A Hybrid DEA-Fuzzy Method for Risk Assessment in Virtual Organizations

Fernanda Sales Bittencourt de LEMOS, Rafael Giordano VIEIRA,
Adriano FIORESE and Omir Correia Alves JUNIOR

Department of Computer Science, Santa Catarina State University,
R. Paulo Malschitzki, Joinville, Brazil
**E-mail: dcc6fsbl@joinville.udesc.br*
www.cct.udesc.br

The Virtual Organization (VO) concept has emerged as one of the most promising forms of collaboration among companies by providing a way of sharing their costs, benefits and risks, in order to attend particular demands. Although these advantages, VOs face several risks that need to be identified, measured, and mitigated through a well defined process. In this way, this paper proposes a hybrid DEA-Fuzzy method for analyzing risk in VO formation. This method assesses the level of risk present in a set of previously selected Service Providers (SPs) using Key Performance Indicators (KPIs), providing a way to helping decide on the VO formation.

Keywords: DEA, Fuzzy Logic, Risk Analysis, Virtual Organizations

1. Introduction

Nowadays, small and medium enterprises (also called SMEs) need to specialize themselves and collaborate in order to increase their value and compete in the global market. The concept of Virtual Organization (VO)[1] emerges from this scenario, where autonomous, heterogeneous and usually geographically dispersed companies can collaborate to form a dynamic alliance, in order to attend to certain demands, sharing costs, benefits and risks, acting as one single enterprise.[2]

Regarding this work, a VO is composed of Service Providers (SPs)[3] that have previously agreed to collaborate in a mutual goal, also referred to as Collaboration Opportunity (CO).[4] In spite of some benefits, VOs have to face higher risks than other general forms of organization that, in part, come from the increasing sharing of responsibilities among companies and the dynamic nature of their relationships.[5,6] Faults in some SPs can affect other partners and lead the given VO to fail in its goals.[6] Therefore, it is very important to measure the risk of each SP, and consequently to the overall VO, for further decision-making.

In this sense, this paper complements the proposal of Ref. 7, proposing a new method to evaluate the risk in VO formation process, given a set of pre-selected SPs, taking into account its Key Performance Indicators (KPIs). For this purpose, the proposed method makes use of Data Envelopment Analysis (DEA)[8] and Fuzzy Sets Theory (FST).[9]

The rest of this paper is organized as follows: Section 2 presents related work. Section 3 specifies the proposed risk analysis method. Finally, Section 4 concludes and discusses future works.

2. Related Work

In the state of the art review, some works related to risk analysis using a wide range of strategies have been identified. Ref. 10 presents a survey mainly focusing on fuzzy risk assessment approaches in projects as a whole. In Ref. 11, the authors considered the fuzzy features and the project organization mode of VOs to propose Multi Strategy Multi Choice (MSMC) risk programming models. Specifically in the VO context, Ref 12 proposes an ETA-FTA based method to measure the risk in VO formation process.

Unlike the Ref. 12, the relative efficiency obtained by DEA allows to know whether there is better SPs that could be selected instead of what was selected for a given service, which may be useful in decision making. Moreover, this paper takes into account the impact of each service on the overall VO risk, which is suitable in real circumstances, where VO partners are often heterogeneous and have different priorities.

Regarding to the classical main phases of a VO lifecycle (creation, operation, evolution and dissolution phases),[4] this paper focuses specifically on Partner's Search and Selection step, which is part of the creation phase. However, sources of risks should be identified and risks measured having in mind the whole VO lifecycle.[13] There are four main sources of risks regarding VOs: trust, communication, collaboration and commitment.[5] In this work, they are modeled as KPIs, and their values are calculated and provided accordingly Ref. 7.

3. The Hybrid DEA-Fuzzy Method

In general, this method aims to measure the risk of n SPs to form a VO, basing on their individual risk levels. The individual risk calculation initiates with DEA,[8] that is a nonparametric programming approach for measuring and evaluating the relative efficiency of a set of units with similar attributes. In this context, the term "efficiency" is related to the unit ability to produce the maximum outputs using the minimal inputs, i.e., to maximize the ratio output/input.[14] Therefore, since the efficiency of an SP is related to the risk of unfulfilling the VO requirements, it is necessary to view the problem in terms of inputs and outputs as to make possible the risk measurement.

