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A robust mathematical model and ACO solution for multi-floor discrete layout problem with uncertain locations and demands

Niloufar Izadinia *, Kourosh Eshghi

Department of Industrial Engineering, Sharif University of Technology, Tehran 14588-89694, Iran

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ABSTRACT

The Multi-Floor Layout Problem (MFLP) is the problem of finding the position of each department in a plant floor in a multi-floor building without any overlapping between departments in order to optimize a particular objective function, more commonly the sum of the material handling costs. In this paper, a special class of MFLP, called Uncertain Multi-Floor Discrete Layout Problem (UMFDLP), is defined. In this problem, a multi-floor building is considered in which an underground store is utilized to contain main storages, and different departments can be located in the other floors in potential pre-determined locations. Furthermore, all material flows are not constant. Moreover, the locations for departments can be chosen from intervals, where no overlaps are allowed.

We develop a Mixed Integer Programming (MIP) model to generate a robust solution for UMFDLP. Furthermore, the lower bound of objective function is obtained. Moreover, an ACO algorithm is designed for solving large instances. Then, a set of problems is generated and tested by the proposed algorithm. The results show the efficiency of our model and algorithm.

1. Introduction

Many firms', organizations', and hospitals' designers tend to design multiple floor buildings due to some reasons, some of which are lack of enough space, air conditioning problems, expanding organizations, easy and fast access to departments and facilities, avoiding human traffic, to name but a few. Additionally, researches show that more than 35% of the system efficiency is likely to be lost by applying incorrect layout and location designs (Huang, Wong, & Tam, 2010). Accordingly, the study about proper layout design in multi-floor buildings comes to value. For many years, researchers on the field of facility and plant layout design have published valuable articles in Multi-Floor Layout Problem (MFLP) and its specific characteristics as compared to single floor layout design.

In a MFLP model at least one of the following decisions must be made.

- Assigning departments to floors.
- The layout of each floor.
- The number of required elevators in the building.
- The coordinates of each elevator.
- Assignment of material flow to the elevators.
- Elevators' capacity.
- Assignment of material flow to departments.
- The number of floors.

However, parameters used in most studies of MFLP were considered to be deterministic while assigning precise amounts to such parameters is usually difficult or impossible, in real world problems.

There are several approaches to consider uncertainty in mathematical models, that is, fuzzy programming, stochastic programming, flexible planning, robust modeling, etc., among which robust optimization approach is one of the comparably new and practical ones. In a layout planning, material flows between departments and demands of materials and products are more probable to be uncertain in that designers cannot measure them with precision. Assuming a particular number for these parameters might result in inappropriate and impractical solutions. Hence, it would be more appropriate to consider a range of values for them rather than a fixed value. Moreover, in a layout problem which departments cannot be located at any point of the floor, and should be assigned to predetermined locations, determination of exact points for locating the center of departments can be a difficult decision. It manifests itself when departments have different shapes and areas, and when constraints of walls, corridors, pre-located departments come into

* Corresponding author. Tel.: +98 912 280 4450; fax: +98 331 262 4268.
E-mail addresses: n.izadinia@gmail.com (N. Izadinia), eshghi@sharif.edu (K. Eshghi).

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account. Thus in this research, we assume a multi-floor layout problem with uncertainty in location of departments, and material flows between departments, as well as those between departments and storage areas. We call this problem Uncertain Multi-Floor Discrete Layout Problem (UMFDLP). We formulate a mathematical model for a layout problem with unequal-area departments which should be located in one of the predetermined locations without overlapping with one another. Through our investigations, our approach in which a layout problem with predetermined locations and unequal-area departments is formulated to avoid overlaps, is not used in the published literature. Moreover, we develop a new method for formulating the robust model for considering the uncertainty in locations. Furthermore, a new ACO is developed for solving the problem instances; a method which according to the computational results is efficient, especially for large instances.

This is a promoted problem as compared to the one we developed in Izadinia, Eshghi, and Salmani (2014), and is more applicable to real world situations. The promotions of this research as compared to the one in Izadinia et al. (2014) are as follows.

- Uncertainty about locations of departments is considered.
- There are material flows between departments in addition to material demands from the storage.
- Material flows between departments are uncertain in the robust model.
- In addition to Bertsimas and Sim (2003) approach for establishing robustness in model for material flows' and material demands' interval change, a new approach for considering uncertainty of locations is developed.
- Unequal-area departments should have no overlapping with one another.
- Instead of locating in any point of floor, the elevator set should be located in one of the pre-defined locations, a supposition which changes the mathematical model drastically.
- An ACO heuristic is developed for solving large-size instances.
- Some departments cannot be located in some locations.

