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A Genetic Algorithm approach for Collaborative Networked Organizations Partners Selection

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Abstract. In the paper a genetic algorithm approach to form potential Collaborative Networked Organizations (CNOs) is presented. When analyzing a set of companies that are potential partners of a CNO, it is possible to collect specific data from each company through which evaluate, once aggregated, for which Strategic Objective (SO) the potential aggregation is most suited. At this purpose a metric, consisting in a set of performance parameters related to different SO types, has been created. Given a large number of companies, through a genetic algorithm approach is then possible to set a specific objective function related to a particular SO (eg. maximize potential creation of new Business Opportunities), and to find the cluster (or clusters) of companies that maximizes the objective function.

Keywords: Business Networks Formation, Genetic Algorithm, Strategic Objectives.

1. Introduction

In the paper a genetic algorithm approach for collaborative networked organizations partner selection is presented. The perspective adopted in this paper is related to the framework described and applied by authors in two preceding works [1][2].

In these studies authors defined and applied a framework to analyse a potential pool of partners and to identify the most appropriate CNOs form that should be adopted. The choice of the Strategic Objectives (SOs) of the collaborative network is a crucial analytical phase that determines the most appropriate form of alliance. In general, when analyzing a pool of companies that want to collaborate, strategic network objectives are not defined 'a priori', but should be the result of an assessment of the possible opportunities deriving from the collaboration. This assessment is conducted by gathering information on several aspects of each company (the so called 'Analysis Dimensions'). By evaluating and consolidating all the information gathered from a network perspective it is possible to define which type of Strategic Objective is achievable by the group, and in turn to identify the most appropriate strategic mission for the CNO, and the most appropriate strategic form among VBE[4], VDO[1] and T-Holding[1]. In [2] authors applied the proposed framework to a case study commissioned by the ICE (the Italian Institute for Foreign Trade) and by a local industrial association (Confartigianato Terni), whose aim was to investigate how the companies belonging to an industrial cluster of the metal-mechanic industry in Italy could be aggregated in an innovative way. A questionnaire through which investigate the analysis dimensions of each company has been defined. Data provided by this tool and by economic and financial statements of the companies have been analysed in a network perspective in a semi-quantitative way. The analysis of the consolidated data allowed clearly identifying which type of SO was at same time desirable and achievable by the alliance. This in turn allowed determining the most appropriate type of CNO. In this paper the above mentioned framework is completed through the definition of a 'metric' that allow to measure in a *quantitative* way which type of SO is most suitable for a group of companies that wants to join together. For this purpose, the metric takes mainly into consideration the so called 'hard' factors [5] (e.g. matching competence, technological fit, etc.), because its scope is limited to the selection of the SO's type. An appropriate pattern of the so called 'soft' factors (e.g. reputation, ethical issues, norms, values, trust, etc.) is considered in this context to be a necessary prerequisite. Thanks to this metric it is possible to extend the usage of the proposed framework to another interesting context: the selection, from a large number of companies, of a cluster (or more clusters, here intended as generic business networks of companies) able to achieve a specific SO. At this scope, a genetic algorithm approach is presented. The perspective adopted in our work is different from many interesting studies presented in literature related to partners selection and evaluation processes [6] that specifically address Virtual Organizations (VOs) creation process, but not the long term CNO formation process.

The paper is organized as follows: in section 2 the classification of SOs is reported; in section 3 the metric for measuring which SO is achievable by a group of companies is presented; in section 4 the genetic algorithm approach is presented.

2. Strategic Objectives of Primary and Secondary Type

How illustrated in [1], the strategic objectives (SOs) a generic CNO can pursue have been classified in SOs of "primary" type and SOs of "secondary" type.

The strategic goals of Primary type represent the ability of the network to permanently increase the value added related to its business core competencies. To achieve these goals it is necessary that the alliance is able to create new Business Opportunities (BOs) and Core Process Opportunities (CPOs):

- Business Opportunities: are related to new markets and new products development, able to increase the network turnover;
- Core Process Opportunities: are related to the increase of effectiveness and efficiency of the core operational activities, able to reduce the network costs.