3.1. *Calculating DEA input/output values*

The process for calculating the inputs of each SP is carried out by repeated calculations of linear regressions, as seen in Figure 3.1. More specifically, for each KPI, is calculated a linear regression for the first participation in a VO, to estimate the value of the second, and then for the first two, to estimate the value of the third, and so until the $m-1$ participations, where is estimated the value of the last participation. The procedures for obtaining the input and output values will be presented as follows:

Let $K = \{K_1, K_2, K_3, K_4\}$ the set of KPIs earlier mentioned (trust, communication, collaboration and commitment), respectively. Let also $H_{ki} = \{h_1, h_2, ..., h_m\}$ the set of historical (real) values and $X_{ki} = \{x_2, ..., x_m\}$ the set of estimated values of the KPI i for the SP k on the m past VOs.

Equation 1 presents the average of estimated values, which are calculated by the linear regressions, i.e., the average of all dotted bar values shown in Figure 1:

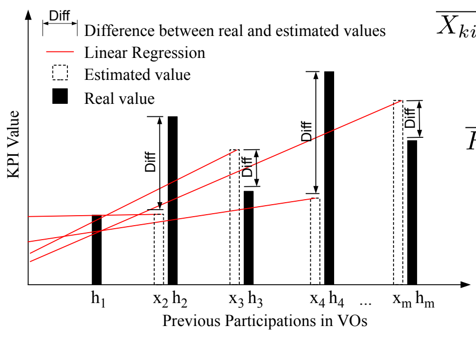

Fig. 1: Calculating the input values of a given SP using its historical values.

$$\overline{X_{ki}} = \sum_{j=1}^{m-1} \frac{\alpha(j) + \beta(j) * (j+1)}{m-1} \quad (1)$$

$$\overline{H_{kj}} = \sum_{i=2}^{m} \frac{h_i}{m-1}, h_i \in H_{kj} \quad (2)$$

$$I_{ki} = \overline{X_{ki}} + \sigma(X_{ki}) \quad (3)$$

$$O_{kj} = \overline{H_{kj}} - \sigma(H_{kj}) \quad (4)$$

where $\alpha(j)$ and $\beta(j)$ are, respectively, the slope and linear coefficient of the

j_{th} past participation of the $SP\ k$ in a given VO for the KPI i. Next, the calculation of the output values is done through averaging all the historical (real) values from the second participation forward, as in the Equation 2.

It is also worth to consider the real and estimated variations for the historical values of a given SP. These variations are represented by the standard deviations of the two averages (estimated and real), and acts over the input and output values as a factor for increasing or decreasing the efficiency of an SP, as seen in Equations 3 and 4, respectively.

In fact, this process is based on a difference between the real value of the KPIs on previous SP's participations in VOs and its estimated values, as seen in Figure 1. Therefore, the more the estimated values are higher than the real ones, the riskier are the SP. At the same time, the more variation has in a given historical series, the more risky are the SP too. Since obtained, the input and output values are applied to the DEA method to calculate the SPs' efficiency, whose process will be explained in the following.

3.2. *Evaluating efficiencies with DEA*

The DEA model named BCC[15] was designed to measure the relative efficiency of units with variable returns to scale, i.e., units whose the increase in their inputs does not result in a proportional change in the outputs. For this reason, the BCC is a suitable model for the problem in question, and can be represented by Linear Programming (LP), as shown in P.1:

$$\text{(P.1)} \quad \begin{aligned} & \min z = \sum_{i=1}^{r} v_i I_{oi} + v_* && (5) \\ & \text{s.t.} \sum_{j=1}^{s} \mu_j O_{oj} = 1 && (6) \\ & \sum_{i=1}^{r} v_i I_{ki} - \sum_{j=1}^{s} \mu_j O_{kj} + v_* \geq 0, k = 1, ..., N_o && (7) \\ & v_i, \mu_j \geq 0, v_* \in R \end{aligned}$$

where I_{ki} and O_{kj} are the input i and output j of the SP k, respectively, and v_i and μ_j are the weights; v_* is a real scale factor; N_o is the number of SPs that offer the same service as the SP o. Since calculated the weights, Equation 8 results the efficiency of the SP o.

$$Eff_o = \frac{\sum_{j=1}^{s} u_j O_{oj}}{\sum_{i=1}^{r} v_i I_{oi} + v_*} \quad (8)$$

3.3. *Fuzzy Approach*

The Fuzzy Sets Theory (FST)[9] is specially helpful when involving human assessment, which is the case of risk management, where humans usually evaluate the risk by using linguistic expressions like "high" or "low".[16] Further, in the VO environment, humans judge the performance of their partners. Hence, this work uses FST to measure the risk of a VO failure due to a particular SP. This analysis take into account two factors: 1) *efficiency of the SP*; 2) *the impact of an isolated failure of the service on the failure of the whole VO.* The first factor is obtained by DEA on the previous step. Nevertheless, it is a human VO manager the responsible for determine the another factor, being another reason to use FST. The triangular shape, which is commonly used in membership functions,[16] is used in this work to all fuzzy sets and is presented in the Figure 2.

