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Expected energy analysis for industrial process planning problem with fuzzy time parameters

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ABSTRACT

Industrial process planning is to make an optimal decision in terms of resource allocation. The planning objective can be to minimize the time required to complete a task, maximize customer satisfaction by completing orders in a timely fashion and minimize the cost required to complete a task. Based on time and energy consumption in an industrial process planning problem, a novel energy analysis method is proposed to solve it. According to different constraints and credibility theory, typical expected value models of energy for it are presented. In addition, a hybrid intelligent optimization algorithm integrating fuzzy simulation, neural network and genetic algorithm is provided for solving the proposed expected value models. Some numerical examples are also given to illustrate the proposed concepts and the effectiveness of the used algorithm.

1. Introduction

Industrial process planning intends to perform the optimal resource allocation. Its objective can include minimizing the time required to complete a task, maximizing customer satisfaction by completing orders on time and minimizing the cost required to complete a task (Li & Ierapetritou, 2008). It is one of the important and fundamental problems in industries. An industrial process planning problem concerns a series of industrial process issues, such as project planning, disassembly planning and maintenance planning.

Early industrial process planning mainly focuses on the deterministic optimization problem. Kelley (1961, 1963) presents some function relationship between project cost and activity duration times and initially formulates a type of deterministic project scheduling problems with the objective to minimize the cost. Deterministic project planning aims to develop a detailed plan specifying activity start and end times/cost in light of precedence and resource constraints. For a review of models, algorithms, classification schemes, and benchmark problems, see Bottcher, Drexl, Kolisch, & Salewski (1999), Herroelen, De Reyck, & Demeulemeester (1998), and Kolisch and Padman (2001).

However, in practice, much uncertainty may be encountered. To account for it, researchers have investigated the process planning problem with uncertain features. Charnes, Cooper, & Thompson (1964) study a stochastic project scheduling problem via chance-constrained programming, where completion time is to be minimized under some time chance constraint. Laslo, Golenko-Ginzburg, & Keren (2008) extend their model to a model with several machines. The solution of this problem is generated by a cyclic coordinate descent search-algorithm seeking the minimum total cost. A special dispatching rule is implemented in the scheduling simulation in order to simultaneously satisfy the scheduling restrictions and minimize the job-shop's expense. Bonfill, Espuna, & Puigjaner (2005) address robustness in scheduling batch processes with uncertain operation times. Kaufmann and Gupta (1988) discuss various types of project planning problems with fuzzy duration times. Ke and Liu (2010) present the project planning problem with fuzzy duration times to achieve the minimum cost. Eshtehardian, Afshar, & Abbasnia (2009) present a method to make the stochastic time-cost trade-off for the project planning problem.

Based on the above discussions, the uncertain process planning problem has been studied extensively. Most of the exiting literature addressing uncertainty has been confined to the analysis of problems under the assumption of uncertain operation time or uncertain operation cost in process planning. However, in many cases, there are two or more variables in uncertain process planning. Consider the following examples: (1) When a certain project

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task is carried out, the project duration time is uncertain, and the working power is variational when a worker or a machine performs the project task. (2) When a certain disassembly task is carried out, the removal time is uncertain due to the influence of uncertain factors, and the operation power is variational when a worker or a machine performs the disassembly task. (3) When a maintenance task is carried out, the maintenance time is uncertain, and the working power is variational when a machine performs maintenance operation activities. In order to deal with these practical problems with multiple uncertain variables, there is a need for the introduction of a new methodology for computing their minimum expected energy.

In this paper, the minimum expected energy is analyzed for process planning problems based on the credibility measure of fuzzy set theory (Liu, 2002, 2004). In addition, the extension of the proposed methodology has broad applications in the following fields such as: transportation, communication, logistics, remanufacturing and project planning.

The rest of the paper is organized as follows: Section 2 states typical expected value models of energy analysis for process planning problems. Section 3 introduces the algorithm to solve these models. In Section 4, presents some numerical examples to test the effectiveness of the used method. Finally, Section 5 concludes this work and describes future research issues.

2. Typical expected value models of energy analysis

2.1. Basic concepts

Fuzzy set theory is introduced by Zadeh (1965), and is well developed and applied in a wide variety of practical problems. In the fuzzy world, there are three important types of measures: possibility, necessity, and credibility.

