



HAL
open science

Partner selection in virtual enterprises

José Crispim, Jorge Pinho Sousa

► **To cite this version:**

José Crispim, Jorge Pinho Sousa. Partner selection in virtual enterprises. *International Journal of Production Research*, 2009, 48 (03), pp.683-707. 10.1080/00207540802425369 . hal-00547665

HAL Id: hal-00547665

<https://hal.science/hal-00547665>

Submitted on 17 Dec 2010

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Partner selection in virtual enterprises

Journal:	<i>International Journal of Production Research</i>
Manuscript ID:	TPRS-2007-IJPR-0863.R1
Manuscript Type:	Original Manuscript
Date Submitted by the Author:	28-Apr-2008
Complete List of Authors:	Crispim, José; Department of Management, University of Minho Pinho Sousa, Jorge; Faculty of Engineering, University of Porto
Keywords:	VIRTUAL ENTERPRISE, META-HEURISTICS, MULTI-CRITERIA DECISION MAKING
Keywords (user):	VIRTUAL ENTERPRISE, META-HEURISTICS



Partner selection in virtual enterprises

José António Crispim^{a*1} and Jorge Pinho de Sousa^{b2}

^aDepartment of Management, University of Minho, Braga, Portugal

^bINESC Porto / Faculty of Engineering, University of Porto, Porto, Portugal

Abstract

A virtual enterprise (VE) is a temporary organization that pools member enterprises core competencies and exploits fast changing market opportunities. VEs offer new opportunities to companies operating with a growing numbers of participants (consumers, vendors, partners and others) in a global business environment. The success of such an organization is strongly dependent on its composition, and the selection of partners becomes therefore a crucial issue. Partner selection can be viewed as a multi-criteria decision making problem that involves assessing trade-offs between conflicting tangible and intangible criteria, and stating preferences based on incomplete or non-available information. In general, this is a very complex problem due to the large number of alternatives and criteria of different types (quantitative, qualitative and stochastic). In this paper we propose an integrated approach to rank alternative VE configurations using an extension of TOPSIS (a technique for ordering preferences by similarity to an ideal solution) for fuzzy data, improved through the use of a tabu search meta-heuristic. A sensitivity analysis is also presented. Preliminary computational results clearly demonstrate the potential of the approach for practical application.

Keywords: virtual enterprises; meta-heuristics; multi-attribute decision-making; TOPSIS.

1. Introduction

A virtual enterprise (VE) is a temporary alliance of independent and geographically dispersed enterprises set up to share skills or core competencies and resources in order to respond to business opportunities, the cooperation among the enterprises being supported by computer networks (Camarinha-Matos and Afsarmanesh, 2003). This is considered one of the most promising business strategies for enterprises to face global competition (Chen et al., 2007) and it is meaningful in quite different contexts such as manufacturing, healthcare, tourism, transportation and others. The success of such an organization is strongly dependent on its composition. In this context, the selection of the right partners is crucial. The creation of a VE is usually triggered by an emerging market opportunity, giving rise to a “project” that is decomposable in relatively independent sub-projects or activities. Therefore, before a VE is formed, the different inputs and outputs of each activity have to be clearly

* Corresponding Author. Email: crispim@eeg.uminho.pt

¹ Department of Management, University of Minho, 4710-057 Braga, Portugal, telephone: 00 351 253604565, fax: 00 351 253601380

² INESC Porto, Campus da FEUP, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal, telephone: 00 351 222094344, fax: 00 351 222094050

Partner selection in virtual enterprises

Abstract

A virtual enterprise (VE) is a temporary organization that pools member enterprises core competencies and exploits fast changing market opportunities. VEs offer new opportunities to companies operating with a growing numbers of participants (consumers, vendors, partners and others) in a global business environment. The success of such an organization is strongly dependent on its composition, and the selection of partners becomes therefore a crucial issue. Partner selection can be viewed as a multi-criteria decision making problem that involves assessing trade-offs between conflicting tangible and intangible criteria, and stating preferences based on incomplete or non-available information. In general, this is a very complex problem due to the large number of alternatives and criteria of different types (quantitative, qualitative and stochastic). In this paper we propose an integrated approach to rank alternative VE configurations using an extension of TOPSIS (a technique for ordering preferences by similarity to an ideal solution) for fuzzy data, improved through the use of a tabu search meta-heuristic. A sensitivity analysis is also presented. Preliminary computational results clearly demonstrate the potential of the approach for practical application.

