A Risk Analysis Method to Support Virtual Organization Partners' Selection

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Abstract. 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 to demands. When manufacturing processes and physical distribution of products are involved, the process of VO creation demands the selection of both Logistic Partners and Industrial Partners. However, this wider VO composition requires several aspects to be considered to ensure the VO correct operation, synthesized in the form of risks. Proper risk analysis provides more solid means to managers evaluate and further decide about the more suitable VO composition for a given business. This work presents an integrated and quantitative risk analysis method to support the Partners' Search and Selection process within the VO creation phase. A set of supporting algorithms have been developed to measure the risk considering a number of risk categories and performance indicators. A general example is showed and results are discussed at the end.

1 Introduction

Virtual Organization (VO) has emerged as a powerful enterprising strategy to leverage Small and Medium sized Enterprises to increase their value and better compete in the market [1]. This is possible due to its intrinsic properties, which provide more systematic forms of collaboration within more dynamic business scenarios, involving autonomous, heterogeneous and geographically dispersed companies to join their efforts with the aim of attending given demands, sharing costs, benefits and risks, acting as one single enterprise [1].

One of the several issues related to VOs refers to how its members are selected. Most of works in the literature see VO members as being all the same type. However, when the business involves manufacturing processes along a value chain, the partners should be considered and in a different way as they have different requirements, starting to see them as partners and not as decoupled companies from the VO. Therefore, in this work a VO is seen as a composition of Logistic Partners (LPs) and Industrial Partners (IPs).

As such, it is assumed that they have previously agreed on collaborating upon a mutual goal, the so-called Collaboration Opportunity (CO) [1]. From the logistics theory point of view, by LP it is considered the types 2PL and 3PL [2], responsible for the transportation, delivering and intermediate storage of products. IPs are the ones responsible for the manufacturing processes of the product associated to the demand, i.e. the CO. It is also assumed that both LPs and IPs are members of a long-term alliance like a Virtual Organization Breeding Environment [3] – VBE, so sharing some basic and common principles of collaboration, working, quality and performance.

Several works in the literature have approached the problem of selecting partners via an analysis focused on members' competences and capabilities [4–6]. However, when dealing with the VO type of networks, it is important to deal with additional risks, that come in part from the increasing sharing of responsibilities among companies and their dynamic nature of relationships [7]. Therefore, there is a lack of more systematic and integrated frameworks to handle the several dimensions of risk, which includes both intra-organizational and inter-organizational aspects of the whole VO.

In a previous work, the same authors designed a method that analyzes the risk upon a set of pre-selected LPs to compose VOs [8], but do not considered the IPs as well. This work extends that considering the risks at the whole VO level, since faults in any partner can make the given VO to fail in its goals. By means of a set of quantitative analysis, involved VO managers can have better conditions to evaluate how risky is every possible VO composition. Another facet of the value proposition of this work refers to the systematization of the risk analysis and associated decision-making processes so providing more agility and transparency in creating a new VO.

The remainder of this paper is organized as follows: Section 2 addresses the partners' search and selection problem in the context of risk analysis. Section 3 introduces the proposed method for risk analysis. Section 4 presents an example of the method. Finally, Section 5 presents some conclusions about current achievements.

2 General Background

Risk management is an important contributor to most fields of decision and control management. In brief, risk can be defined as the probability of an event to occur and that causes a negative or positive impact on the organization's goals when it takes place [9]. When dealing with the interrelationships of networked organizations, the risk is associated with the entire net, i.e. the VO as a whole. Therefore, in the context of this research, a risk is characterized by the potential of each partner (LP or IP) that is able to compose a VO does not cope with the given CO's requirements jeopardizing the VO accomplishment.

According to the literature, a number of risk analysis methods has been identified as potentially suitable for VOs, e.g. [5, 10, 4, 11]. In this sense, and in the context of risks, it is assumed the following requirements for VO risks analysis: partners should be analyzed both individually and collectively; all "links" (or relations) between any two partners must be considered and measured; there is a need for analyze all partners together when considering the interrelationships among them via some performance criteria. In that same way, there is a number of methods that can be applied to model risks and their analysis, as explained in [8]. ETA (Event Tree Analysis) [10] and ANP (Analytic Network Process) [5] had been previously selected. In order to support the relations among partners an Intensity Analysis technique [11] was selected and combined with ETA and ANP.