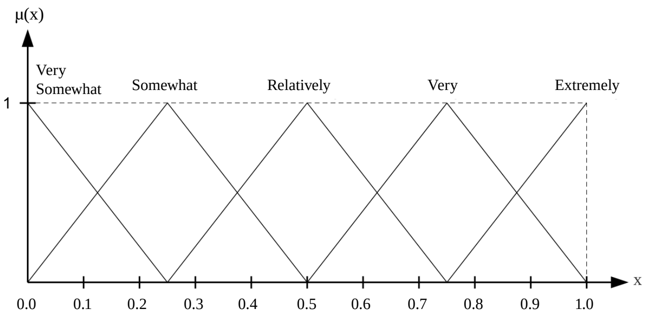

Fig. 2: Membership function for all the fuzzy sets.

For a given collaboration opportunity that a VO responds, the failure of a service can be more harmful to overall VO operation than others. In this way, the more critical is a service, the less its provider can run the risk of failing. Otherwise, the greater the risk of compromising the entire VO. These relations between the factors must be translated into IF-THEN Fuzzy Rules, which along with fuzzy sets, forms the knowledge base of the inferencing system.[17] For example, "*IF service is extremely important AND the provider is relatively efficient THEN the VO is very risky*". The Table 1 presents a possible set of rules that comprises the causal relations between the factors, where each acronym corresponds to a fuzzy set. The "*E*" suffix means "*Efficient*", "*I*" means "*Important*" and "*R*" means "*Risky*", and the prefix "*E*" means "*Extremely*", "*V*" means "*Very*" , "*R*" means " *Relatively*", "*S*" means "*Somewhat*" and "*VS*" means "*Very Somewhat*".

Hence, given the SPs' efficiency obtained by DEA and the importance

Table 1: Fuzzy rules showing the influence of the relation between efficiency of an SP and the importance of its service over the VO risk as a whole.

Service Importance	Provider Efficiency				
	Extremely (EE)	Very (VE)	Relatively (RE)	Somewhat (SE)	V. Somewhat (VSE)
Extremely (EI)	RR	VR	VR	ER	ER
Very (VI)	SR	RR	VR	VR	ER
Relatively (RI)	SR	SR	RR	VR	VR
Somewhat (SI)	VSR	SR	SR	RR	VR
V. Somewhat (VSI)	VSR	VSR	SR	SR	RR

of services on the CO accomplishment, the fuzzy inferencing process (Fuzzification → Inference → Deffuzification)[17] must be carried out n times, and for each run, the outcome of the process is the risk R_i of the VO fails due to a failure of the SP i. The defuzzification process is based on the well-known Center of Gravity (COG) method. Finally, the VO global risk, i.e., the risk of the VO failing, is calculated by averaging R_i for $i = 1, ..., n$.

4. Conclusion

In general, risk analysis has become an inherent problem in Virtual Organization (VO) formation since bad choices can lead to impairment as a whole. Therefore, the definition of strategies for risk assessment are key to ensure the success of the VO. In this way, the main contribution of this paper is a hybrid DEA-Fuzzy method to measure the risk of a set of Service Providers (SPs) to compose a VO.

One of the main contributions of the proposed method it is the relative efficiency calculated by DEA. With this, it is possible to compare a given preselected SP with all the others nonselected SPs of the same service, which allows to know whether, among all the others possibilities of partners, it is a good choice or not. This is interesting because a selected SP with low efficiency can still be the best available, being its discard useless. Moreover, this proposal enables to prioritize the services according to their real importance for the VO success, being advantageous the use of FST, which supports the handling of imprecise data given by humans (e.g. partners and VO managers). In real circumstances, experts can modify the fuzzy rules to fit them the VO interests. The method to input and output determination that considers the variation of the SPs' historical data comprises another contribution of this work. In this way, the risk of a provider is related not only to its performance level, but also to its predictability.

As a future work, the method will be tested in near-real scenarios in order to compare it with other methods that have the same goal. Moreover, it is intended to test different fuzzy rules.

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