Keywords: virtual enterprises; meta-heuristics; multi-attribute decision-making; TOPSIS.

1. Introduction

A virtual enterprise (VE) is a temporary alliance of independent and geographically dispersed enterprises set up to share skills or core competencies and resources in order to respond to business opportunities, the cooperation among the enterprises being supported by computer networks (Camarinha-Matos and Afsarmanesh, 2003). This is considered one of the most promising business strategies for enterprises to face global competition (Chen et al., 2007) and it is meaningful in quite different contexts such as manufacturing, healthcare, tourism, transportation and others. The success of such an organization is strongly dependent on its composition. In this context, the selection of the right partners is crucial. The creation of a VE is usually triggered by an emerging market opportunity, giving rise to a “project” that is decomposable in relatively independent sub-projects or activities. Therefore, before a VE is formed, the different inputs and outputs of each activity have to be clearly

1
2
3 defined. The cooperation relationship can be represented by an activity network with precedence's.
4
5 The problem of partner selection also arises when the VE needs to be reorganized by adding/expelling
6
7 some members or by re-assigning tasks or roles in order to better cope with new market
8
9 circumstances.
10

11
12 In this paper the focus is on developing a flexible multi-project/multi-period decision support
13
14 tool to help the Decision Maker (DM) during the partner selection process. These questions, multi-
15
16 period dynamics and flexibility, are very important in the VE research field because of the temporary
17
18 distinctive nature of this type of collaboration.
19

20
21 The proposed approach presents a hybrid algorithm that selects the partners taking a given the
22
23 horizon into consideration and uses, for the first time in this field (for our best knowledge), a multi-
24
25 objective multi-period metaheuristic combined with the TOPSIS technique in a fuzzy environment, to
26
27 search and rank non-dominated potential VE configurations.
28

29
30 The flexibility of the approach arises from the possibility of choosing different objectives and
31
32 constraints for each project and from the variety of variable types that the DMs can use to express
33
34 their preferences. In general, in the previously published works, flexibility is small because the
35
36 models are adjusted to a network with specific characteristics, e.g. operational costs (Ma et al., 2007)
37
38 or risk factors (Li and Liao, 2007). This can be observed when we look at other methodologies that
39
40 have been applied to solve the partner selection problem such as mathematical programming (Dotoli^b
41
42 et al., 2006) or fuzzy mathematical programming (Araz et al., 2007), where the decision problem is
43
44 formulated mathematically. The drawbacks of this lack of flexibility are even more apparent when we
45
46 are forming a VE, because the decision environment can change a lot.
47
48

49
50 Other approaches require an intensive participation of the DM. This is, for example, the case
51
52 of AHP, where the DM is required to perform pair-wise comparisons between the criteria and the
53
54 supplier alternatives (e.g. Sari et al., 2007). In order to overcome this inconvenient and to maintain the
55
56 quality of the original data, we do not aggregate information, and therefore we do not make use of
57
58 weights in the search phase. We believe that it is difficult for the DM, in this early phase where the
59
60 solution space can be quite vast (the number of alternatives tends to infinite), to set weights on a
realistic level and to understand the interdependencies among the objective functions. Different

1
2
3 weights provide different solutions but the same solution can be generated by different weights, and
4 this may be confusing to the DM. Consequently, have chosen the Pareto non-dominated concept to
5 perform our search (a solution is Pareto optimal if there are no other feasible solutions with higher
6 value of some objectives without a lower value in at least one other objective). We only use weights at
7 the final stage because we want the DMs to rank the criteria importance, using their expertise or
8 experience, so that the obtained solutions are closer to their ideals.

9
10
11
12
13
14
15
16 In terms of information gathering, we know that the selection and evaluation of partners is a
17 difficult problem due to the complex interactions between the different entities and because the
18 expression of their preferences may be based on incomplete or partially non-available information. To
19 deal with this problem under a multi-criteria perspective, we allow several types of information
20 (numerical, interval, qualitative and binary) in order to facilitate the expression of the stakeholders'
21 preferences or assessments about the potential partners. This is an important requirement in practice
22 as the multiplicity of factors considered when selecting partners for a business opportunity such as
23 cost, quality, trust and delivery time, cannot be expressed in the same measure or scale. In general,
24 partner selection approaches do not use mixed types of variables, applying only fuzzy numbers (e.g.
25 Cao^c and Zhou, 2006), or linguist terms (e.g. Lin et al., 2007), or numbers, indexes and ratios (e.g.
26 Sari et al., 2007). In cases where there is an attempt to use both quantitative and qualitative
27 information, there is usually gone lack of flexibility, as we are forced to pre-define the scale
28 cardinality (e.g. 9-scale or five-point likert scale, Araz et al. 2007).

