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An improved genetic algorithm based approach to solve constrained knapsack problem in fuzzy environment

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ABSTRACT

In this paper, we have proposed an improved genetic algorithm (GA) to solve constrained knapsack problem in fuzzy environment. Some of the objects among all the objects are associated with a discount. If at least a predetermined quantity of the object(s) (those are associated with a discount) is selected, then an amount (in $) is considered as discount. The aim of the model is to maximize the total profit of the loaded/selected objects with obtaining minimum discount price (predetermined). For the imprecise model, profit and weight (for each of the objects) have been considered as fuzzy number. This problem has been solved using two types of fuzzy systems, one is credibility measure and another is graded mean integration approach. We have presented an improved GA to solve the problem. The genetic algorithm has been improved by introducing 'refining' and 'repairing' operations. Computational experiments with different randomly generated data sets are given in experiment section. Some sensitivity analysis have also been made and presented in experiment section.

1. Introduction

The knapsack problem (KP) is a combinatorial optimization problem. Objective of the KP is to maximize the total value (profit) without exceeding the maximum weight. It models a situation analogous to filling a backpack, unable to bear more than a certain weight, with all or part of a given set of objects each having a weight and value (profit). KP is one of the classic NP-hard combinatorial optimization problems with a wide range of applications (cf. Balas & Zemel, 1980; Gilmore & Gomory, 1966; Gonzalez, Hager, & Zhang, 2011; Kellerer, Pferschy, & Pisinger, 2003; Puchinger, Raidl, & Pferschy, 2010). For its variants of successful application we refer some other examples in last decades; cover resource allocation (Aisopos, Tserpes, & Varvarigou, 2013; Bretthauer & Shetty, 1997;Bretthauer, Shetty, Syam, & Vokurka, 2006), demand forecasting (Hua & Zhang, 2006), portfolio selection (Li, Sun, & Wang, 2006), network flows (Helgason, Kennington, & Lall, 1980; Ventura, 1991). Alternatively, knapsack formulation is another mathematical approach which formulates the problem of maximizing profit or utility under constrained resources and is popularly applied in business for investment optimization (Lin & Yao, 2001; Lin, 2008).

Several heuristic, meta-heuristic, local search, and hybrid algorithms have been developed by different researchers to solve KP. Chu and Beasley (1998) used the genetic algorithm for a while the best available heuristic procedure and introduced the well-known OR-Library benchmark instances. Simulated annealing based approach to 3-D packing with multiple constraints has been proposed by Daughtrey, Fennel, and Schwaab (1991) and Colaneri, Della Croce, Perboli, and Tadei (2003). Cochard and Yost (1985) developed a heuristic that first time solved the packing problem with the help of knapsack problem and then tries to balance the airplane by swapping groups of items. Klamroth and Wiecek (2000) have proposed the theoretical dynamic programing framework for the multi-objective integer KP. Jolai, Rezaee, Rabbani, Razmi, and Fattahi (2007) implemented an exact algorithm for the bi-objective 0–1 KP by exploring developments for the multi-objective linear programming problem. Figueira, Tavares, and Wiecek (2010) have proposed a generic labeling algorithm to solve multiobjective integer KP. A two-phase branch and bound algorithm has been developed by Visée, Teghem, Pirlot, and Ulungu (1998) to solve binary KP. Bazgan, Hugot, and Vanderpooten (2009) have studied an improved dynamic programming algorithm for the multiobjective KP. Baykasoglu and Ozsoydan (2014) have used an improved firefly algorithm for to solve dynamic

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multidimensional KP. On the other hand, a hybrid EDA-based algorithm have been developed by Wang, Wang, and Xu (2012) to solve multidimensional KP.

However, only a few papers have been published for fuzzy knapsack problem. For these approaches we refer the α-level based approach (Kao & Liu, 2000, 2003; Saati, Memariani, & Jahanshahloo, 2002) and possibility approach (Lertworasirikul, Fang, Joines, & Nuttle, 2003) to solve DEA knapsack problem. Liu (2008) explained a fuzzy DEA/AR approach to the selection of flexible manufacturing systems. Lin and Yao (2001) used fuzzy number in knapsack problem. Kasperski and Kulej (2007) solved the 0–1 knapsack problem with fuzzy data. Chen (2009) has described continuous knapsack problem with fuzzy weights of the objects. To the best of our knowledge we first time use credibility measure in knapsack problem. Fuzzy formulation for knapsack problem using graded mean integration (GMI) approach is also very effective and innovative in some real life situation.

In this paper, we have presented a constrained KP in imprecise environment. Here, some of the objects are available for which discount has been offered if the selected quantity is greater than a predetermined level. The model is also formulated with fuzzy profit and weight. For our problem triangular fuzzy number (TFN) is considered. Credibility measure and graded mean approach are used to deal with the fuzzy number. To solve this type of complicated problem, an improved GA has been introduced. This GA has been improved by introducing 'refining' and 'repairing' operations.

The following sections are arranged as below. Section 2 is allocated to discuss the practical significance of the problem. In Section 3, we define the proposed problem. Algorithm at a glance and algorithm for proposed problems are described in Section 4. Section 5 describes the experimental results. The paper is concluded in Section 6.