In the strategic goals of Secondary type we can include all the other synergies that brings to new Supporting Process Opportunities (SPOs), that are related to increase the efficiency and effectiveness of all the supporting activities, such as finance, control, quality, research, administration, education, etc., that are able to emphasize the benefits of Primary type.

Figure 1 show the companies' analysis dimensions that have to be investigated in order to evaluate if a potential CNO is able to generate new BOs, CPOs and SPOs, that is, to fulfill the strategic goals that have been defined in the previous step. The dimensions identified are: Segments of Business [8], Primary and Supporting Activities [9], Critical Resources [10], Financial statements analysis [11].

As reported in [2] the proposed framework has been applied to a case study. The questionnaire is the survey tool that has been utilized to collect information on qualitative and quantitative variables from each company, and consists of three distinct sections, each one related to one of the analysis dimensions defined. Data provided by the questionnaires have then been integrated trough economical and financial data provided by the companies' balance sheets.

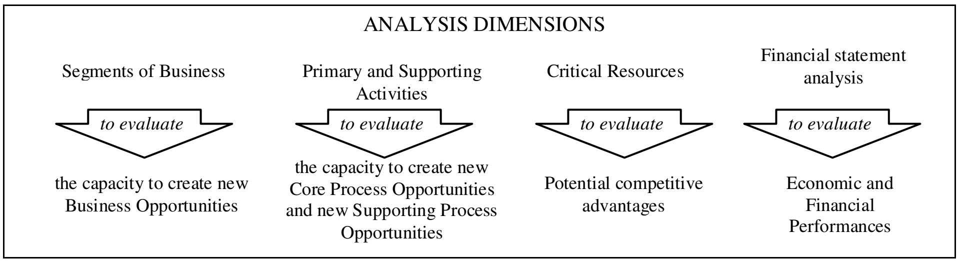

Figure 1. Analysis dimensions.

3. A Metric for Measuring Strategic Objectives Achievability

The metric proposed herein is applicable to a determined group of company. Data provided by the questionnaire and balance sheets of each company are used in this section to calculate a series of performance parameters through which asses the ability of the potential network to achieve a specific SO.

There are three set of parameters, each one related to one of the three types of strategic objectives achievable: *BOs*, *CPOs* and *SPOs* parameters. A higher value of a parameter will indicate that the group has a high probability of achieving the strategic objective to which the parameter is referred. Due to space limitation, only a part of the *CPOs* and *BOs* parameters that have been defined will be described in the following paragraphs. The remaining *CPOs*, *BOs* and *SPOs* parameters will be presented in an extended version of the paper. Each parameter P_k is associated to a weight WP_k and to two vectors of ordered values $\{x_1, ..., x_n\}$ and $\{y_1, ..., y_n\}$ used to discretize and normalize the parameter value through the following function:

$$f(P_k)\begin{cases} 0 & if \quad P_k \le x_1 \\ y_i & if \quad x_{i-1} < P_k < x_i \quad i = 2,...,n-1 \\ y_n & if \quad P_k \ge x_n \end{cases} \qquad (1)$$

The weighted, discretized and normalized value of the parameter is equal to $WP_k \cdot f(P_k)$. The weights and vectors values for some of the *BOs* and *CPOs* parameters are shown in Table 1 and Table 2.

Notation

N	=	Number of companies in the group
T_i	=	Turnover of company i
E_i	=	total external costs (purchases and closing stock + production, commercial and administrative services)
S_{TOT}	=	total number of industrial sectors (covered by at least one company)
S_{ij}	=	turnover fraction made in industrial sector j by company i
Sb_{ij}	=	1 if $S_{ij} > 0$; = 0 otherwise (=1 if industrial sector j is covered by company i)
T_{INi}	=	total expenditures for inbound transportations
T_{OUTi}	=	total expenditures for outbound transportations
A_{ij}	=	expenditure fraction on total purchases of company i for product j
Ab_{ij}	=	1 if $A_{ij} > 0$; = 0 otherwise
$A_{(2\text{-}4)j}$	=	1 if $2 \leq \sum_i Ab_{ij} \leq 4$; = 0 otherwise (=1 if product j is purchased by a number of company between 2 and 4)
$A_{(\geq 5)j}$	=	1 if $\sum_i Ab_{ij} \geq 5$; = 0 otherwise (=1 if product j is purchased by more than 5 companies)
C_{ij}	=	Turnover fraction of company i made with client j
Cb_{ij}	=	1 if $CL_{ij} > 0$; = 0 otherwise
$C_{(2\text{-}4)j}$	=	1 if $2 \leq \sum_i Cb_{ij} \leq 4$; = 0 otherwise (=1 if client j is common to a number of companies between 2 and 4)
$C_{(\geq 5)j}$	=	1 if $\sum_i Cb_{ij} \geq 5$; = 0 otherwise (=1 if client j is common to more than 5 companies)
MAC_{TOT}	=	total number of machines typologies (used in at least one company)
MAC_{ij}	=	number of machines j owned by company i
$MACb_{ij}$	=	1 if $MAC_{ij} > 0$; = 0 otherwise
TEC_{TOT}	=	Total number of different technologies (adopted by at least one company)
$TECb_{ij}$	=	1 if tecnology j is adopted by company i; = 0 otherwise