29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45 The remainder of the paper is organized as follows. In Section 2 the problem is described, in
46 Section 3 the literature on the domain is briefly surveyed, in Section 4 the method used to solve the
47 problem is presented, in Section 5 an illustrative example is described and finally, in Section 6 some
48 preliminary conclusions are presented.

49 50 51 52 53 54 55 56 **2. Problem description**

57
58 Assume a network representing all potential partners (companies) and their relationships. A
59 specific entity is responsible for the VE formation process (this entity is here referred to as the
60

Decision Maker or DM). Companies and relationships are characterised by a set of criteria, some assigned to the nodes and some assigned to the edges of the network. Part of these criteria will define the objectives and the constraints of the problem. The first step in this modelling process is to carefully define what criteria are going to be considered in both subsets. The DM will assign weights to the objectives according to his/her beliefs about their relative importance for the project under consideration.

The network includes a set of companies (nodes) connected with each other, capable of performing activities and of providing a finite amount of resources, available over specific intervals of time. From detected market opportunities, projects are created. A project involves a set of activities that demand a specific amount of resources and have to be performed within a given time interval. These activities have a number of precedence relationships and therefore form an activity network.

Then the partner selection problem consists in choosing the best group of companies to perform all activities of a given project(s) taking into account a set of objectives and constraints (Figure 1). The main constraints of the problem are *time windows* and the *minimum amount of resources* required.

Figure 1: Multiple projects in a network and VEs

In what follows we present a general model for the problem:

Indices

$t = 1, \dots, T$ time periods

$j = 1, \dots, N$ candidates (companies)

$m = 1, \dots, M$ criteria

$h = 1, \dots, H$ activities that a network is capable of perform

$p = 1, \dots, P$ projects

Parameters

l_{mj} : score (contribution) of criterion m for candidate j

l_{mj}^o for objective criteria

l_{mj}^c for constraint criteria

d_{ip} : processing time of activity i of project p

$O_{ip}=[s_{ip}; f_{ip}]$: time window (interval) to perform activity i of project p

D_p : due time to perform the project p

A_p : set of activities in the project p

Q_{ip} : quantity of resources needed to perform activity i of project p

$V_j=[u_j; y_j]$: interval of time in which candidate j is available

r_{jt} : capacity (available quantity of resources) of candidate j in period t

W_i : set of candidates for performing activity i

B_p : maximum possible investment for project p (budget)

b_{ij} : cost of performing activity i by candidate j

Decision variables

$$x_{ijt} = \begin{cases} 1 & \text{if activity } i \text{ is contracted to candidate company } j \text{ for period } t \\ 0 & \text{otherwise} \end{cases}$$

Objective functions

We consider multiple objectives such as cost, quality, flexibility, etc. represented by $z_1, z_2, \dots, z_m, \dots$

$$\text{Max } z_1 = \sum_t \sum_i^{A_p} \sum_j^{W_i} l_{1j}^o x_{ijt}, \quad \forall p \in P \quad (1)$$

$$\text{Min } z_2 = \sum_t \sum_i^{A_p} \sum_j^{W_i} l_{2j}^o x_{ijt}, \quad \forall p \in P \quad (2)$$

...

$$\text{Max } z_m = \sum_t \sum_i^{A_p} \sum_j^{W_i} l_{mj}^o x_{ijt}, \quad \forall p \in P \quad (3)$$

...

Constraints

$$\sum_i^{A_p} \sum_j^{W_i} \sum_t^{d_{ip}} x_{ijt} b_{ij} \leq B \quad \forall p \in P \quad (4)$$

$$\sum_j^{W_i} \sum_t^{d_{ip}} x_{ijt} r_{jt} \leq Q_{ip} \quad \forall p \in P, \forall i \in A \quad (5)$$

$$\sum_t^{d_{ip}} \sum_j^{W_i} x_{ijt} f_{ip} \leq \sum_t^{d_{kp}} \sum_j^{W_k} x_{kjt} s_{kp}, \quad \forall i, k \in A \text{ and } i \text{ precedes } k, \forall p \in P \quad (6)$$

$$\sum_t^{d_{sp}} \sum_j^{W_s} x_{sjt} f_{sp} \leq D_p \quad \forall s \in A, \forall p \in P \quad (7)$$

$$\sum_t^{d_{ip}} \sum_j^{W_i} x_{ijt} = 1, \quad \forall i \in A, \forall p \in P \quad (8)$$

$$u_j \leq f_i - d_i, \quad \forall i \in A, \quad \forall j \in W_i \quad (9)$$

$$y_j \geq s_i + d_i, \quad \forall i \in A, \quad \forall j \in W_i \quad (10)$$

$$\sum_t^{d_{ip}} \sum_j^{W_i} x_{ijt} l_m^c \geq C_p, \quad \forall i \in A, \forall p \in P \quad (11)$$

