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The facility layout problem in non-rectangular logistics parks with split lines

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A B S T R A C T

A logistics park is an exactly delimited domain having a large space to efficiently and effectively organize, manage, and ship goods. The facility layout problem in a logistics park is concerned with determining the proper physical organization of a number of interacting functional areas. It differs from traditional facility layout problems in the context of split lines – railways or highways – which may cross a logistics park and partition it into several parts. Logistics parks also commonly have an irregular shape instead of a rectangular shape. These additional features make the facility layout problem in a logistics park complex and require explicit modeling. This research proposes two mathematical programming models to obtain competitive solutions to the facility layout problem in a logistics park. The first model involves allocating the functional areas into different parts resulting from the given split lines. The second model uses slicing structure technique to determine the final layout of all functional areas. Given that the facility layout problem in a logistics park is NP-complete, a heuristic approach combining improved adaptive genetic algorithm with scatter search is presented. Computational results show that the both proposed models and solution approach are effective and efficient.

1. Introduction

Nowadays businesses are forced to reduce logistics costs and improve serviceability that result in reduction of truck turnaround time, maximization of space utilization, and providing services without delay. All of these requirements have created a tremendous amount of pressure on existing stand-alone warehouses. As a result, a new concept – logistics park – has been created to meet these logistics requirements. A logistics park, which is an exactly delimited domain in a park, is utilized as a means to efficiently and effectively organize, manage, and ship goods.

Especially, logistics parks strive to prosper businesses in China. According to a survey by China Federation and Logistics and Purchasing (2012), there were about 207 domestic logistics parks in 2006 and it increased to 754 in 2012 and this significant increment (264%) indicates the major role of the logistics park in Chinese logistics and business development. A logistics park is commonly located in a strategic area that can easily be accessed from main highways, railways, and airports. Moreover, a logistics park typically has a large space for ample trucks, mass warehousing, office parking, and logistics services such as information transaction, distribution processing, multimodal function, and support service functions. Generally the space of a logistics park is divided into several non-overlapping regions called functional areas (FAs). A FA is able to offer one specific logistics service. Logistics parks are commonly configured with five to eight FAs to provide various kinds of logistics services (Liang, Yang, & Wang, 2013; Tang, 2009).

The facility layout problem (FLP) is an arrangement of departments with known dimensions to minimize operating cost and maximize system efficiency. FLP exists in various contexts, e.g., positioning machines in a workshop or locating buildings on a factory premises. It has been widely accepted that 20% to 50% of the total operational cost is accounted for material handling cost, and this cost can be reduced, at least from 10% to 30%, by improving layout design (Tompkins, White, Bozer, & Tanchoco, 2010). A FLP generally has a set of constraints as follows: (1) all departments must be located within a given zone or facility; (2) these departments must not overlap with one another, and some departments must be fixed at certain locations or forbidden for being in specific regions; and (3) the layout must fulfill aspect ratio (height to width or width to height) constraints for the dimension of departments, because departments with proper aspect ratios are

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more practical in real-world applications (Meller & Gau, 1996). A solution to the FLP is a block layout that specifies the relative location and dimensions of each department.

The FLP in a logistics park (FLP-LP) is concerned with positioning FAs to locations within a logistics park. Proper arrangement of FAs is very important to the efficiency and cost saving of a logistics park. The arrangement of FAs lies on a number of factors such as locations of FAs, the adjacency of FAs, distances among FAs, resources of FAs, etc. Inappropriate placement of FAs can cause major time and cost overruns. Therefore, the FLP-LP is an important and fundamental strategic issue. In addition, with the rapid development of logistics parks, FLP-LP has received increasing attention from scholars and practitioners (Yang, Taudes, Deng, Chen, & Tian, 2015).

Unlike FLPs, in real-world applications, a logistics park typically has an irregular shape, such as an arbitrary polygon or curve. This feature complicates the FLP-LP. For example, some constraints, which indicate that departments cannot overlap with each other and departments are entirely contained within the facility, are represented by the coordinates and dimensions (width and length) of rectangular shaped departments. However these constraints are not applicable when the departments have irregular shapes. Similarly some of solution techniques dealing with rectangular shaped block may not also be applicable, e.g., when a facility has a rectangular shape, the aspect ratio can be used to restrict the occurrence of an extremely long and narrow department. However, when a facility has an arbitrary shape, dealing with aspect ratios is challenging. In addition, split lines, such as railways or highways, sometimes traverse a logistics park and divide it into several parts, thus a new strategy is necessary to ensure that resulting FAs are not divided by split lines. These additional features make the FLP-LP complex and require an explicit modeling technique.

The FLP has been proven to be NP-complete (Konak, Kulturel-Konak, Norman, & Smith, 2006). Given that the FLP-LP is at least as difficult as the FLP, FLP-LP also belongs to the class of NP-complete problems. As a result, no computationally efficient approach has been found to obtain an optimal solution to the FLP-LP. Therefore, developing efficient heuristic algorithms to solve the FLP-LP is necessary.