In this problem, there are "*I*" unequal-area departments that should be located in pre-determined locations of a building with "$F+1$" floors without overlapping with one another, and the elevator set. The elevator set should be placed in pre-determined locations in the building to carry materials between departments on different floors, and from storages to departments. The underground store of the building is the storage where each of "*S*" storage locations are located. All "*I*" departments can be arranged in the upper "*F*" floors. Each storage may stock one of "*M*" materials and some storages will not be used, which means $M \leqslant S$.

The general structure of this paper is as follows. First, a comprehensive review about MFLP and robust optimization is presented. Afterwards, our basic models for MFDLP and UMFDLP are developed in Section 3. In Section 4, the developed ACO algorithm for the models is explained, followed by a lower bound for the model in Section 5. In Section 6, computational results are presented and based on these results, a comparison is drawn between the mathematical model for MFDLP and UMFDLP. In Section 7, the major applications of the proposed model is elaborated upon. Finally, the main points of the whole paper are summed up in the conclusion.

2. Literature review

The major attraction of facility layout problem lies in its tremendous theoretical and practical applications. Meanwhile, many firms in the case of limited lands, are likely to consider refurbishing or constructing multi-floor buildings (Bozer et al., 1994). Accordingly, for the first time in the literature, Moseley in 1963 introduced MFLP (Kochhar & Heragu, 1998). In his model, departments were allocated to predetermined locations in floors. Afterwards, Johnson (1982) presented a CRAFT-based heuristic algorithm to solve MFLP. From that time, the multi-floor facility layout problem attracted the attention of researchers. Meller and Bozer (1997) compared approaches to multi-floor facility layout problem. They also presented a two-stage approach in which the floor for each department was decided in the first stage, and in the second stage the position of departments in their floors were determined.

Kochhar and Heragu (1998) presented a model for MFLP in which the total number of floors was considered to be variable, while constructing each floor had the same cost. They considered dynamic production demand and mix changes condition.

Some articles added practical assumptions to the problem with respect to the application of the place for which the layout is generated. Patsiatzis and Papageorgiou (2002) presented a mixed integer linear formulation for the problem with consideration of safety distance. Chen, Xiao, and Tang (2011) developed a multi-objective model with consideration of vertical transportation time and waiting time by simulation. Patsiatzis and Papageorgiou (2002), Park, Koo, Shin, Lee, and Yoon (2011) and Lee (2014) asserted that in special applications, because of some issues like exploitation possibility, designers should determine a model in which a minimum distance between some departments is mandatory in the layout.

Kia et al. (2014) developed a model for multi-floor layout with cellular manufacturing systems in a multi-period planning horizon with the objective of minimizing the costs of material handling, purchasing machines, machine processing, machine overhead, and machine relocation. They solved their model with a genetic algorithm. Ahmadi and Akbari Jokar (2016) developed a three stage mathematical programming method for multi-floor problems which can be used in single floor problems too. They used mixed integer programming model and nonlinear programming models in the stages. Izadinia et al. (2014) for the first time in published literature introduced a kind of MFLP called MFDLP in which departments were located in predetermined locations without any overlapping with elevator set. Before this model, avoiding overlaps were considered only in the continuous space for layouts. They also used (Bertsimas & Sim, 2003) robust approach for interval uncertainty of materials demand for the first time in the multi-floor layout problem.

Some studies used meta-heuristics to solve MFLP. For instance, Matsuzaki et al. (1999) developed a GA heuristic for multi-floor facility layout problem with consideration of capacity for elevator. Lee et al. (2005) used GA to generate multi-floor layout in which a five-segmented chromosome represented multi-floor facility layout. They minimized the total cost of material transportation and adjacency requirement between departments where there are constraints of area and aspect ratios of departments. Krishnan and Jaafari (2011) developed a GA for the problem with considering of aspect ratio for departments and adjacency ratio between departments in multi-bay environments. Pessoa et al. (2008) presented a study in which a heuristic algorithm and exact solving techniques were provided.

The origins of robust optimization go back to around 1950 when some tools such as worst case analysis and Wald's Max–Min model were applied to solve problems (Wald, 1950). Classic robust optimization has three major approaches (Izadinia et al., 2014). First, the scenario approach introduced by Mulvey and Vanderbei (1995). Scenarios are possible situations and desirable properties of a solution. Accordingly, for all proposed scenarios, a robust solution must remain close to the optimal one. In other words, the robust solution is the solution which remains approximately or exactly optimum, no matter which one of the scenarios happens. The degree of closeness is dependent on the sensitivity of the problem.