Constraints (4) state that the sum of costs cannot be larger than the global budget for the project under analysis. Constraints (5) impose that candidate j , if contracted to perform activity i in period t , can provide up to Q_{ip} units of the product in that period. Constraints (6) impose the precedence relationships between activities, i.e., states that, for two activities i and k with a precedence relation, execution of k (s_{kp}) can only begin after i finishes. Constraints (7) ensure that the project is completed no later than the project deadline, i.e., the last activity of the project s must be equal or less than the project due time. Constraints (8) impose that, for any period for a given activity, only one candidate (or group of enterprises working as an individual element) can be selected. Finally, constraints (9) and (10) ensure that the time interval when the resources of candidate j are available fits the “time window” for activity i (Figure 1), and constraints (11) impose that, for each additional constraint, a minimum (maximum) value has to be accomplished. Other constraints, related to third party logistics (3PL), might be included but, as an alternative, these aspects can be covered by the objective function, considering some additional criteria.

Figure 2: Time window constraint with several hypotheses

3. Literature review

A review of the literature about partner selection methods in various research contexts (such as supply chain design, agile manufacturing, network design, dynamic alliances, and innovation management) has been performed in order to investigate the distinct approaches used to tackle this problem. We have concentrated this survey on research based on mathematical or quantitative decision-making approaches published in the last years (since 2001), and have grouped those approaches according to the methodology adopted. The survey included 57 papers covering quite different perspectives.

Three classification criteria have been adopted for categorising the reviewed articles:

- *Research context*: virtual enterprise/dynamic alliance, manufacturing, and supply chain/network;
- *Methods used to solve the problem* (almost all the research papers we found use hybrid algorithms);
- *Criteria/factors* on which the partner selection is based.

Table 1: Research Context/Methods Organization

The findings from this survey (57 papers) can be summarised as follows.

- 1) 74% of the papers were published in the last two years (since 2005).
- 2) In terms of research context (table 1), 51% of the papers are on virtual enterprises, 17% on manufacturing, and 32% on supply chains. Although there is a large number of papers published in this area (supply chain, network design), many of them have not been considered in the survey because they do not tackle partner selection as an isolate problem, but try rather to optimize or create a chain/network configuration considering questions such as localization, inventory management and/or transportation.
- 3) Although 90% of the papers describe hybrid methodologies, the quantitative approaches to partner selection can nevertheless be grouped into three main categories: optimization approaches (exact and heuristic algorithms) – 56%; multi-criteria decision aiding (such as AHP, MAUT, fuzzy set

theory) - 33%; and other methods such as simulation or clustering - 11%. Within optimization approaches 63% are on heuristic algorithms and 37% on exact algorithms. Genetic algorithms are very popular within heuristic approaches (70%), and only 2 in 13 articles use tabu search as an alternative method. The “main” algorithm is often combined with contributions from fuzzy set theory, because of the ill-defined nature of the selection process. In MADM, the combination of fuzzy numbers with AHP is the most frequent.

4) Criteria may be grouped into two main classes (table 2): a) risk (e.g. political stability, economy status of the region, financial health, market fluctuations, competency), costs and time factors (35%); and b) other attributes (such as trust, technology level, capacity resources, organization structure, financial status, past performance, quality, etc.). In this last group: a) 49% use quantitative information expressed by numbers, percentages or performance indices; b) 19% use numerical scales; c) 11% use fuzzy numbers to deal with the vagueness of the DM preferences; and d) 22% use linguistic terms to facilitate the expression of DM preferences. Usually the linguistic terms are fuzzified, i.e., transformed in fuzzy sets.

Table 2: Criteria on which the partner selection is based

From this survey, it is also possible to draw some useful preliminary conclusions about the main research trends for partner selection in a virtual enterprise context, namely there is:

- an enormous concern about optimising the solution, i.e. to select the right partner;
- a need to obtain complete and diversified information (multiple attributes) about each potential partner;
- subjectivity in the data;
- a need to facilitate the expression of the decision maker's assessments about the potential partners;
- a real concern with dynamic aspects (i.e. time dependent issues).