In the state of the art review, some works related to risk analysis for VOs have been identified. In [7] thirteen KPIs (Key Performance Indicators) were identified as general risk sources for VOs, further identifying the importance of each one. In [12] the advantages of AHP/ANP over the other multi-criteria decision making methods to assess VO risk sources were discussed. In [13] an approach for the analysis of benefits in collaborative processes among partners, including a number of performance indicators, was introduced. In spite of their important contributions, none of them have presented methods or models to analyze the risk in VO partner's search and selection step in a systematized and integrated way, comprising the different types of risks through a combination of qualitative and quantitative methods. Yet, proposals that have considered both logistics and industrial partners.

3 The Proposed Method

The proposed method corresponds to an incremental part on top of two steps previously developed by the authors. Industrial partners were selected based on capabilities [14]. Logistics partners were also selected based on their capabilities as well as on performance measurement using a 15 KPI model [6]. Risks upon logistics partners were added over this, picking the most adequate KPIs for risk purposes out of the 15 used in the other stage, which were four: trust, communication, collaboration and commitment [6]. In this paper, in order to calculate the risk for the entire VO (i.e. industrial + logistics partners) also regarding the intensity of collaboration, three sources of risk were considered as the most critical ones [15]: **trust**, **commitment** and **information sharing**. They were modeled as KPIs and their values were calculated using the method developed in [6].

The fundamental rationale of the proposed method is to consider the intensity of previous collaboration among involved partners. In the previous work risk was calculated only considering performance indicators, meaning that a VO could be at last composed by the best companies from the performance point of view but that have never been worked together. The premise is that this lack of previous relations can affect the whole VO performance, i.e. this can put the VO in risk. Therefore, it is important to also consider such relations, complementarity. Regarding this, the proposed risk analysis method was divided in three hierarchical layers, as generally presented in Fig. 1.

The first layer is responsible to manage all the aspects related with the partner's search and selection, including the selection criteria and the used

KPIs [6]. The second layer provides an extension of a risk analysis method that selects LPs to compose VOs [6] to also consider an analysis upon the pre-selected IPs and the relationship intensity between all of them. This layer evaluates the pre-selected LPs (represented by triangles) and IPs (rectangles). Finally, third layer aggregates the results from the second layer to assess the risk level for the whole VO. This third level represents the core of the research presented in this paper. More specifically, it applies the Analytic Network Process (ANP) [5] method over the previous analyzed partners (LPs and IPs) to measure the aspects of collaboration among them and to further generate a Global Risk Level (GRL) score for the VO. Managers can then compare this afterward for the final decision-making about the most suitable members composition the given VO.

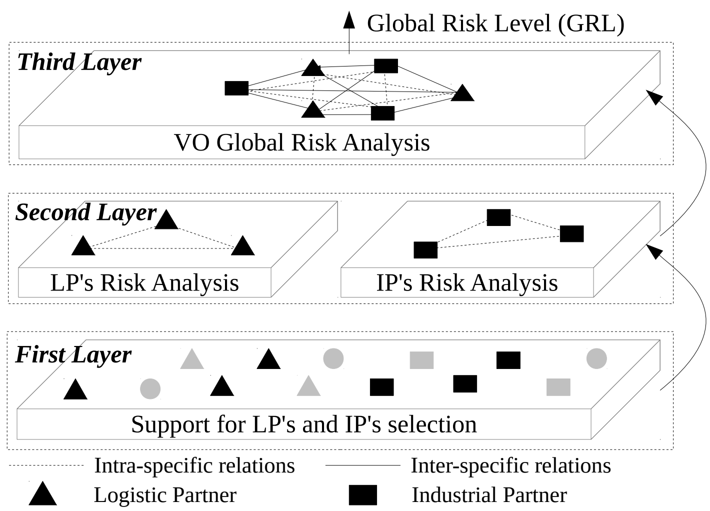

Fig. 1. Overview of the proposed method.