Let t be a fuzzy variable with membership function μ, and let u and r be real numbers. The possibility, necessity and credibility of a fuzzy event $\{t \le r\}$ is defined respectively by

$$Pos\{t \le r\} = \sup_{t \le r} \mu(u) \tag{1}$$

$$Nec\{t \le r\} = 1 - Pos\{t > r\} = 1 - \sup_{t > r} \mu(u) \tag{2}$$

$$Cr\{t \le r\} = \frac{1}{2}(Pos\{t \le r\} + Nec\{t \le r\}) \tag{3}$$

The concept of the expected value of a fuzzy variable t can be defined as follows:

$$E(t) = \int_0^{+\infty} Cr\{t \le r\} dr - \int_{-\infty}^{0} Cr\{t \le r\} dr \tag{4}$$

For example, by a triangular fuzzy variable we mean the fuzzy variable t fully determined by the triplet (a, b, c) of crisp numbers with $a < b < c$, whose membership function is given by

$$\mu(r) = \begin{cases} \dfrac{r-a}{b-a}, & \text{if } a \le r \le b, \\ \dfrac{r-c}{b-c}, & \text{if } b \le r \le c, \\ 0, & \text{otherwise.} \end{cases} \tag{5}$$

From (1)–(3), the possibility, necessity, and credibility of $t \le r$ are presented as follows respectively:

$$Pos\{t \le r\} = \begin{cases} 0, & \text{if } r \le a, \\ \dfrac{r-a}{b-a}, & \text{if } a \le r \le b, \\ 1, & \text{if } r \ge b. \end{cases} \tag{6}$$

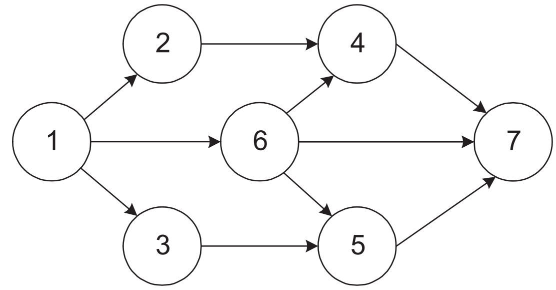

Fig. 1. Network structure graph for process planning (e.g. project planning).

$$Nec\{t \le r\} = \begin{cases} 0, & \text{if } r \le b, \\ \dfrac{r-b}{c-b}, & \text{if } b \le r \le c, \\ 1, & \text{if } r \le c \end{cases} \tag{7}$$

$$Cr\{t \le r\} = \begin{cases} 0, & \text{if } r \le a, \\ \dfrac{r-a}{2(b-a)}, & \text{if } a \le r \le b, \\ \dfrac{c-2b+r}{2(c-b)}, & \text{if } b \le r \le c, \\ 1, & \text{if } r \ge c. \end{cases} \tag{8}$$

Based on the above concepts, we can model the minimum expected energy problem with fuzzy time parameters for process planning problems.

2.2. Typical expected value models

In this paper, taking the project planning network for example, some classic expected value models are presented. In order to model the minimum expected energy problem for project planning, we give a directed acyclic network $G = (N, E)$, as shown in Fig. 1, where $N = \{1, 2, \cdots, n\}$ is the set of nodes standing for the project tasks and E is the set of directed edges. Edge $e_{ij} = (i, j)$ is a directed edge from i to j, which denotes the project i should be carried out before project j. The project operation time t_{ij} between nodes i and j is a fuzzy variable, which denotes the length of the directed edge $e_{ij} = (i, j)$. Simultaneously, the project operation power p_{ij} between nodes i and j is also a variable, which is subject to the certain range, namely $l_{ij} < p_{ij} < u_{ij}$. Where l_{ij} is the lower bound of the operation power between nodes i and j, u_{ij} is the upper bound. A feasible path can be denoted by $x = \{x_{ij} | (i, j) \in E\}$, where $x_{ij} = 1$ denotes the directed edge (i, j) locates in the path x, while $x_{ij} = 0$ denotes the directed edge (i, j) not in the path x. That is, $x = \{x_{ij} | (i, j) \in E\}$ is a path from nodes 1 to n in a directed acyclic network if and only if

$$\sum_{(i,j) \in E} x_{ij} - \sum_{(i,j) \in E} x_{ij} = \begin{cases} 1, & i = 1 \\ 0, & 2 \le i \le n-1 \\ -1, & i = n \end{cases} \tag{9}$$

$x_{ij} = 0$ or 1 for any $(i, j) \in E$.

Thus the total time and energy of completing the assigned project task along the path x can be denoted as follows, respectively:

$$T(t, x) = \sum_i \sum_j t_{ij} x_{ij} \tag{10}$$

$$W(p, t, x) = \sum_i \sum_j p_{ij} t_{ij} x_{ij} \tag{11}$$

In addition, solving the minimum expected energy becomes complex because both operation time and operation power are fuzzy. In this paper, the following approach is proposed to solve this problem: firstly, the minimal