4. Developed approach

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

The classic model based on risk and cost factors is a 0-1 integer programming with a nonlinear objective and several inequality and equality constraints (Cao and Gao, 2006). Due to the complexity and the nonlinearity of the model, it cannot be efficiently solved by conventional methods. With exact algorithms it is in general impossible, for large problems, to obtain a satisfactory solution in a reasonable computational time. Metaheuristics assume therefore an important role in solving this kind of problems.

In this work, we have implemented a Tabu Search (TS) metaheuristic (see e.g. Glover and Laguna 1997). By a memory mechanism, TS is able to forbid certain movements during the search process, in order to diversify it. To do this, it stores the most recently accepted solutions or solution attributes (in a “tabu list”) so that solution cycling is prevented (this is one of the main competitive advantages of TS when compared with other heuristic approaches). In our problem, by repeatedly running these algorithms, it is possible for a given project, to generate a large set of solutions taking into account the different attributes (thus generating a set of “trade-off” solutions). However, this set should also be small enough to be treatable and understandable by the DM. Moreover, it should cover the entire “trade-off curve”, i.e. it should contain solutions that represent well the different possible compromises between the attributes. Ideally we would like to have a representative set of nondominated alternative solutions.

A solution (i.e. a potential VE configuration) is represented by a set of companies in the network, associated to the different project activities, along with the corresponding attribute values. In implementation terms, the set of initial solutions is generated through the following simple process:

- Create a *table of enterprises, activities and constraints* (e.g. capacities). A given activity may be performed by a group of enterprises if, for example, separately they do not have enough resources. In this case, the group of enterprises is added to the network as a single unit and the attribute values associated to this unit result from the attribute values of the different enterprises.
- By scanning that table, a candidate solution (set of enterprises) is created that optimizes each criterion considered separately. This means that this initial set is composed by as many solutions as criteria.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
A multi-start improvement strategy was adopted, with these initial solutions. The improvement of a solution is then done by local search, with a neighbourhood structure that consists in swapping, for each activity, an enterprise in the current solution with an enterprise outside the solution (from the *table of enterprises*). The activities are explored by the order they have been defined in the project. In this way, the search starts by attempting to bring into the solution an alternative enterprise that can do the first activity. If this replacement leads to a non-dominated alternative, this new set of enterprises is saved in the *table of alternatives*. Then this process is repeated with the other activities. The best solution found is kept as the new current solution since the strategy used in the neighbourhood search is the “best improvement”.

25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
Two tabu lists are used: the first forbids the utilization of the enterprises recently chosen, and the second forbids the choice of the last activity selected. The tabu tenure of the first tabu list is determined randomly from a given interval (in our case, [number of nodes/10; number of nodes/2]). This exploration of the neighbourhood is repeated until the search cannot reach any alternative solution (i.e. non-dominated alternative) during a constant number ξ of consecutive iterations (in our case, 5000 iterations). The search only accepts feasible solutions. An intensification strategy is adopted after a given number of consecutive dominated solutions are found, and this strategy consists of re-starting the procedure with one of the non-dominated start solutions kept.

4.2 *Multi-attribute decision-making*

4.2.1 *Linguistic Approach*

45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
There are many decision situations in which the attributes cannot be assessed precisely in a quantitative form, due to their particular nature (e.g. trust) or because either information is unavailable or the cost of their computation is too high. In these situations an “approximate value” may be acceptable and so the use of a qualitative approach is appropriate (Herrera et al., 2004). “Linguistic variables” will represent qualitative aspects, with values that are not numbers but words or sentences in a natural language, thus making it easier to express preferences. Since linguistic variables are not

directly mathematically operable, to cope with this difficulty, each linguistic variable is associated with a fuzzy number characterizing the meaning of each generic verbal term. *The linguistic term set*, usually called S , comprises a set of linguistic values that are generally ordered and uniformly distributed. For example, a set S of seven terms could be given as follows: $S = \{s_0 = \text{none}; s_1 = \text{very low}; s_2 = \text{low}; s_3 = \text{medium}; s_4 = \text{high}; s_5 = \text{very high}; s_6 = \text{perfect}\}$, in which $s_a < s_b$ if $a < b$. The semantics of the elements in the term set (the meaning of each term) is given by fuzzy numbers defined on the $[0, 1]$ interval and described by membership functions.

