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System with probabilistic fuzzy knowledge base and parametric inference operators in risk assessment of innovative projects

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ABSTRACT

This paper presents the properties, identification issues and utilisation of a new concept of probabilistic fuzzy system for the innovative project risk assessment. This system constitutes the extension of Mamdani probabilistic fuzzy system. For this purpose, a group of risk factors, which influence risk variables, has been chosen. Linguistic risk variables are inputs to the innovation risk assessment system. The structure of fuzzy sets for linguistic values takes into account knowledge of a number of experts. Knowledge is presented as fuzzy IF–THEN rules together with probability measures of fuzzy events occurrence in the antecedent and conclusion of rules. The paper presents a new method of identification of the analysed system. The method uses parametric family of triangular t-norms, which facilitates inference parameters optimisation, enables flexible adjustment of a system to empirical data and makes the system more precise. The modified FP-Growth algorithm to create probabilistic fuzzy rule base is used. Using assumption of the minimal support of rules enables decreasing of knowledge base complexity while preserving the level of identification quality, comparable to the system with full marginal and conditional probability distributions. The results of the system inference have been compared with regression model and Mamdani fuzzy inference system. Finally, the numerical experiments show more precision of system inference than the compared method. The example of analytical use of created probabilistic fuzzy knowledge base in the context of technical innovation risk assessment is also presented.

The constructed expert system has an identification character and it can be develop as a tool to help the assessment of applications for funding the implementation of innovative projects by the institutions established for this purpose.

1. Introduction

Innovations constitute the main source of creating competitive advantage of a company. The basic reason for this statement is a strong need of distinguishment among companies and the need of surprising consumers with new products. Introducing innovations is not easy though and it carries the necessity of making high-risk decisions. It is mainly caused by high costs, long realisation period and still not verified technology. Skilful risk management in a company, which decided for implementing innovation, should be analysed in a systematic and planned manner (Knosala, Boratyńska Sala, Jurczyk-Bunkowska, & Moczała, 2014).

In recent years, the task of fuzzy risk analysis has been studied in the number of approaches. Chen (1996) used simplified fuzzy number arithmetic operations to subjective mental workload assessment and fuzzy risk analysis. Wang and Elhag (2006) presented the fuzzy TOPSIS (Technique for Order Preference using Similarity to Ideal Solution) method based on alpha level sets and a nonlinear programming optimisation. Pisz (2011) used traditional fuzzy inference system to project risk assessment with hierarchical structure of risk factor. A number of approaches have used generalised fuzzy numbers and its similarities to deal with fuzzy risk analysis. For example, some methods were proposed by Chen and Chen (2007), Hejazi, Doostparast, and Hosseini (2011), Wei and Chen (2009) and Xu, Shang, Qian, and Shu (2010). They provided some new similarities of generalised fuzzy numbers and some new arithmetic operators. The other approach to fuzzy risk assessment is to use artificial intelligence in failure and effect analysis method. A large literature review about this methods were presented by Liu, Liu, and Liu (2013). Fuzzy rule-base system has been also often used to fuzzy risk assessment (Idrus, Nuruddin, & Rohman, 2011; Li, Huang, Zengc, Maqsoodd, & Huange, 2007;

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Pisz, 2011). However, much less publications are available in the literature that discuss the issue of joining together fuzziness and randomness in one conception of the system to risk assessment. Recently, several authors (Almeida & Kaymak, 2009; Dutta, 2015; Qin, 2012; Tatari, Akbarzadeh-T, & Sabahi, 2012) have proposed a probabilistic fuzzy approach to risk assessment. To the authors' knowledge, the probabilistic fuzzy system has been scarcely investigated from the point of view of application to the innovative project risk assessment.

The risk of project realisation is connected with uncertainty concerning the success of introduction of new technological solutions as well as uncertainty concerning external factors such as the possibility of obtaining new financial means, competitors' actions, demand for innovations, acceptance of customers, economic situation etc. The uncertainty may be classified both in probabilistic as well as fuzzy categories (Zadeh, 1995). Probabilistic uncertainty concerns limited possibility of prediction of future proceedings and objects performance such as competition, customer, designed technological system, environmental factors etc. Fuzzy uncertainty is connected with verbal determination of events. Words can have various meanings for various people (experts) who are members of teams working on an innovative project.

