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Robust Facility Layout Design under Uncertain Product Demands

Shanshan Zha*, Yu Guo, Shaohua Huang, Falin Wang, Xiao Huang

College of Mechanical and Electrical Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing, 210016, China

* Corresponding author. Tel.: +86-025-84895840; E-mail address: sszha@nuaa.edu.cn

Abstract

Facility layout problem (FLP) is one of the classical and important problems in manufacturing system. It involves determining the optimal placement of different types of facilities within the boundaries of workshop so that materials handling cost is optimized. Aiming at dynamic facility layout problem caused by uncertainty of product demands, a novel continuous formulation of robust facility layout is presented on the basis of fuzzy-random theory. The main factors causing uncertainty demands are analyzed and the uncertain demands are represented by fuzzy random variables. To minimize material handling cost between the various departments, a robust layout model with unequal-area departments is established under fuzzy random environments. Moreover, the position-based flexible particle swarm optimization algorithm is proposed to obtain feasible optimization solutions. Finally, a case study of manufacturing system has been utilized for the verification of the above model and optimization.

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Keywords: Robust Facility Layout; uncertain product demands; optimization model

1. Introduction

Facility layout problem (FLP) has significant impact upon manufacturing costs, work in process, lead time and productivity. FLP involves determining the optimal placement of different type of facilities within the space of workshop. Such facilities include machines, workstations, utilities etc. Material handling cost is the most critical measure to determine the reasonability of a layout since it forms 20-50% of the total manufacturing costs and it can be decreased 10-30% by efficient layout design [1,2]. Due to the fact that FLP is an NP-hard problem and combinatorial optimization problem (COP), various mathematical models and heuristic or intelligence methods have been developed in past two decades.

Dynamic facility layout problem (DFLP) takes into account possible changes in the material demands over multiple periods [3]. The planning horizon is generally divided into weeks, months, or years. There are two approaches towards DFLP: flexible and robust. Flexible approach assumes that layout will accommodate changes from time to time with low arrangements and easily relocated machines. It may delays the lead time and make customer satisfaction levels decline sharply with production interruption and relocation [4]. Robust approach is not necessarily an optimal solution for every period of facility layout, but for entire time planning horizon. Unlike the flexible layout needs rearrangement costs, robust layout has the advantage of low rearrangements and production interruption costs. It was proposed that robustness of a layout as the number of times that the layout falls within a pre-specified percentage of the optimal solution under different material demands [5].

2. Literature Review

Most of the researchers in the literature focused on the changes of material demands from period to period under deterministic environment [6,7]. With fuzzy production information, changes of product volume, and product varieties, material demands for each period exist uncertainty to some extent. Material demands is considered as a stochastic variable with the normal distribution, which could be predicted on the basis of past information relating to product [8]. Chan and Malmborg (2011) [9] adopted Monte Carlo simulation to empirically search for robust solution under stochastic demand scenarios. G.Aiello et al. (2012) [10] proposed that the uncertainty of material demands

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between facilities and defined the material demands for each period as fuzzy numbers. Kaveh and Dalfard (2012) [11] defined product demand (i.e. material flow) as a fuzzy number and modeled in fuzzy programming including expected value, chance-constrained programming and dependent-chance programming.

The first robust layout model was presented as a QAP model with stochastic material demands for a single period [5]. Afterwards, some researchers have established a robust layouts model for multi-production scenarios in manufacturing system [12,13]. Pillai and Subbarao (2008) [14] developed a robust layout design methodology with equal-area department and adopted total penalty cost to test the suitability of the suggested layout model for DFLP. Liu (2014) [15] improved the existing robust indicator and design a robust constrain to improve robustness of final layout. Neghabi et al. (2015) [16] proposed a robust layout under uncertain environment with dynamic and uncertain value for departments' dimensions. Izadinia (2016) [17] proposed a mixed integer programming model to generate a robust solution for multi-floor layout problem.

Although previous studies have significantly improved FLP with uncertainty, it is difficult to reflect the subjective and objective imprecision and complexity simultaneously. Decision-making processes often stay in a hybrid uncertain environment. So it is hard to know precisely whether the uncertain environments is fuzzy or random. Therefore, this study proposes fuzzy random variables to handling with the dual uncertainty, which makes more comprehensive and practical for facility layout design.

3. Key Problem Statement

As mentioned in the literature, presence of ambiguity in material flow information and changes of product for each sections lead the dynamic facility layout problem. Realizing the idealistic of considering material demands as a certain variable, most researchers consider its uncertainty of the problem. The approaches solving uncertain facility layout problems can be classified into two general groups of probabilistic and fuzzy approaches [3].

In practice, FLP decision-maker cannot estimate the precise product demand in advance for rapid changes of market and scarcity of accurate statistical demand data. Therefore, it is difficult to confirm precisely whether the environment is fuzzy or random. For the former, fuzzy logic has been introduced to handle this imprecision in a certain range. For the latter, product demands fluctuate from day to day or week by week with process adjusting, product quality, and so on. As mentioned above, probability theory has been applied to handle this kind uncertainty. Under this situation, there is need to stress the twofold uncertainty, as it allows for a more comprehensive analysis of the FLP product demands uncertainty.

There are two distinct characteristics considered in this paper. First, unequal-area facilities need to be considered. If each facilities have been assigned with uniformly area, it will reduce the rate of area utilization. Second, fuzzy random variables are applied to replace the deterministic material demands in this paper. Essentially, a facility layout plan is drawn up usually before the implementation. Uncertain fluctuation leads decision-makers difficulty for estimate precise material demands changes in the process of production. Therefore, the material demands between workstations cannot be determined in advance for ambiguity of renewal information related to production, which leads to consider uncertainty. Because of multi-varieties and rapid response to market, it is appropriate to use fuzzy variables to model the precise material demands history data and decision-makers' forecasting data. At the same time, material demands may to be adjusted from day to day or week by week, which indicate material demands is a variable in a period that exists probability to some extent. As mentioned above, probability theory has been applied to solving FLP in previous researches, in which the material demands approximately follows a normal distribution. Consequently, the material demands between any two departments or workstations at any period need to consider both fuzziness and randomness. In a word, a fuzzy random variable is suggested in this paper to demonstrate the dual uncertainty in the material demands.

4. Mathematic Modeling for DFLP

Based on the problem statement above, a dynamic facility layout model with unequal area under fuzzy random environment established in this paper seeks to find a robust layout. The model is formulated under the following assumptions:

(1) There are multi-periods consist of entire planning horizon.

(2) The profile of department area is seen as rectangle ignoring its outline details.

(3) Each facilities are placed parallel to x, y axis.

(4) The material demands between departments are defined as fuzzy random variables.

Nomenclature

d_{jk}^t manhattan distance between facility j to facility k

d_l, d_u material demands maximum value and minimum value respectively

$f_{\tilde{\bar{D}}_p^t\{\alpha,\gamma\}}(x)$ increasing functions

$g_{\tilde{\bar{D}}_p^t\{\alpha,\gamma\}}(x)$ decreasing functions

r_j^t binary variable , denote whether the facility j is to be arranged at period t

x_j the centroid of facility i at the horizontal coordinate

y_j the centroid of facility i at the vertical coordinate

D_p^t demands of part p in period t

$EV\left[\tilde{\bar{D}}_p^t\{\alpha,\gamma\}\right]$ denotes the expected value of material demands at t period

F_p^t delivery frequency of part p in period t

L,W the length and the width of the workshop

MC_1 total material handling costs for flexible model