The theory of Fuzzy Sets was introduced by Zadeh in 1965. It was developed to solve problems in which the descriptions of activities and observations are imprecise, vague and uncertain. A fuzzy set is a class of objects, with a continuum of membership grades that can be taken as intermediate values between 0 and 1. A fuzzy subset A of a universal set $S(x)$ is defined by a membership function $f(A(x))$ which maps each element x in $S(x)$ to a real number on $[0, 1]$. When the grade of membership for an element is 1, the element is considered to be absolutely in that set. When the grade of membership is 0, that element is absolutely not in the set. Ambiguous cases are assigned values between 0 and 1 (Lin, H-Y. et al., 2007). Since the linguistic assessments given by the individuals are approximate, because it may be impossible or unnecessary to obtain more accurate values, Herrera et al. (2002) consider that trapezoidal or triangular membership functions are good enough to capture the vagueness of those linguistic assessments. In our case we have adopted triangular membership functions because they are intuitively easy for the decision makers to use and calculate.

Therefore, the membership function considered in this work is:

$$\mu_i = \begin{cases} 1 & \text{if } b_i = x \\ 0 & \text{if } x \notin \text{to term label} \\ \frac{x - a_i}{b_i - a_i} & \text{if } a_i \leq x \leq b_i \\ \frac{c_i - x}{c_i - b_i} & \text{if } b_i \leq x \leq c_i \end{cases} \quad (11)$$

Figure 3: A set of seven terms

In our work, we accept different types of variables: numerical, interval, and linguistic and, in the case of linguistic variables, we also accept different cardinalities for S , and different semantics in the term set, depending on the DM and/or the attribute in question. This becomes an advantage as it allows the DM to be more or less detailed, when dealing with different attributes.

4.2.2 Fuzzy TOPSIS procedure

TOPSIS is one classical Multi-Criteria Decision-Making method, developed by Hwang and Yoon (1981). Based on the idea that the chosen alternative should be as “close” as possible to the positive ideal solution and, on the other hand, as “far” as possible from the negative ideal solution (see Figure 2), the method is very easy to implement. However, it assumes the satisfaction of the following requirements: a previous assignment of weights to the attributes by the DM, and a fixed, pre-defined number of alternatives (Shih et al., 2004).

Figure 4: TOPSIS

Fuzziness is inherent to most decision making processes when linguistic variables are used to describe qualitative data. In this context, we will use an extension of the TOPSIS procedure for fuzzy data based on the following steps:

1. Identify the evaluation criteria
2. Generate the alternatives
3. Evaluate alternatives in terms of the criteria (i.e. compute the fuzzy values of the criterion functions)
4. Identify the weights of the criteria
5. Construct the fuzzy decision matrix
6. Compute the normalized fuzzy decision matrix
7. Construct the weighted normalized fuzzy decision matrix
8. Identify a fuzzy positive ideal solution and a fuzzy negative ideal solution

9. Compute the distance between each alternative i and the fuzzy positive ideal solution (eq. 12) and between each alternative i and the fuzzy negative ideal solution (eq. 13)

10. Compute the “closeness coefficient” to determine the ranking order of all alternatives (eq. 14)

$$d_i^+ = \sum_{j=1}^N d(v_{ij}, v_{ij}^+), \quad i \in M, \quad (12)$$

$$d_i^- = \sum_{j=1}^N d(v_{ij}, v_{ij}^-), \quad i \in M \quad (13)$$

where N is the total number of alternatives and M the set of criteria and $v_{ij}^+ = (1, 1, 1)$ is the fuzzy positive ideal solution and $v_{ij}^- = (0, 0, 0)$ is the fuzzy negative ideal solution for each criterion (benefit or cost criterion).

$$R_i = d_i^- / (d_i^+ + d_i^-), \quad i \in M \quad (14)$$

Our approach presents some differences to the standard procedure namely:

a) To construct the fuzzy decision matrix we first need to transform the numerical values, interval values and linguistic terms into fuzzy sets (see Herrera et al., 2004) by using equation (11). Due to the incommensurability among attributes, to do this transformation we previously need to normalize the values of the attributes (thus not requiring to do step #6 above). The most commonly used normalization method is as follows (Wang^b and Parkanc, 2006):

$$z_{ij} = \frac{x_{ij} - x_j^{\min}}{x_j^{\max} - x_j^{\min}}, \quad i=1, \dots, n \quad j \in \Omega_1, \quad (15)$$

$$z_{ij} = \frac{x_j^{\max} - x_{ij}}{x_j^{\max} - x_j^{\min}}, \quad i=1, \dots, n \quad j \in \Omega_2, \quad (16)$$

where $X = n \times m$ is a decision matrix, z_{ij} are the normalized attribute values, $x_j^{\min} = \min_{1 \leq i \leq n} \{x_{ij}\}$, $x_j^{\max} = \max_{1 \leq i \leq n} \{x_{ij}\}$, and the sets Ω_1 and Ω_2 are, respectively, the sets of benefit attributes and cost attributes.