Performance Parameters: CPOs, BOs, and SPOs parameters

CPOs parameters measures the potential ability of the group of N companies to achieve new Core Process Opportunities as a network. The Parameters reported in Table 1 are the following:

- CPO_1 = incidence of total inbound transportation costs on total turnover;
- CPO_2 = incidence of total outbound transportation costs on total turnover;
- CPO_3 = number of product types purchased by a number of companies between 2 and 4;
- CPO_4 = incidence on total turnover of purchasing costs related to products purchased by a number of companies between 2 and 4;

CPO_5 = number of product types purchased by a more than 5 companies;
CPO_6 = incidence on total turnover of purchasing costs related to products purchased by more than 5 companies.

The higher the value of these parameters, the higher the possibility to achieve some core process opportunities such as synergies in transportations activities (CPO_1 and CPO_2) or collaborative procurement opportunities (CPO_3 to CPO_6). In order to evaluate through a unique parameter the ability to achieve generic *CPOs*, an overall parameter, F_{CPO} , is defined by summing the discretized, weighted and normalized values of all the considered *CPOs* parameters:

$$F_{CPO} = \sum_p W_{CPOp} \cdot f(CPO_p) \tag{2}$$

Table 1. CPOs Parameters.

CPO_p Parameter	W_{CPOp}	$\{x_1, ..., x_n\}$	$\{y_1, ..., y_n\}$
$CPO_1 = \sum_i T_{INi} \Big/ \sum_i T_i$	3	{0.33, 0.66}	{5, 10}
$CPO_2 = \sum_i T_{OUTi} \Big/ \sum_i T_i$	3	{0.05, 0.2, 0.3}	{2, 5, 10}
$CPO_3 = \sum_j A_{(2-4)j}$	2	{2, 5, 10}	{2, 5, 10}
$CPO_4 = \sum_i \sum_j A_{ij} A_{(2-4)j} E_i \Big/ \sum_i T_i$	2	{0.05, 0.1, 0.2}	{2, 5, 10}
$CPO_5 = \sum_j A_{(\geq 5)j}$	5	{2, 5, 10}	{2, 5, 10}
$CPO_6 = \sum_i \sum_j A_{ij} A_{(\geq 5)j} E_i \Big/ \sum_i T_i$	5	{0.05, 0.1, 0.2}	{2, 5, 10}

BOs parameters measure the potential ability of the group to find new Business Opportunities as a network. The parameters reported in Table 2 the following:

BO_1 = degree of diversification of industrial technologies;
BO_2 = degree of diversification of machines types;
BO_3 = degree of diversification of industrial sectors;
BO_4 = number of clients common to a number of companies between 2 and 4;
BO_5 = incidence on total turnover of clients common to a number between 2 and 4 companies;
BO_6 = number of clients common to more than 5 companies;
BO_7 = incidence on total turnover of clients common to more than 5 companies.

The higher the value of this parameters, the higher the possibility to create new Business Opportunities by exploiting complementarities in technologies, machines, and industrial sectors (BO_1 to BO_3) or by supplying integrated products/services to common clients (BO_4 to BO_7). As in the previous case, to evaluate through a unique parameter the ability to achieve generic *BOs*, an overall parameter, F_{BO}, is defined by summing the discretized, weighted and normalized values of all the considered *BOs* parameters:

$$F_{BO} = \sum_p W_{BOp} \cdot f(BO_p) \quad (3)$$

In an analogous way, a series of *SPOs* parameters are defined (not reported due to space limitation), and the ability to achieve generic *SPOs* can be measured by a unique parameter F_{SPO} obtained by weighting, discretizing, normalizing and finally summing all the *SPOs* parameters.