In the next subsections each layer of the method will be explained in details.

3.1 First Layer

The first layer aims basically to provide the support for LP's and IP's search and selection. It primary bases in a model of KPIs and in a methodology for the selection of partners [6]. In the context of this work, this methodology provides the initial setup of partners that will compose a VO. The KPI model is composed of fifteen strategic indicators, which includes not only the intra-organizational perspective, but inter-organizational as well. The partner's selection model developed in [6] is performed primarily by calculating the level of collaboration, thoughtfully evaluating the performance of each partner based on their historical performance in past VOs, on their technical competence, temporal availability, and on the demand's requirements [6, 16].

3.2 Second Layer

The second layer performs a risk analysis considering two different groups: one group formed of the pre-selected LPs and another group formed of the pre-selected IPs (first layer). This analysis is carried out because LPs and IPs have more strict relations with themselves than each others. Formally, it is assumed that the global VO (i.e., formed by LPs and IPs) is represented by a complete graph $G = (V, E)$, where V corresponds a set with LPs and IPs and E the relations between the elements of V. In order to handle the two different groups of partners, the graph G was split into two complete sub-graphs $G' = (V', E')$ and $G'' = (V'', E'')$, where V' and V'' represents the set of LPs and IPs, respectively, and E' and E'' represent the relations among them. One can also consider two types of relations among the partners. There are the *intra-specific relations* that occur just among IPs **OR** LPs and there are the *inter-specific relations* that consider the relations between LPs **AND** IPs. In this stage, just the intra-specific relations are considered.

The procedures for analyzing the individual risk of G' and G'' are carried out through an extension of the previous work [8], by adding the following modifications, as seen in Fig. 2:

- completely automation of the previous method (i.e., removing the mediation of the VO manager in the two stages of the method);
- enhancement of the risk sources (KPIs) applied to analyze the individual risk of each partner. In this case, although there was been used the same KPIs for both LPs and IPs, these KPIs will be analyzed in different ways, given the particularities of the two types of services (i.e. logistic and industrial);
- the method itself was modified in order to better accomplish its goals. Now, the collective analysis is performed by analyzing the intensity of intra-specific relations. It means that, after analyzing the risk of each single partner, the partner's intensity aspects will be also considered to analyze the risk of G' and G'' as a whole.

For the sake of simplicity, the formalization procedures will just consider the operations for one of the two group of partners (G' and G''), since these operations are equally performed for the two groups. Therefore, it can be formalized as follows:

Let $G' = (V', E')$ be a sub-graph of G as previously mentioned, where $V' = (v'_1, v'_2, ..., v'_n)$ represents a set of n LPs. Let $K' = (K'_1, K'_2, K'_3)$ a set of three KPIs (trust, commitment and information sharing) associated to each v'_n. Applying ETA calculation for each element of V', it will be result in $P(v'_i) = (P_1(v'_i), P_2(v'_i), ..., P_8(v'_i))$ as a set of all possible outcomes from the $2^{|K'|}$ event combinations in the ET (where $|K'|$ represents the number of elements in K'). The detailed procedures for obtaining $P(v'_i)$ can be seen in [8]. After defined all possible outputs of P for each v'_i, the method calculates the $S(v'_i)$, which represents its quantitative risk level. The procedure for calculating the $S(v'_i)$ takes into account the appliance of a Harmonic Weighted Average (HWA)

