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A robust model for multi-floor layout problem ☆

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ABSTRACT

Multi-floor layout problem (MFLP) can be categorized as one of the most crucial basic problems in the real world especially in the field of plant layout design. Specially, the aim of this problem is to find the locations of each department, storage, and elevator in the floors of a multi-floor building and without overlapping to minimize the total material handling cost. In order to consider practical issues in theory and presenting an applicable problem, for the first time in the published literature for MFLP, we develop a robust mathematical model indiscrete and uncertain environment in which some parameters can be changed in predetermined intervals. In fact, one of the most considerable factors is material flow among departments and storages which is assumed to have uncertain values rather than fixed amounts. In this study, we develop a Mixed Integer Programming (MIP) robust model for a new form of MFLP, we called MFDLP where the cellar is considered to contain main storages and upper floors in which departments will be located in predetermined locations. Moreover, there is an elevator set for transferring materials between floors and should be located without overlapping with departments and storages. Finally, the presented model is tested and assessed on some problems and its efficiency is shown.

1. Introduction

The lack of enough space in cities and the exorbitant costs associated with the provision of space, particularly in metropolitan ones, force designers and engineers to consider multi-floor layouts in organizations, plants, and corporations. Sometimes, environmental factors and other important criterion are brought on to bear on their considerations for designing multi-floor buildings. For instance, in tropical areas, air-conditioning would be more efficient in multi-floor buildings than in other ones with just one floor (Goetschalckx & Irohara, 2007). Due to limited space in such buildings for stocking materials, material flow, and the traffic of human resources among departments, appropriate planning for the provision of more space and the location of departments has had a very wide appeal among researchers. Designers' experience and experts' opinions suggest that more than 65% of the system efficiency is likely to be lost by applying incorrect layout and location designs (Huang, Wong, & Tam, 2010). On the other hand, between 20% and 50% of operating expenses in manufacturing can be attributed to facility planning and material handling (Singh & Sharma, 2006). They claimed that it is the most decisive factor in determining the efficiency of a layout and of top priority as such.

In the literature, a wide range of models and algorithms for solving MFLP have been presented. Nevertheless, only few of them have been applied for solving real-world problems. Robust optimization is an approach which can be adopted to bridge the gap between theory and practice to develop mathematical models which are applicable in practice. Generally, most of the articles in the literature of MFLP are on deterministic environment while in practice it is impossible to specify fixed values for problems' parameters. In fact, because of the existence of a number of uncertain factors when dealing with real problems, it would be in appropriate to exclude such uncertain issues out of our equations. On the other hand, we cannot measure some values with precision, which it might result in drastic changes in some parts of our problems. For instance, the exact determination of consumers' demand for some products is a tough decision for companies and it would be more appropriate to consider a range of values for costumers' demands instead of a fixed value. If we forecast incorrect values for product demands, our corporation may face bankruptcy in the long run as a result of non-specialized demand estimations.

In the literature, facility planning can be categorized into two general groups: (I) facility layout problems and (II) facility location problems which may be modeled in discrete or continuous areas. In the former, there has been a growing tendency to disregard facility dimensions and most of the developed models do not account

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for departments' overlaps. On the other hand, in facility layout problems, facilities have dimensions. In most of layout problems in the literature, each facility can be placed on any point of the floor. However, what we here mean is a facility layout problem where each rectangular department can only be assigned to predefined places (points) on each floor. We call it multi-floor discrete layout problem (MFDLP). Accordingly, we have "*I*" different departments that will be located in different locations of a building with "*F* + *1*" floors. In this building, each of "*S*" storages (each storage may stock one of "*M*" materials and some storages may not be used, meaning that $M \leq S$) will be located in the cellar and all "*I*" departments can be arranged in the upper "*F*" floors. Moreover, an elevator set is embedded in the building to ease the flow of materials among departments and storages on different floors. A front view of the building in which the elevator and departments are located is shown in Fig. 1. In this figure, "*lf*" indicates *l*th location on the *f*th floor and Storage "*s*" is *s*th location in the cellar.

The general structure of this paper is as follows. Firstly, a concise and comprehensive review is provided on some important relative researches. Afterward, our basic model for MFDLP is developed in Section 3 for the proposed problem whose nonlinear parts are linearized in Section 4. Section 5, then, defines the robust MFDLP, followed by a discussion of its proposed mathematical model in Section 6. In Section 7, computational results are presented and based on these results a comparison is drawn between the mathematically based model for MFDLP and the robust one. Finally, the main points of the whole paper are summed up in the conclusion.