Table 2. BOs Parameters

BO_p Parameter	W_{BOp}	$\{x_1,\ldots,x_n\}$	$\{y_1, \ldots, y_n\}$
$BO_1 = 1 - \dfrac{\sum_{i=1}^{N}\sum_{j=1}^{TEC_{TOT}} TECb_{ij}}{N \cdot TEC_{TOT}}$	5	{0.6, 0.8}	{5, 10}
$BO_2 = 1 - \dfrac{\sum_{i=1}^{N}\sum_{j=1}^{MAC_{TOT}} MACb_{ij}}{N \cdot MAC_{TOT}}$	5	{0.6, 0.8}	{5, 10}
$BO_3 = 1 - \left(\sum_{i=1}^{N}\sum_{j=1}^{S_{TOT}} Sb_{ij} \Big/ N \cdot S_{TOT}\right)$	5	{0.6, 0.8}	{5, 10}
$BO_4 = \sum_j C_{(2-4)j}$	2	{2, 5}	{5,10}
$BO_5 = \sum_i \sum_j C_{ij} C_{(2-4)j} T_i \Big/ \sum_i T_i$	2	{0.05, 0.1}	{4, 10}
$BO_6 = \sum_j C_{(\geq 5)j}$	5	{2, 5}	{5,10}
$BO_7 = \sum_i \sum_j C_{ij} C_{(\geq 5)j} T_i \Big/ \sum_i T_i$	5	{0.05, 0.1}	{4, 10}

4. A Genetic Algorithm Approach

The proposed metric can be applied to a group of potential partners. Given a large number of companies, the metric makes also possible to set a specific objective function related to a particular SO (eg. maximize potential creation of new Business Opportunities), and to find the cluster (or more clusters) of companies that maximizes the objective function. In order to define the desired solution features, three possible input parameters, that define the constraints that a feasible solution must respect, are taken into consideration:

NC = the desired number of clusters that has to be find;
$minC$ = minimum number of companies in each cluster;
$maxC$ = maximum number of companies in each cluster.

From an initial set of M companies, the algorithm will give as output NC clusters of companies, each containing a number of companies between $minC$ and $maxC$. The genetic algorithm approach seems to be particular suited to explore the space of this combinatorial problem, in which companies cannot be evaluated singularly. In fact, the contribution of each company to many of the performance parameters above described is dependent by which other companies are in the same cluster.

Representation, decoding and fitness functions. In a genetic algorithm approach, each Individual represents a possible solution of the problem. Thus, the individual is formed by one or more clusters of companies. The algorithm has been implemented in Java, and the representation of an individual has been made using an object oriented approach. Each Individual k contains a List of I_k clusters C_{ki}, $i = 1,\dots,I_k$. Each cluster C_{ki} contains a certain number of companies n_i, so that the total number of companies contained in all the clusters C_{ki} is equal to the initial set of M companies. However, when decoding an individual, only the feasible clusters (i.e. respecting the relation $minC \le n_i \le maxC$) have to be taken into consideration for calculating the fitness function. So F_k, the set of feasible clusters of individual I_k, is sorted in descending order with respect to the selected fitness function, and only its first NC clusters are considered when decoding the individual. Thus the individual fitness is calculated by considering only $C_{ki} \in F_k$ for $i \le NC$. This set of clusters is the output of the decoding phase of an individual. It is noteworthy that, depending from the number of clusters to find and the minimum and maximum number of companies per cluster, one or more companies of the initial set of M companies could not be selected to be part of this final set of clusters generated by the individual decoding. Four possible fitness functions, shown in Table 3, can be selected. By selecting one of the fitness functions defined in Table 3, it is possible to search for potential cluster(s) able to achieve specific SOs. Through the F_{ALLO} fitness function the type of SO is not specified 'a priori' for all the clusters, but the algorithm will search for the best combination of clusters able to achieve different SOs.

