Expert Systems With Applications 81 (2017) 12–21

Contents lists available at ScienceDirect

Expert Systems With Applications

journal homepage: www.elsevier.com/locate/eswa

A multi-start algorithm to design a multi-class classifier for a multi-criteria ABC inventory classification problem

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ARTICLE INFO

Article history:
Received 24 June 2016
Revised 1 October 2016
Accepted 18 February 2017
Available online 16 March 2017

Keywords:
Multi-criteria ABC inventory classification
Multi-class classification
Neural networks
Multi-start algorithm

ABSTRACT

In this paper we deal with the problem of designing a classifier able to learn the classification of existing units in inventory and then use it to classify new units according to their attributes in a multi-criteria ABC inventory classification environment. To solve this problem we design a multi-start constructive algorithm to train a discrete artificial neural network using a randomized greedy strategy to add neurons to the network hidden layer. The process of weights' searching for the neurons to be added is based on solving linear programming formulations. The computational experiments show that the proposed algorithm is much more efficient when the dual formulations are used to find the weights of the network neurons and that the obtained classifier has good levels of generalization accuracy. In addition, the proposed algorithm can be straight applied to other multi-class classification problems with more than three classes.

1. Introduction

In this paper we deal with the problem of designing a classifier able to learn the classification of existing units in inventory and then use it to classify new units according to their attributes in a multi-criteria ABC inventory classification environment.

Effective inventory management is a critical element to the efficiency of the Supply Chain Management operations, providing a competitive advantage to the company into the business. The number of Stock-keeping Units (SKU) is always a difficult decision for any company. There are thousands of items in an inventory and it is economically infeasible to have control over all of them. In order to handle this problem arises the ABC analysis in inventory management. This technique was derived from Wilfredo Pareto's famous observation about the distribution of national incomes in Italy (Chen, Li, & Liu, 2008).This classification analysis is based on the idea that a large part of all costs are represented for a few inventory items.

The ABC analysis consists on dividing items into three categories (A, B or C) based on their annual dollar usage. Group A is the most valuable items group. Items of this group represent the 80% of the annual total cost, but only the 20% of the total inventory items. Group B is formed by inventory items with annual cost about 15% of the total cost. This group has the 30% of the total inventory items. Finally, C group has the items with the lowest annual cost, approximately 5% of the total. This last group is the biggest in total inventory items, it represents the 50%.

Because of its easy-to-implement nature and its applicability to numerous situations, this technique is still popularly used in practice (Keskin & Ozkan, 2013). However, nowadays it is known that classification of items using a single criterion (the annual dollar usage of the items) can generate troubles to the company, since there are other criteria, both quantitative and qualitative, that are important for decision-making process at the inventory management such as ordering costs, logistics costs, stock-out penalties and obsolescence costs (Torabi, Hatefi, & Pay, 2012). This situation has triggered the emergence of the Multi-criteria inventory classification (MCIC).

MCIC was proposed in the eighties decade by Flores and Whybark (1987). They introduce this concept in order to explain that inventory management based on a single criterion could turn into difficulties when the decision maker has to consider several important dimensions to control the situation. Despite their research included a classification method for only two criteria, their approach

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http://dx.doi.org/10.1016/j.eswa.2017.02.048
0957-4174/

established the beginning for further proposed multi-criteria methods.

The MCIC problem can be considered as a particular case of the multi-class multi-attribute classification (MCMAC) problems and in this context there are two well defined problems.

The first problem is to determine which class belongs each item, that is, to group items into classes according their attributes. In a general MCMAC problem, classes are defined by non-linear boundaries in attribute space. This problem is known as a clustering problem in Data Mining, while in Machine Learning it is referred as an unsupervised learning problem.

Having all existing items grouped into classes, the second problem arises when it is necessary to assign new units to previously defined classes. In the general MCMAC environment, the problem consists on training a classifier able to learn the classes' characterization in order to decide to which class belong the new items. This problem is a classification problem in Data Mining and a supervised learning problem in a Machine Learning context and in general, it consists on finding good approximations of the defining class boundaries.

In the multi-criteria inventory classification context we named these problems as *a priori* and *a posteriori* MCIC problems, respectively. We make this distinction because we observed that they are not well differentiated in the MCIC literature. We believe that using this distinction it is easier to put in order the literature review and it would be clearer in what problem is focused our work.