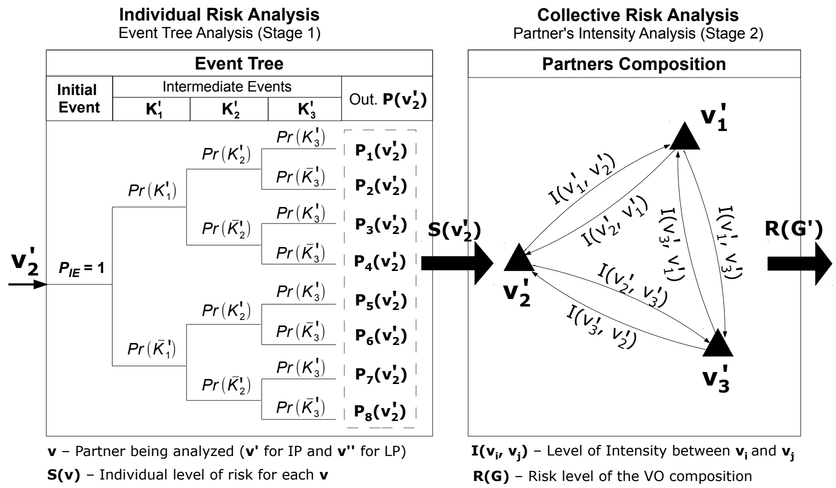

Fig. 2. The second layer of proposed method. Improved from [8]

over all $P(v_i')$ values [17]. Therefore, from the set of $S(v_i')$ obtained results (i.e., the risk of each partner), the method will be able to analyze the G' risk.

The collective analysis of G' (i.e., for all $v_i' \in G'$) will be performed by measuring the level of intensity among the partners who compose it. The intensity (or also referred level of correlation) is a concept widely adopted in network theory for measuring how connected are two or more elements in a network (that can be represented by authors, companies, etc) [11]. Its is primarily based in the use of specific indicators and methods to carry the analysis, which can change according the adopted approach.

In this paper, the intensity is modeled between two partners (whose relations include LPs to LPs or IPs to IPs) and takes into account two different indicators [11]: the **VO co-participation** and the **feedback**. The VO co-participation between two partners v_i' and v_j' is referred as $C(v_i', v_j')$ and means the amount of VOs that they have previously collaborated. The feedback of a partner v_i' over v_j' is referred as $F(v_i', v_j')$ and means the average score that a provider v_i' gives to a partner v_j'. Note that C is calculated equally in a bi-directional relation, while F is calculated separately for each of two directions.

Given the two previous mentioned indicators, the intensity $I(v_i', v_j')$ can be calculated by averaging $C(v_i', v_j')$ and $F(v_i', v_j')$ values. Once the two indicators have different evaluation scales, (i.e., two partners can attend any amount of VOs, but the feedback is restrict in a scale from 0 to 10) then is defined a normalization vector $\boldsymbol{n}(f(x))$, where $f(x)$ represents the function to be normalized in a scale that varies from 0 to 1, as seen in Eq. 1. Thus, applying Eq. 1, it can be obtained the normalized VO co-participation $C_N(v_i', v_j') = C(v_i', v_j')n(C(E'))$ and feedback $F_N(v_i', v_j') = F(v_i', v_j')n(F(E'))$. Thus, the level of intensity is defined according Eq. 2:

$$\boldsymbol{n}(f(x)) = \left(\frac{1}{max(f(x))}\right) \quad (1)$$

$$I(v'_i, v'_j) = \frac{C_N(v'_i, v'_j) + F_N(v'_i, v'_j)}{2} \quad (2)$$

Once again, from the intensity among all v'_i of G', it is necessary to perform a general calculation to obtain the risk level of G'. The risk level is represented by $R(G')$ according Eq. 3, where the first term calculates the average of the individual risk levels of each $v'_i \in G'$ and the second term calculates the average of the sum of intensities $I(v'_i, v'_j)$ and $I(v'_j, v'_i)$. The values obtained are then averaged again in order to obtain the final level of risk.

$$R(G') = \frac{1}{2}\left(\sum_{i=1}^{|V'|} \frac{S(v'_i)}{|V'|} + \sum_{j=1}^{|V'|-1} \sum_{k=j+1}^{|V'|} \frac{I(v'_j, v'_k) + I(v'_k, v'_j)}{2\,|V'|}\right) \quad (3)$$

3.3 Third Layer

The third layer of the proposed method performs a high level analysis of the VO, by aggregating the results provided by the second layer (i.e., the set of LPs and IPs) to calculate a Global Risk Level (GRL) of the VO as a whole. To perform this, it is used the Analytic Network Process (ANP) [5], given its ability to deals with interdependent attributes providing an integrated environment for evaluation of the existent relationships in complex systems. Moreover, the ANP method is successfully employed in decision-making problems involving variables with multiple criteria, and relations among them.