2. Practical significance of the problem

For vegetable wholesaler: Sometimes, it is observed from the market that a vegetable wholesaler/retailer collects vegetable from different farmers using a van with limited capacity (carry limited weight). In some of the cases some farmer gives free/gratis (in $) to the wholesaler if he/she purchases above a certain amount of vegetable. For example, 2$ is discounted from the total amount of purchased cost, if 40 kg of cucumber (we assume that there is a total of 50 kg cucumber) is purchased; otherwise, no discount is permitted. In other word, it is one type of discount, i.e., discount is to be given when at least a minimum amount of vegetables is purchased from farmer. Selling maximum vegetables with gratis is beneficial to the farmers, as we know that such type of vegetables is usually dried/wastage/disillusioned after one or two days. Again we know that for different vegetables there are different profits. For example, Iceberg lettuce is less profitable than Garlic bulbs, etc. For this system our proposed model is very useful.

For cold storage policy: In a cold store, there are different cabin with different accommodation (temperature, light, ice, etc.) and different fruits, vegetables, and other storable materials are stored in different cabin according to needs. Again, we know that for different facility cabin accommodation expense is different and every store have limited capacity of storing materials. So the managers of cold store try to store such storable materials that are profitable on the basis of storing charge, because we know that for some valuable fruits and vegetables storing charge is high (extra charge is considered), i.e., storing profit is high for store owners. Sometimes, it is observed that if farmers/cultivators or a business person stores large amount of vegetables in a store then some less/discount is considered for him/her. We hope for this type of storing management our proposed model is very helpful.

3. Mathematical prerequisite

In this section we have explained the mathematical prerequisite for fuzzy models of credibility measure and graded mean integration.

Fuzzy number: A fuzzy number is a generalization of a regular, real number in the sense that it does not refer to one single value but to a connected set of possible values, where each possible value has its own weight between 0 and 1. This weight is called the membership function. A fuzzy number is thus a special case of a convex, normalized fuzzy set of the real line.

Triangular fuzzy number (TFN): A TFN $\tilde{a} = (a_1, a_2, a_3)$ has three parameters a_1, a_2, and a_3, where $a_1 < a_2 < a_3$ and is characterized by the membership function $\mu_{\tilde{a}}$, given by

$$\mu_{\tilde{a}}(x) = \begin{cases} \frac{x-a_1}{a_2-a_1} & \text{for } a_1 \leqslant x \leqslant a_2 \\ \frac{a_3-x}{a_3-a_2} & \text{for } a_2 \leqslant x \leqslant a_3 \\ 0 & \text{otherwise.} \end{cases}$$

3.1. Credibility measure

Optimistic values and pessimistic values: In order to rank fuzzy variables, we may use these two types (optimistic and pessimistic) of critical values.

Definition (Liu, 2002): Let $\tilde{\xi}$ be a fuzzy variable, and $\alpha \in (0, 1]$. Then

$$\tilde{\xi}_{\sup}(\alpha) = \sup\{r \mid Cr\{\tilde{\xi} \geqslant r\} \geqslant \alpha\}$$

is called the α-optimistic value to $\tilde{\xi}$, and

$$\tilde{\xi}_{\inf}(\alpha) = \inf\{r \mid Cr\{\tilde{\xi} \leqslant r\} \geqslant \alpha\}$$

is called the α-pessimistic value to $\tilde{\xi}$.

From the definition we may say that the fuzzy variable $\tilde{\xi}$ will reach upwards of the α-optimistic value $\tilde{\xi}_{\sup}(\alpha)$ with credibility α, and will be below the α-pessimistic value $\tilde{\xi}_{\inf}(\alpha)$ with credibility α. It is also true that the α-optimistic value $\tilde{\xi}_{\sup}(\alpha)$ is the supremum value that $\tilde{\xi}$ achieves with credibility α, and the α-pessimistic value $\tilde{\xi}_{\inf}(\alpha)$ is the infimum value that $\tilde{\xi}$ achieves with credibility α.

Lemma 1. *Let $\tilde{\xi}$ be an equipossible fuzzy variable on (a, b). Then its α-optimistic and α-pessimistic values are*

$$\tilde{\xi}_{\sup}(\alpha) = \begin{cases} b, & \text{if } \alpha \leqslant 0.5 \\ a, & \text{if } \alpha > 0.5, \end{cases} \quad \tilde{\xi}_{\inf}(\alpha) = \begin{cases} a, & \text{if } \alpha \leqslant 0.5 \\ b, & \text{if } \alpha > 0.5. \end{cases}$$

Lemma 2. *Let $\tilde{\xi} = (a, b, c)$ be a triangular fuzzy variable. Then its α-optimistic and α-pessimistic values are*

$$\tilde{\xi}_{\sup}(\alpha) = \begin{cases} 2\alpha b + (1-2\alpha)c, & \text{if } \alpha \leqslant 0.5 \\ (2\alpha-1)a + (2-2\alpha)b, & \text{if } \alpha > 0.5, \end{cases}$$

and

$$\tilde{\xi}_{\inf}(\alpha) = \begin{cases} (1-2\alpha)a + 2\alpha b, & \text{if } \alpha \leqslant 0.5 \\ (2-2\alpha)b + (2\alpha-1)c, & \text{if } \alpha > 0.5. \end{cases}$$

3.2. Graded mean integration approach

Graded mean integration representation (GMI) of fuzzy number:

Chen and Hsieh (2000) introduced GMI method based on the integral value of graded mean α-level of generalized fuzzy number. The graded mean α-level value of generalized fuzzy number