b) Since each solution involves a given number of companies for the same project activities, and to evaluate that solution we take the values of each attribute considered for each company separately, we may need to use an aggregation mechanism to evaluate each potential VE configuration. This obviously leads to some loss of information. To avoid it we consider some artificial attributes that characterize the solution itself. In this way, for a given project with I activities and a network of enterprises characterized by M attributes, the solution includes the enterprises that will perform the I activities ($M \times I$ attributes). Following this principle we do not need to perform any aggregation and we keep all the information of all enterprises in the solution.

c) Instead of using fuzzy numbers in the fuzzy decision matrix we use fuzzy sets since we want to give more autonomy to the DM (through the use of different and more extensive cardinality ranges in linguistic attributes). Therefore we use distance formulas for membership functions (see Balopoulos et al. 2007). For any two fuzzy sets $A, B \in f(S(X))$, with membership functions μ and ν , respectively, we use the following normalized euclidean distance:

$$d_{nE}(\mu, \nu) = \sqrt{\frac{1}{n} \sum_{i=1}^n (\mu(x_i) - \nu(x_i))^2} \quad (17)$$

4.2.3 Sensitivity Analysis

Sensitivity analysis adequately reflects the final DM's assessments about the criteria importances, since they are determined subjectively. In the example below, the weights are given in terms of a percentage, but it is possible that the DM uses linguistic terms to express the criteria importances. The DM certainly wishes to identify the impact of changes in the weight coefficients on the ranking order obtained. This analysis is made by changing each weight criterion, maintaining the others constant, i.e. with the same proportionality, in order to obtain stability intervals for each criterion.

5. Illustrative example

Assume we would like to form a VE to perform 2 projects decomposed in 6 activities each (Table 3). Project 1 can start immediately and has to be completed before day 165. Project 2 can start

1
2
3 on day 10 and has to be completed before day 234. Data are such that projects can be performed
4 simultaneously, and one company or group of companies are able to perform more than one activity in
5 a project, or to perform activities in both projects.
6
7
8
9

10
11
12 **Table 3:** Projects data
13
14

15
16 Consider a network where 12 different activities that require 10 different resources can be
17 performed. The network is composed by 100 companies characterized by: company code (number in
18 the interval [1-100]; activity; interval time for the availability of resources; capacity; and 8 evaluation
19 attributes (Table 4). The attribute types may be: linguistic, numerical and interval. We may want to
20 maximize the attribute (benefit criteria) or minimize it (cost criteria). If the attribute is linguistic, the
21 scale cardinality has to be defined (3, 5, 7). Figures have been randomly generated. The duration of
22 activities is also randomly defined in the interval [30, 100], the *earliest start time* randomly defined in
23 the interval [0, 365 - duration], the *latest finish time* randomly defined in the interval [earliest start
24 time, 365] and the *quantity of resources* randomly defined in the interval [100, 1000].
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50

51 **Table 4:** Description of attributes
52
53
54
55
56
57
58
59
60

Figure 3 presents the precedence diagram of each project, and Figure 4 presents a Gantt chart of the resources showing possible conflicts between the activities.

Figure 5: Sequence graphs for projects 1 and 2

Figure 6: Gantt chart of projects 1 and 2

We can notice that there are conflicts between activities concerning the use of the same resource, for example, activities D and G require resource 8 at the same time. To avoid these situations and to

ensure that a feasible solution is obtained, we allow the existence of some slack, for each activity. By applying the Tabu Search procedure we have obtained 10 non-dominated alternatives as shown in Table 5. In this table, each row contains the VE composition for the project activities (i.e. the companies assigned to the activities). For example, solution VE1 for project 1 includes companies 83, 81, 48, 68, 39 and 81, respectively for activities 1, 2, 3, 4, 5 and 6.