The ANP initial set up consists of identifying and structuring the elements belonging to three basic groups: goal (A_G), criteria (A_C) and alternatives (A_A). In this work, the goal (or objective) is to calculate the Global Risk Level (GRL) of the VO. The criteria are represented by the outputs of the second layer, i.e., the set $A_C = \{S(x), R(x)\}$, where $S(x)$ and $R(x)$ represent the individual level of risk of each v'_i or v''_i and the level of risk of G' or G'', respectively (note that the values of the criteria change according to the partner being analyzed). The alternatives are represented by the set $A_A = \{v'_1, ..., v'_n, v''_1, ..., v''_m\}$ comprising all the v'_i and v''_i partners. Fig. 3 depicts the network structure, which comprises the goal, criteria, alternatives, and the relationships represented by the arrows.

Having structured the problem of analyzing the risk in the VO in terms of the three ANP clusters, the calculation of the method can be summarized in four steps, as follows:

1. **Define relationship weights:** At this step, all the relationships between criteria (A_C), alternatives (A_A) and the goal (A_G) are weighted. These relationships, when normalized, represent the influence of an element on the other. However, they can be, initially, defined in non normalized values. In this work, these relationships are split into three types: *relationships*

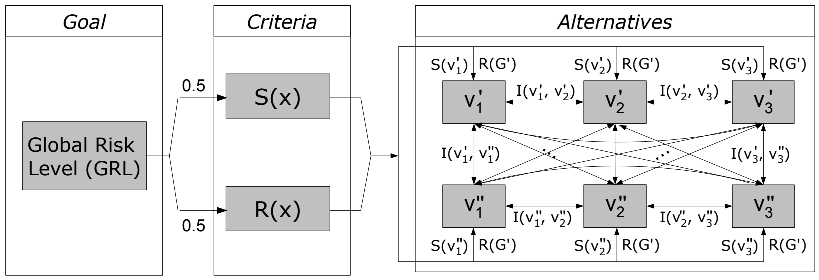

Fig. 3. The third layer of proposed method.

from goal to criteria (importance of the individual risk level of each partner and the overall risk of the composition of all partners); *relationships from criteria to alternatives* (influence of the two criteria over a partner); and *relationships from alternatives to alternatives* (level of intensity that a partner enforces over the other).

2. **Build an unweighted supermatrix:** At this step, the normalized values [17] obtained in the Step 1 are added to the unweighted supermatrix S_U. This supermatrix models the relationships among all the elements of the system and it represents the importance of each element within its own clusters. The supermatrix S_U has dimension $d \times d$, where $d = |A_A| + |A_C| + |A_G|$, i.e., the number of partners, criteria and the goal, as can be seen in the Eq. 4:

$$S_U = \begin{array}{c} \\ v_1^{'} \\ \vdots \\ v_m^{''} \\ S(v) \\ R(v) \\ G \end{array} \begin{array}{c} \begin{array}{cccccc} v_1^{'} & \dots & v_m^{''} & S(v) & R(v) & G \end{array} \\ \begin{bmatrix} 1.00 & \dots & I(v_1^{'}, v_m^{''}) & 0.00 & 0.00 & 0 \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ I(v_m^{''}, v_1^{'}) & \dots & 1.00 & 0.00 & 0.00 & 0.00 \\ S(v_1^{'}) & ... & S(v_m^{''}) & 0.00 & 0.00 & 0.50 \\ R(G') & ... & R(G'') & 0.00 & 0.00 & 0.50 \\ 0.00 & ... & 0.00 & 0.00 & 0.00 & 0.00 \end{bmatrix} \end{array} \quad (4)$$

The relationships between criteria and between alternatives and goal are not considered in this work, and hence, their values are assigned to zero in the supermatrix shown in Eq. 4.

3. **Build a weighted supermatrix:** Given the unweighted supermatrix S_U obtained in Step 2, this step performs the specification of a weighted supermatrix S_W, i.e, a stochastic matrix that represents the general importance of each element considering all groups (A_G, A_C and A_A) simultaneously. To make this possible, another normalization procedure is performed, where for each column, each element is divided by the sum of

all its elements, as shown in Eq. 5.

