_i^y + \frac{l_i^y}{2} \leq c_j^y - \frac{l_j^y}{2} + L^y\left(1 - z_{ij}^y\right), \forall\, i \neq j, \quad (6)$$

$$\frac{l_i^x}{2} \leq c_i^x \leq L^x - \frac{l_i^x}{2}, \forall\, i,$$
$$\frac{l_i^y}{2} \leq c_i^y \leq L^y - \frac{l_i^y}{2}, \forall\, i, \quad (7)$$

$$z_{ij}^x + z_{ji}^x + z_{ij}^y + z_{ji}^y = 1, \forall\, i \neq j, \quad (8)$$

$$z_{ij}^x, z_{ij}^y \in \{0, 1\}, \forall\, i \neq j. \quad (9)$$

The mathematical model aims to minimize total MHC between departments, subject to the following sets of constraints:

– equation (2) defines the rectilinear distance norm between departments,

– constraint (3) ensures that the area requirements for each department are satisfied, being this constraint the one that increases the complexity of the problem due to its non-linear nature;

– constraint (4) ensures that the total area of the departments is within the dimensions of the floor space.

The aspect ratio constraint, which allows a maximum aspect ratio between the longest and shortest sides of each department, is established in (5). The set of constraints (6) and (7) prevent the departments from overlapping, and ensure that the departments are located within the floor plan. Finally, constraint (8) defines the relative location of each department, while constraint (9) establishes the binary conditions of the location variables.

4 Solution Procedure for the Unequal-Area Facility Layout Problem

The UAFLP is known to be a NP-class problem (Kulturel-Konak & Konak, 2013; Meller & Gau, 1996), which requires huge computational capacities to be solved to optimality for large instances. In the following sections, the description and application of a GA metaheuristic for solving the UAFLP for the case of the garment industry is presented. Once the problem has been appropriately represented, the selected heuristic or metaheuristic algorithm is applied. Some metaheuristic Genetic algorithms (GA) (García-Hernández et al., 2015; Kulturel-Konak & Konak, 2013; Lee et al., 2003; Liu & Meller, 2007), simulated annealing (SA) (Allahyari & Azab, 2018; Bozer & Wang, 2012; Salas-Morera et al., 2020; Turgay, 2018) and ant colony optimization/ant systems (ACO/AS) (Komarudin & Wong, 2012; Kulturel-Konak & Konak, 2011a; J. Liu & Liu, 2019; Wong & Komarudin, 2010), which are found to be the most common metaheuristics for solving the UAFLP in the recent literature.

In relation to the application of the UAFLP to real-life industrial scenarios, literature is scarce. The cases of the ovine slaughterhouse (Salas-Morera et al., 1996), the carton pack recycling and the chopped plastic plants (García-Hernández et al., 2013) have been addressed and also considered as data instances for the problem. Other real-life applications of the UAFLP include the manufacturing of metalworking tools (Allahyari & Azab, 2018), the manufacturing of auto parts (Balamurugan et al., 2008) and the production of diesel motors (Liu et al., 2018).

When determining the best facility layout alternative, most of the publications have focused on material handling costs (MHC). MHC is a distance-based metric, where the distance is measured according to one of the following distance norms: rectilinear (Manhattan) distance, Euclidean distance, squared Euclidean distance or Chebyshev distance (Gonçalves & Resende, 2015; Xie et al., 2018). Rectilinear distance norm, which is computed as the sum of the horizontal and vertical distance between two points, is frequently considered by authors because it represents real-world layout problems (Gonçalves & Resende, 2015).

5 Conclusions

This article presented a review for the unequal-area facility layout problem, higthligthing its importance and presenting the mathematical formulation of the problem, from which it is possible to identify a high number of variables, parameters and restrictions that makes its solution a complex process. For that reason, it was found in the literatures that several metaheuristic procedures have been developed for the problem solution, as it is the case of genetic algorithms for evolution-based and ant colony for trajectory-based techniques.

As future research work, the model can be applied in many industrial sectors that require layout design for improving their operations, as many small factories in latin America. For that, it is required the development of solution techniques for solving the model, from which Genetic algorithms are chosen due to their easy application and good results in this kind of problems.

Other future research line is to consider more characteristics of the problem, such as dynamic and stochastic environments may also be considered to close the model to the real-world industrial case, as well as the joint optimization of the unequal-area facility layout with other operations management decisions, such as production planning and scheduling.

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