2. Literature review

Recently, the importance of developing a practical model for MFLP has attracted a lot of attentions among researchers around the world which resulting in different effective mathematical models and algorithms. Moseley was the first researcher who concentrated on this problem in 1963 (Kochhar & Heragu, 1998). He presented a model in which departments were allowed to be arranged on the predetermined locations of a multi-floor building. Following this study, Johnson proposed a heuristic algorithm to solve MFLP (Chen, Xiao, & Tang, 2011). This algorithm was based on CRAFT algorithm with the same considerations (Johnson, 1982). In fact, calculating distances among departments is one of most noticeable issues in MFLP. In 1988, a comprehensive study was done on this problem with two main considerations to develop an algorithm (Hahn, Smith, & Zhu, 2010). The first consideration was ensuring the same dimensions for all departments and the second one was embedding an elevator in the building.

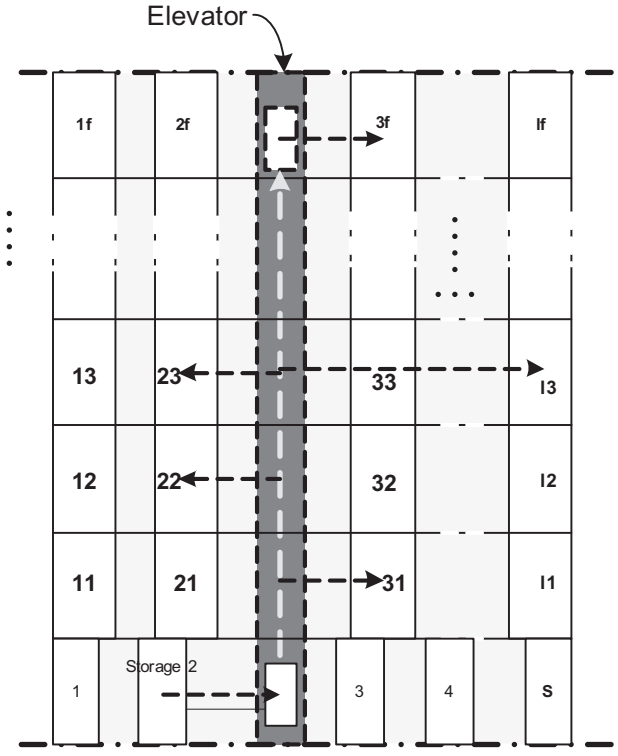

Fig. 1. Front view of a sample MFDLP.

In general, in a multi-floor location problem, instead of making decisions relevant to one-floor location problems, decisions need to be made for the following items:

1. Assigning departments to floors.
2. Calculating the number of required elevators in the building.
3. Determining the coordinates of each elevator.
4. Assigning material flow to the elevators.

In presenting a model, some of these items can be considered as predetermined and fixed variables (Goetschalckx & Irohara, 2007). One of the foremost papers in the field of MFLP was presented by Kochhar and Heragu (1998). They developed a model in which the total number of floors in the building was considered to be variable while the same costs were considered for constructing each floor. Also, Pessoa et al. (2008) presented a study in which a heuristic algorithm was implemented to solve the problem and exact solving techniques were provided for the generating the optimum solution. Interestingly, Krishnan and Jaafari (2011) and Chen et al. (2011) applied this strategy in their papers. Park, Koo, Shin, Lee, and Yoon (2011) believed that in special applications, we may have some issues such as exploitation possibility which force us to determine a model in which a minimum distance is mandatory. As a result, they developed a model to apply such features whereby a tradeoff between material flows and the minimum required distances among departments was considered.

First applications of robust optimization was in around 1950 when some tools such as worst case analysis and Wald's MaxMin model were applied to solve problems (Wald, 1950). Generally, following three major methodologies have been adopted in robust optimization in the literature:

1. Scenario approach: this approach was first proposed by Mulvey and Vanderbei (1995). They characterized their desirable properties of a solution to model by utilizing a set of scenarios for their data values instead of using point estimations. According to their definition, a robust solution must remain close to the optimal one for all input scenarios.
2. Elliptic model of uncertainty: Ben-Tal, Ghaoui, and Nemirovski (2009, 2004), Ben-Tal and Nemirovski (2002) proposed this approach whereby elliptic values are replaced with exact ones for parameters and a new exact model can be developed to overcome uncertainties.
3. Interval model of uncertainty: this third approach was applied in Bertsimas and Sim (2006), Bertsimas and Sim (2003), Soyster (1973). In this method interval values are considered for parameters.

According to our investigation on the MFLP literature, there are not special studies on the robust multi floors problems and most of the robust layouts are in simple views as in one-floor layout problems. However, in the field of flexible layout, it would be no stretch to claim that Shore and Tompkins (1980) were pioneers in FLP. They presented a model to generate a flexible layout for uncertain environments with a penalty function criterion. Afterward,