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Mathematical models for selection of optimal place and size of connections considering the time-value of money

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ABSTRACT

In this study, mathematical models to select the optimal place and size of connections are studied considering the time-value of money. A connection is defined as a part that links different sets of departments through which some interdepartmental material flows must go [S. Huang, R. Batta, R. Nagi, Variable capacity sizing and selection of connections in a facility layout, IIE Transactions 35 (2003) 49–59]. The goal of this paper is to select the location and capacity of the connections so as to minimize the sum of material movement, connection installation and connection maintenance costs minus the salvage value considering the time-value of money. Mixed integer nonlinear programming models are developed for discrete and continuous capacity options. The mixed integer nonlinear programming models of the continuous cases are reduced to mixed integer linear programming models, using proved properties of these problems. For the discrete capacity cases, a computational example and sensitivity analysis of the solutions with respect to possible future changes in the values of parameters are developed and presented.

1. Introduction

Material handling system (MHS) design consists of the determination of mechanisms needed to support the required facility interactions. As pointed out by Tompkins and James [1], an MHS is one of the main components of the facilities planning hierarchy. Thus, any cost saving in this area can contribute significantly to the overall efficiency of the production system.

Although MHS issues are long-term decisions, engineering economy factors are not usually considered in MHS design studies. This can reduce the validity of the MHS related decisions.

This paper considers a location problem in which flows between pairs of facilities must flow through a connection. A connection is defined as a part that links different sets of departments through which some interdepartmental material flow must go [2]. Some examples of such connections are as follows: (i) an input/output (I/O) station of a department (Montreuil and Ratliff [3]) that connects the department with its outside environment, also known as ingress/egress or pickup/drop off for material; (ii) an aisle that connects different sets of departments; (iii) a staging, inspection, and distribution station (iv) a hub in hub-and-spoke network (O'Kelly [4]); and (v) an international land border crossing between two countries (Robenhymer and Estrada [5]).

In this paper, given a set of candidate connection sites, we calculate the optimal location and size (capacity) of the connections while considering engineering economy factors. All material flows have to pass through the connections. The capacity of each connection should be calculated in terms of the volume of material that should flow through it. This would depend on the size of door/gate or width of an aisle, for example. The connections with different capacities have different construction and maintenance costs associated with them. The goal of this research is to develop a selecting approach for the location and capacity of the connections considering their relevant costs and the time-value of money. The total cost of the MHS is comprised of the facilities related costs (the connection installation and the connection maintenance costs) and the material movement costs minus the salvage value. The maintenance and material movement costs are long-life and make major part of the total cost, so it is very important to consider engineering economy factors in the mathematical models of the problem. A miniature form of a typical problem is illustrated in Fig. 1. In this figure, there are four departments and three candidate connection sites. The lines that connect departments and candidate points are possible flow paths. So at least one of the three candidate points should be chosen to locate a connection.

In addition to distribution systems and layout planning problems, location models in which flows between pairs of facilities must travel through connections can be used in other types of problems. There are some applications of them in metropolis related problems, Marín

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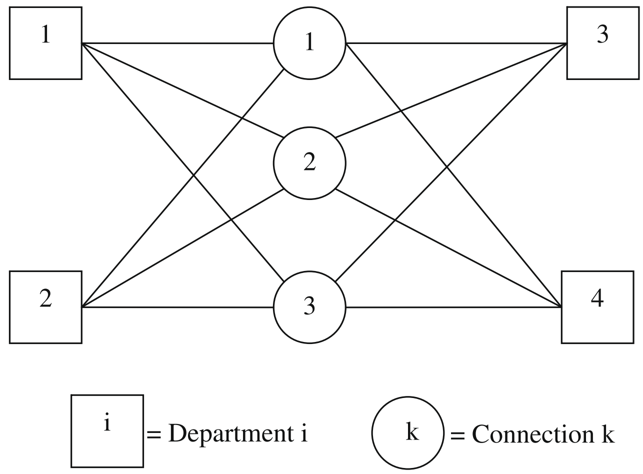

Fig. 1. An example.

and García-Ródenas [6] located the infrastructure of the Rapid Transit Network on a discrete space of alternatives. Horner and Groves [7] located park-and-ride facilities in a network flow-based framework. Södermon [8] developed a mixed integer linear programming model to select the location and capacity of the cooling plants and the cold media storages and to route the distribution pipe-lines to individual consumers in a district cooling network. Moreover, the mentioned models can be used in cell or switch location related problems in mobile communication networks [9,10].

The remainder of this paper is organized as follows. In the next section, literature survey of the problem is presented. Section 3 introduces a solution approach and three mathematical programming models. Section 4 consists of a numerical example and sensitivity analysis of the model for the discrete capacity cases. Finally, Section 5 is devoted to the conclusions and future research directions.

2. Literature review

The papers that have considered capacity and facility location decisions in the context of a material flow network design problem are not few. Most of the previously published papers have considered connection capacity sizing and location problems separately. Initial papers discussed the capacity factor of facilities while neglecting their location. Magnanti and Wong [11] provided a comprehensive survey on the application of network design models by mathematical programming techniques. Other studies on the capacity of a network include Khang and Fujiwara [12], and Herrmann et al. [13,14]. Cohn et al. [15] considered a new variation to this class of problems, in which the cost associated with an arc depends not only on the amount of flow moving across that arc, but on the amount of flow on other arcs in the network as well. On the other hand, some researches focused on the location of input/output stations, pickup stations, etc. Montreuil and Ratliff [16] proposed a methodology for characterizing and locating input/output stations within a workshop. Kiran and Tansel [17] developed a procedure to determine the best locations of pickup and delivery stations along a predefined flow path to minimize the system's operational cost. Luxhoj [18] proposed a procedure to practical layout planning to determine the location of facility ingress/egress points of departments in a manufacturing system. Benson and Foote [19] provided a new distance metric, the shortest path distance between departments along aisles, to layout aisles and door locations. Wang, Bhadury and Nagi [20] determined optimal locations of the supply facilities as well as Input/Output points on the demand facilities, in order to minimize total transportation costs. Ross and Jayaraman [21] described two heuristics utilizing the simulated annealing (SA) methodology to calculate the location of cross-docks and distribution centers in supply chain network design. Romeijn et al. [22] formulated the two-echelon supply chain design problem as a set-covering model and proposed a framework for location decisions.

Some researchers considered a location problem in which flows between pairs of facilities must flow through the connections. Huang et al. [2] discussed the discrete version of the problem when the capacity of the connections was variable. In other paper, Huang et al. [23] considered the discrete case while modeling the connections as M/G/1 queues. In these papers, the potential locations were from a discrete set but the problem was NP-hard. Huang et al. [24] sought to locate a given number of the connections and allocate flows to them in the case of continuous version, with the goal of minimizing the transportation cost in which both cases of capacitated and uncapacitated connections were considered.

Literature review indicated that few researchers have considered the capacity sizing and facility locating aspects simultaneously. However, the engineering economy factors were absent in all of these models. Discarding these factors affects the validity of the answers because a major portion of the MHS costs are related to energy and maintenance which are long-life costs. The inaccuracy of answers in the case of ignorance of the engineering economy factors compared to the case of considering them is obvious in the 4th section of this paper. The purpose of this paper is introducing the time-value of money to the variable capacity sizing and location of the connection problem. In addition, it presents efficient solution methods for solving practical versions of the problem.

3. Problem formulation

In this section, three mathematical programming formulations are presented. The required sets, parameters and decision variables are as follows:

N set of departments
A set of possible flow paths ($(l,j) \in A$ if and only if there is flow from l to j)