This paper is structured as follows. Section 2 presents a recent survey about the FLP and the FLP-LP. Section 3 describes the FLP in a non-rectangular logistics park with and without split lines. Section 4 discusses two mathematical programming models for the FLP-LP. The first model places FAs into different parts and the second model determines the final block layout. Section 5 addresses heuristic algorithms to solve the proposed models. In addition, Section 6 presents computational experiments demonstrating the strength and potential of the proposed models and heuristic algorithms. Finally, Section 7 concludes the paper.

2. Literature review

The FLP has received considerable attention over the last few decades. Meller and Gau (1996), Singh and Sharma (2006), and Drira, Pierreval, and Hajri-Gabouj (2007) presented an overview of facility layout design. Based on these surveys, the literature on facility layout can be divided into three broad categories.

The first category involves algorithms addressing the general FLP. Several researchers developed methods to find optimal solutions (e.g., Meller, Chen, & Sherali, 2007). However, these methods to solve the FLP have a major limitation that they are not capable of obtaining the optimal solution for large-sized problems within a reasonable time. Thus, most of the methods to solve large-sized problems are based on heuristics promising to find a good solution in a relatively short amount of time. These heuristics include simulated annealing (e.g., Bozer & Wang, 2012), genetic algorithm (GA) (e.g., García-Hernández, Pierreval, Salas-Morera, & Arauzo-Azofra, 2013) and tabu search (TS) (e.g., Scholz et al., 2009; Kulturel-Konak, 2012), ant colony optimization (ACO) (e.g., Kulturel-Konak & Konak, 2011; Wong, 2010), artificial immune system (e.g., Haktanirlar Ulutas & Kulturel-Konak, 2012), particle swarm optimization (Asl & Wong, 2015), and certain combinations of the aforementioned heuristics (e.g., Ku, Hu, & Wang, 2011). A number of researchers also solved the general FLP by using other methods. For example, Salas-Morera, Cubero-Atienza, and Ayuso-Munoz (1996) proposed some computer-aided techniques for the FLP. Jankovits, Luo, Anjos, and Vannelli (2011) described a two-stage convex-optimization-based framework for efficiently finding competitive solutions for FLPs. The first stage is to establish the relative position of departments, and the second stage is to determine the final layout based on semidefinite programming. Tarkesh, Atighehchian, and Nookabadi (2009) employed a multi-agent technique in which agent interactions form the facility layout design. Altuntas, Selim, and Dereli (2014) proposed a fuzzy DEMATEL-based solution approach taking into account both qualitative and quantitative factors of FLP. García-Hernández, Palomo-Romero, Salas-Morera, Arauzo-Azofra, and Pierreval (2015) introduced expert's knowledge into genetic algorithm for FLP.

The second category is concerned with the extension of the general FLP that considers additional issues, which arise from real-world applications, such as the dynamic FLP (DFLP). The DFLP involves finding positions for different departments over multiple time periods by minimizing the sum of material handling and rearrangement costs. Rosenblatt (1986) first presented a solution technique for this problem. Numerous solution techniques were then developed for the DFLP (e.g., Pourvaziri & Naderi, 2014; Ulutas & Islier, 2015). Another situation addresses the optimization of two or more objectives simultaneously, i.e., the multi-objective FLP (MOFLP), which includes qualitative and quantitative evaluations to obtain more effective solutions (Şahin, 2011). Numerous methods were suggested to solve the MOFLP (Matai, 2015; Ripon, Glette, Khan, Hovin, & Torresen, 2013). Another extension under this category is a multi-floor facility layout, which received attention as land supply becomes increasingly insufficient and expensive (Lee, Roh, & Jeong, 2005).

The third category is concerned with specially structured instances of the problem. In this category, an extensively studied one is the single-row FLP (SRFLP). SRFLP focuses on arranging a given number of rectangular departments next to each other along a line to minimize the total weighted sum of the center-to-center distances among all pairs of departments. A large number of exact and approximate methods were developed for this problem. Exact methods includes branch and bound (Simmons, 1969) and cutting planes (Amaral, 2009). Several heuristic methods were proven effective, particularly in large-sized cases, such as TS (Samarghandi & Eshghi, 2010), ACO (Solimanpur, Vrat, & Shankar, 2005), scatter search (SS) (Satheesh Kumar, Asokan, Kumanan, & Varma, 2008), and GA (Kothari & Ghosh, 2014).

With the fast development of logistics parks, the FLP-LP has attracted increasing attention from the industry and academia. Šulgan (2006) presented the basic characteristic of a logistics park and proposed the theoretical case of the logistics park development. Zeng (2008) proposed the layout of an airport logistics park based on qualitative analysis of interrelation of all FAs and transportation condition of the logistics park. The method of systematic layout planning (SLP) (e.g., Muther, 1961), a practical and organized method for rearranging existing or laying out new facilities quantitatively, was widely applied in the FLP-LP. As the SLP arranges the departments manually and subjectively, it is a time consuming process, especially when the size of problem is large. Moreover, different planners may obtain different layout solutions.

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