Taking into account the above, in a MCIC environment, for decision-makers the problem is not finished with the classification of all the inventory items as new unclassified items frequently come to the warehouse. When the ABC classification is based on a single criterion it is very easy to classify new SKUs, because the classification is made using a single variable ranges. In multi-criteria classification the problem is more complex, since it is necessary to know the characterization of each class in the criteria space and thus to find which class each new SKU belongs.

The most common approaches for solving the *a priori* MCIC problem are AHP-based methods and weighted linear optimization models that are taken from Multi-Criteria Optimization. The main goal of these methods is to reduce the multi-criteria problem to a single criterion one by determining weights for criteria and a single score used to assign items to classes. Usually, these methods do not consider the classification of new SKUs and the current solution may change if new SKUs are considered.

When the *a priori* MCIC problem is solved by reducing it to a single criterion problem, the *a posteriori* MCIC problem is very easy to solve. The main disadvantage of this approach is that lot of information about classes' characterization could be lost in the process of reducing the multi-criteria problem to a single criterion one. A more accurate approach is to consider the *a posteriori* MCIC problem as an approximation problem and to solve it using back-propagation neural networks or support vector machines with non-linear kernel functions.

The purpose of this work is to develop a method for solving the *a posteriori* MCIC problem keeping the discrete essence of the classification problem and without transforming or reducing it to another kind of problems. Then, in order to solve the ABC multi-criteria inventory classification problem, we design a method for training a three-layer neural network with discrete activation functions to learn a previously defined classification.

The main contributions of the present work can be summarized as:

- This is the first work designing a classifier based on neural networks with discrete activation functions to keep discrete essence of the *a posteriori* MCIC problem.
- In order to minimize the neural network size, we design a training method based on a multi-start constructive algorithm that uses a randomized greedy strategy to add neurons to the network hidden layer.
- As the neurons' weights are obtained by solving Linear Programming formulations, in order to speed up the training process and solve large data instances we solve the corresponding dual formulations.

The remainder of this paper is organized as follows: Section 2 presents a literature review about *a priori* and *a posteriori* MCIC problems. Some general concepts about neural networks for classification and foundations for the proposed solution method are presented in Section 3. Section 4 describes the proposed solution method based on a multi-start algorithm as well as some improvements made to accelerate the solution process. Section 5 reports the computational experiments and Section 6 provides conclusions and remarks for future research.

2. Multi-criteria inventory classification

In this section we present a literature review about methods for solving the *a priori* and the *a posteriori* inventory classification problem.

Regarding to the *a priori* MCIC problem, Flores, Olson, and Dorai (1992) proposed the use of the Analytic Hierarchy Process (AHP) to reduce the multiple criteria to a univariate and consistent measure to consider multiple inventory management objectives and provided a multi-criteria dataset that has been used in almost all subsequent researches about multi-criteria ABC inventory classification. A very similar approach was used by Partovi and Burton (1993) to evaluate several, qualitative and quantitative, criteria on inventory classification. Guvenir and Erel (1998) developed a method to learn criteria weights based on genetic algorithm and proposed a clusters' generation in order to classify items using these weights. Braglia, Grassi, and Montanari (2004) integrated a decision diagram with a set of AHP models that are used to solve various multi-attribute decision sub-problems at the different levels/nodes of the decision tree and developed an inventory management policy matrix to link the different classes. Doumpos and Zopounidis (2004) proposed a method based on pairwise comparisons that incorporates the preferential information on the decision-maker judgement policy. Huiskonen, Niemi, and Pirttil (2005) developed a flexible tool, based on a self-organizing map, to establish management strategies to C-products, in order to get control in their impact on the customer-service.

In the last decade the *a priori* multiple criteria ABC inventory classification problem has continued being intensively studied. Bhattacharya, Sarkar, and Mukherjee (2007) presented a way of classifying inventory items using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) model and compared their model with other ABC classification techniques. Rezaei (2007) proposed a method using a fuzzy analytic hierarchy process to calculate a normalized weight score to perform the items' classification. Cakir and Canbolat (2008) extended the Rezaei (2007) model with a real inventory data and decision makers application. Jamshidi and Jain (2008) obtained a weight for each criterion based on simple exponential smoothing weight assignments and calculated a normalized score to make the items' classification. Chu, Liang, and Liao (2008) proposed a ABCfuzzy inventory control approach which can handle variables with either nominal or non-nominal attribute, to incorporate manager's experience and judgement into inventory classification. Rezaei and Dowlatshahi (2010) considered a ruled-based measurement system based on fuzzy logic taking into account ambiguities that commonly exist in the reasoning process. Chen (2011) proposed an im-