Table 3. Fitness functions

Find clusters that maximize:	Fitness function
CPOs	$F_{CPO} = \sum_{i=1}^{NC} F_{CPOi}$
BOs	$F_{BO} = \sum_{i=1}^{NC} F_{BOi}$
SPOs	$F_{SPO} = \sum_{i=1}^{NC} F_{SPOi}$
indifferently *CPOs*, *BOs*, or *SPOs*:	$F_{ALLO} = \sum_{k=i}^{NC} \max\{F_{CPOi}, F_{BOi}, F_{SPOi}\}$

Initial population. An initial population is created by randomly generating a number P of individual. Each individual is created by iteratively forming clusters; each cluster has number of companies, randomly chosen from the initial set, between minC and maxC. Each time a cluster is formed, the set of companies belonging to the cluster is removed from the initial set. The procedure continues until the initial set is empty or it contains less than minC companies. In the latter case, the last cluster is formed including the remaining companies, although their number is out of the feasibility range.

Reproduction and mutation. Each generation of the genetic algorithm provides reproduction and mutation phases. In the reproduction phase, all the individuals of the population are coupled through a binary tournament selection procedure[12]. Then each couple of parents p_1 and p_2 generates two children, c_1 and c_2. For example, child c_1 is generated in this way: a cluster C belonging to p_1 is randomly chosen; then the companies belonging to C are removed from clusters belonging to p_2; finally C is added to p_2. The resulting individual is c_1. Child c_2 is obtained inverting p_1 and p_2 roles. In this way, after the reproduction phase, the population size is equal to $2P$. Each individual of this population has now a certain probability m to undergo the mutation phase. Each mutated individual is added to the population, but the original one is also maintained in the population. There are three possible types of mutation, randomly selected with probability m_1, m_2, and m_3 respectively. In the first type of mutation two clusters are randomly selected and are joint together. In the second type a cluster, randomly selected among clusters with a number of companies higher than $2 \cdot minC$, is halved, generating 2 clusters. In the third type, two companies, belonging to different clusters, are swapped. Note that the first type of mutation can generate clusters with a number of companies out of the feasible range. The mutation phase is responsible (together with the initial population creation phase) of the heterogeneity of the number of clusters I_k in each individual k. The population now is sorted, following one of the four fitness function proposed, and only the first P individuals survive and pass to the next generation. After a number of generation G, the algorithm stops, and the individual with the highest fitness is considered the final solution.

5. Discussion and Conclusions

The proposed metric has been validated by calculating the three performance parameters F_{BO}, F_{CPO} and F_{SPO} for the cluster of companies considered in the case study described in [2]. The study was commissioned by 'Confartigianato Terni', a local agency of 'Confartigianato', the main Italian industrial Association of SMEs, with about 700000 associated companies, and 120 local agencies spread over the territory. The resulting values (F_{BO}=265, F_{CPO}=45, F_{SPO}=35) are consistent with the qualitative analysis of results described in [2], that indicated the creation of new BOs as the most suited SO for the cluster. They are also consistent with the evolution of the cluster that, after the understanding of the basic characteristic of the proposed network model and the strategic logic of the collaboration, manifested a successfully capability to explore and catch new BOs, f.e. providing integrated products/services in the renewable energies plants sector. Confartigianato is currently considering the development of a software based on the metric and the algorithm presented in the paper, that, after a testing and validating phase through real data from the field, could be used by the local agencies as a decision supporting tool for networks formation. The genetic algorithm approach presented here in is a supporting decision tool to individuate, among an extensive number of companies, potential clusters of companies that can achieve specific strategic objectives. Through the proposed approach it is be possible to find out which companies, among the associated partners, could joint together to fulfill a specific mission. In particular the associations could suggest not only the cluster(s) composition, but also the type of strategic objective the cluster(s) should/could pursue. Furthermore, by analyzing the values of each performance parameters related to a determined cluster, and selecting the parameters that give the major contribute to the total fitness, it is also possible to indicate the particular opportunity that can be caught. For example, a high value of BO_6 indicates that there are some clients common to more than 5 companies. This suggests the possibility, for a network, to offer a new integrated product/service to that clients, given by the combination of products/services provided by the single companies.

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