4. **Calculate limit supermatrix:** The last step on the ANP consists in to calculate a limit supermatrix S_L, which is obtained by raising the weighted supermatrix S_W to power ($S_L = (S_W)^k$ for $k = 1, 2, ...$) until the convergence of its values, such that every column $(S_L)_j$, $(S_L)_j = (S_L)_{j+1}$. This convergence always occurs since the stochastic nature of the supermatrix S_W. Hence, the final results are represented by a column matrix X that is generated from any column $(S_L)_i$. The matrix X presents the level of risk of each partner in relation to the goal, as can be seen in Eq. 4:

$$(S_W)_{ij} = \frac{(S_U)_{ij}}{\sum_{k=1}^{d}(S_U)_{kj}} \qquad (5)$$

$$X = \begin{matrix} v_1' \\ \vdots \\ v_m'' \end{matrix} \overset{A_G}{\begin{bmatrix} w_1 \\ \vdots \\ w_{n+m} \end{bmatrix}} \qquad (6)$$

Thus, summing all elements of the matrix column X it can be obtained the Global Risk Level (GRL) of the VO.

4 An Illustrative Example

This section presents an illustrative example of the proposed method to provide a better understanding of its operation. Initially, suppose that a CO was created to attend a particular demand and a set of three LPs and three IPs were selected by the first layer of the proposed method to compose a new VO $G = (V, E)$. The LPs and IPs are represented, respectively, by two complete sub-graphs of G, $G' = (V', E')$ where $V' = (v_1', v_2', v_3')$ and $G'' = (V'', E'')$ where $V'' = (v_1'', v_2'', v_3'')$.

In order to measure the risk level of the G' and G'', they are submitted to the second layer of proposed method, firstly applying ETA calculation. In ETA, the risk when considering G' and G'' takes into account the quantification of the three risk sources: *trust*, *commitment* and *information sharing*. Although in this example the analysis of the KPIs are not considered, its values are necessary to obtain the set of probabilities $P(v)$, as calculated in Table 1. It also shows the individual risk level of each partner ($S(v_i)$) that is used to calculate the risk of the sub-graph G' and G''.

The next step is to perform the collective analysis of G' and G''. To make this possible, the intensity analysis will be carried out. Table 2 (left) presents a hypothetical number of previous VO participation and the feedback of each relationship among all pairs v_i, v_j. The intensity of each two partners is so calculated according in Eq. 2 and presented in Table 2 (right). The risk level of G' and G'' can be also calculated as follows:

$$R(G') = \frac{1}{2}\left(\frac{0.584+0.767+0.569}{3} + \left[\frac{0.43+0.9+0.57+0.56+0.55+0.51}{2*3}\right]\right) = 0.730$$

$$R(G'') = \frac{1}{2}\left(\frac{0.614+0.734+0.885}{3} + \left[\frac{0.70+0.66+0.87+0.92+0.93+0.85}{2*3}\right]\right) = 0.783$$

Table 1. Results from event combinations for all partners of G' and G''

	$P(v)$								
	$P_1(v)$	$P_2(v)$	$P_3(v)$	$P_4(v)$	$P_5(v)$	$P_6(v)$	$P_7(v)$	$P_8(v)$	$S(v)$
v'_1	0.392	0.168	0.168	0.072	0.098	0.042	0.042	0.018	0.584
v'_2	0.612	0.153	0.108	0.108	0.068	0.017	0.012	0.003	0.767
v'_3	0.360	0.240	0.090	0.060	0.120	0.080	0.030	0.020	0.569
v''_1	0.494	0.026	0.123	0.006	0.266	0.014	0.066	0.003	0.614
v''_2	0.608	0.152	0.032	0.008	0.152	0.038	0.008	0.002	0.734
v''_3	0.810	0.090	0.090	0.001	0.000	0.000	0.000	0.000	0.885

Table 2. (left) Quantitative values of VO Co-Participation and Feedback for all partners of G' and G''; (right) Level of intensity among all partners of G' and G''.