Theoretical discussions and basic research concerning relations between randomness and fuzziness as well as probabilistic interpretations of fuzzy sets may be found in literature (Czogala & Hirota, 1986; Dubois & Prade, 1986; Kosko, 1990; Laviolette & Seaman, 1994; Liang & Song, 1996; Ralescu & Ralescu, 1984; Wang, 1983; Yager, 1999; Zadeh, 1968). In the last years a lot of attention has been paid to the possibility of joining mentioned uncertainties in one concept of a system. There are various solutions. Some authors (Chen & Xiao, 2011; Li, Duan, & Liu, 2010; Liu & Li, 2005) design models with using directly probabilistic fuzzy sets, characterised by a three-dimensional membership function. This concept has the drawback of hindered analysis of the problem directly based on the interpretation of the rules, since the multi-dimensional description of the membership function reduces the readability of rules. Others join the probabilistic and fuzzy sets theories in order to extend the traditional fuzzy rule-based model by probabilistic measures (Almeida & Kaymak, 2009; Almeida, Verbeek, Kaymak, & Sousa, 2014; Hengjie et al., 2011; Lee, Park, & Bien, 2008; Meghdadi & Akbarzadeh-T, 2001; Sozhamadevi & Sathiyamoorthy, 2015; Tang, Chen, Hu, & Yu, 2012). The latter approach, which is taken into account in the paper, is more favourable as far as knowledge base interpretation is concerned (Lee et al., 2008). The presentation of fuzzy rules with the probability of proper fuzzy events directly in the model enables an easy analysis of cumulated knowledge and direct rule modification with the use of both expert's knowledge and empirical data. In this approach, we can note also that models consist of a set of if–then rules, where the antecedent of each rule are fuzzy sets and the consequents are Generalized Autoregressive Heteroskedasticity (GARCH) models (Almeida, Baştürk, Kaymak, & Sousa, 2014; Hung, 2011). The Mamdani probabilistic fuzzy system is used most often (Almeida & Kaymak, 2009; Almeida, Verbeek, et al., 2014; Tang et al., 2012). The mentioned system models reality as fuzzy rules using probability measures to define conditional frequency of fuzzy events occurrence in conclusion, so they contain only information about output's conditional probability distribution. In order to describe more broadly the uncertainty of chosen innovative risk constituents, the proposed approach uses additionally probability measure for fuzzy events in antecedents of rules as the empirical marginal probability distribution. A different representation of knowledge has been taken from Walaszek-Babiszewska (2007, 2011). In this model the probability of fuzzy events is determined as numerical value from the range [0,1]. The new approach to determine the stochastic dependence of fuzzy random variables as copula has shown in Stupňanová (2015). This approach to the presentation and analysing of the fuzzy probabilities in the system would be difficult to use, due to large multidimensionality of dependence.

The concept of inference system with probabilistic fuzzy knowledge base (PFIS) and the way of constructing the model have been described by the author in Rudnik and Walaszek-Babiszewska (2012) and Rudnik (2013). The representation of knowledge, which contains the full marginal and conditional probability distribution has a significant disadvantage – large increase in the number of rules. Furthermore, the result of the inference method is often not precise, due to the wrong choice of parameters inference. Considering the above drawbacks, a new identification method of the system is suggested in the paper. The identification method uses parametric inference operators which enable the flexible adjustment of the system to empirical data. Parametric triangular t-norms give the possibility to obtain hyper plane of values from a drastic t-norm to Zadeh t-norm, so the inference operators can be optimised. Beyond that, the method aims at reducing the number of rules. The proposed identification method is used to present the constructing of flexible inference system with probabilistic fuzzy knowledge base as a new concept of the system for innovative projects risk assessment.

The paper is organised as follows. In Section 2, the characteristics of innovation and innovative risk are presented. The basic probabilistic fuzzy approach is given in Section 3. The construction of inference system with probabilistic fuzzy knowledge base and the method of its identification with the use of parametric inference operators are described. The modified FP-Growth algorithm to create probabilistic fuzzy rule base is presented in Appendix A. The details of a probabilistic fuzzy system construction for innovative risk assessment are given in Section 4. In Section 5, the simulation results and discussion are presented to demonstrate the effectiveness and applicability of the probabilistic fuzzy system. The conclusions are reported in Section 6.

2. Notion of innovation and innovative risk

The term "innovation" comes from a Latin word *innovatio* and means renewal. It was introduced to economic sciences by J.A. Schumpeter who determined five possible situations connected with the essence of innovation (Godin, 2008; Schumpeter, 1934). Literature describes innovations from technical, economic and organisational point of view. The notion "innovation" relates to both processes and results of a given action (innovation as a result). The condition for using the notion is having the feature of a novelty (also understood as the first usage in a given space) and the possibility of its direct usage in order to gain certain social and economic profits. For this reason not every innovation must be a novelty in the strict sense, it may mean that this is a new product on the national, regional or the company level (Bukowski, Szpor, & Śniegocki, 2012; Gopalakrishnan, Bierly, & Kessler, 1999; Knosala et al., 2014; Manuel, 2007; Roy & Riedel, 1997; Taran, 2011; Vonortas & Xue, 1997).

In literature there are classifications of innovations resulting from the author's individual approach to the researched problem. The paper presents technical innovations risk assessment. Technical innovations concern technical and technological changes which lead to, most often, product or process innovations (Budziński & Mróz, 1998; Janasz, 1994; Janasz & Kozioł-Nadolna, 2011; Landwójtowicz & Knosala, 2014; Sosnowska et al., 2005).

The realisation of an innovative project is connected with different types of risk. The most important ones are those which result in failure of the goal achievement assumed by the company. It indicated that an effective implementation of innovations requires