	G'			G''		
$C;F$	v'_1	v'_2	v'_3	v''_1	v''_2	v''_3
v'_1	–	15; 5.5	27; 7.1	33; 6.8	65; 9.1	41; 8.3
v'_2	15; 6.3	–	22; 6.9	10; 8.3	68; 9.7	67; 8.3
v'_3	27; 7.4	22; 7.6	–	49; 7.0	26; 8.3	14; 9.8
v''_1	33; 5.5	10; 5.7	49; 6.8	–	39; 8.1	66; 7.6
v''_2	65; 8.7	68; 9.4	26; 9.5	39; 7.4	–	62; 9.3
v''_3	41; 7.0	67; 8.9	14; 7.1	66; 8.5	62; 7.7	–

	G'			G''		
I	v'_1	v'_2	v'_3	v''_1	v''_2	v''_3
v'_1	–	0.39	0.56	0.59	0.94	0.72
v'_2	0.43	–	0.51	0.52	0.99	0.91
v'_3	0.57	0.55	–	0.71	0.61	0.60
v''_1	0.52	0.36	0.70	–	0.70	0.87
v''_2	0.92	0.98	0.67	0.66	–	0.93
v''_3	0.66	0.96	0.46	0.92	0.85	–

The third layer of the method consists in aggregating the partners of G' and G'' and the results of second layer ($S(v')$ and $R(G')$) to analyze them as a whole. This is done using ANP method calculation, whose network structure was presented in Section 3. Therefore, it will be assigned the three *normalized* relations (goal to criteria, criteria to alternatives and alternatives to alternatives) to build the unweighted supermatrix S_U.

Next, it is carried out the normalization procedure for each column of the unweighted supermatrix, which will result in the weighted supermatrix S_W. The limit supermatrix S_L can be also built by raising S_W until their values converge. This matrix shows the risk level of each partner in relation to the goal. The final results are represented by a matrix X that is generated from any column of S_L:

$$\mathrm{X} = \begin{array}{c} \\ A_G \end{array} \begin{array}{c} \begin{array}{cccccc} v'_1 & v'_2 & v'_3 & v''_1 & v''_2 & v''_3 \end{array} \\ \begin{bmatrix} 0.10 & 0.07 & 0.12 & 0.09 & 0.08 & 0.13 \end{bmatrix} \end{array}$$

Finally, summing all elements of X, the Global Risk Level of the VO can be calculated:

$$GRL = \sum_{i=1}^{|X|} X_i = 0.09 + 0.07 + 0.11 + 0.09 + 0.08 + 0.12 = 0.59$$

Considering this example, the VO as a whole has 59% chance of success.

5 Conclusion

This paper has presented results of an ongoing research about inserting risk dimension when selecting VO partners. This includes both industrial partners and logistics partners, members of a VBE type of long-term alliance.

Besides comprising the VO as a whole, the proposed risk analysis method also takes the intensity of previous collaboration among partners into account in order to have a more comprehensive perspective about the risk. Involved VO managers are provided with numeral values strongly based on KPIs in way to be more confident when selecting the members for given VOs. All these aspects are not covered at all in the state-of-the-art, which basically deal only with industrial partners and without considering their past relations.

The proposed method splits the problem solver into three hierarchical layers, which one using adequate techniques for risk calculation and modeling. Although implemented in a controlled environment and using with hypothetical values, the achieved results showed the method's consistency and evidences about its potentialities for being applied in real cases.

The results obtained from the collective risk analysis tests (for both LPs and IPs) concluded that the qualification and quantification of the level of intensity between partners added with the ANP method gave more transparency and assertiveness in risk measuring process. This systematic process is important since partners (industrial and logistics partners) are autonomous and are members of long-term alliances. Therefore, transparency in the involved processes is crucial for trust building. Moreover, being a more organized process, it has the potential to mitigate risks and increase the agility in the VO formation process.

The proposed method does not aim to automate the risk analysis. Instead, it aims to help VO managers with more information in their decision-making when creating VOs.

Future work includes to test the method in near-real scenarios as well as to create a framework for risk analysis including the operation phase of the VO.

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