Table 5: Non-dominated alternatives

5.1 Fuzzy TOPSIS approach

Following, the inputs have been fuzzified, according to their own membership function and linguistic variables terms set, without performing any type of aggregation. An example of the fuzzy sets employed can be seen in table 6 for project 1, non-dominated alternative 1 and criterion 7 (cost per unit). The calculations for project 1, non-dominated alternative 1, activity 2, criterion 7 and cardinality 4 (corresponding to M in figure 1) to determine the correspondent element of the fuzzy set are: $0.14370811 = (0.67 - 0.64557) / (0.670 - 0.5)$, with 0.64557 being the normalized value obtained through $(218 - 116) / (218 - 60)$ where 218 and 60 are the maximum and minimum values for that criteria in the original data, respectively, and 116 is the original value for the alternative 1, activity 2 in respect to criterion 7.

Table 6: Example of fuzzy sets

Afterwards, we calculated the ranking of the non-dominated alternatives set, shown in table 6, through the computation of the distances between each alternative and the fuzzy set positive and negative ideal solutions, as well as the “closeness coefficients”. Only at this stage, do we make an aggregation of information, in order to show the results to the DM in understandable way. Otherwise, the DM was forced to analyze which would be the best alternative for each criterion, which could be tedious and difficult. Moreover, in spite of the fact that, in our example, the best alternative has the shortest distance to d^+ and the highest distance to d^- , that may not be the case and then it would be

1
2
3 even more difficult to the DM to chose one alternative (one example of this issue can be found in
4
5 Crispim and Sousa (2005)³.
6
7
8
9

10 **Table 7:** Closeness coefficients / ranking of the alternatives
11

12
13
14 Analysing the results obtained from the two ranking approaches, we would recommend for
15 project 1, recommend VE₄, clearly better (0.05128) than VE₃, in the second position with 0.04535;
16
17 and for project 2, VE₃.
18
19
20
21

22 **5.2 Sensitivity analysis**

23
24 The stability intervals of each criterion, see Figure 7, show the intervals where the first
25 position of the ranking previously obtained (table 6) remains unaffected. For example (figure 5), in
26 project 1 the weight of the first criterion can change between [-1%, 23%[without affecting the
27 winning VE configuration (VE₄).
28
29
30
31
32

33
34 **Figure 7:** Projects 1 and 2 - stability interval
35
36
37

38 **6. Conclusions**

39
40 Partner selection in VE is a critical process and consists in choosing the entities to be involved
41 in an emergent business opportunity, according to their attributes and interactions. The work
42 presented in this paper is in line with the key trends we have identified in a comprehensive literature
43 survey, by namely considering: a) multiple attributes to describe/structure the decision problem; b)
44 different types of “variables” in order to facilitate the expression of the preferences of the decision-
45 maker; c) the subjectivity of information that leads to the use of a “fuzzy” approach; d) an
46 optimization perspective through the use of metaheuristics; and e) the dynamic aspects occurring
47 when various projects take place simultaneously.
48
49
50
51
52
53
54
55
56
57
58
59
60

³ page 152; table 4

1
2
3 The purpose of this study is to develop an easy-to-use and flexible multi-period decision
4 support system for the partner selection problem. The development of dynamic (multi-period) and
5 flexible approaches is very important in the VE research area because of the temporary distinctive
6 nature of this type of collaboration. The flexibility of the approach arises from the possibility of
7 choosing different objectives and constraints for each project, and from the variety of variable types
8 that the DMs can use to express their preferences. This way, the main managerial implication of this
9 work is to provide a generalized research framework that can be used to analyze and structure many
10 partner selection situations.
11
12

13
14
15
16 The proposed approach presents a hybrid algorithm that uses, for the first time in this domain
17 (for our best knowledge), a multi-objective multi-period metaheuristic combined with the TOPSIS
18 technique in a fuzzy environment, to search and rank potential VE configurations.
19
20

21
22
23 This work can also be of great relevance in the Professional Virtual Communities context,
24 namely in *research and development projects* where coordinators try to find a group of persons with
25 different skills and capacities for performing some specific research activities.
26
27

28
29
30 Our conclusions may have been partially affected by the fact that we have gathered simulated
31 data. In future research we will therefore need to apply real world data and improve the approach to
32 cope with situations where the product or service to be delivered is not known or structured in
33 advance.
34
35
36
37
38
39
40
41
42
43

44 **References**

- 45
46 Araz C., Ozfirat M.P. and Ozkarahan I., 2007. An integrated multicriteria decision-making methodology for outsourcing management.
47 *Computers & Operations Research*, 34, 3738 – 3756.
48
49 Bettencourt, F. and Rabelo, R.J., 2005. A Systematic approach for VE partners selection using the SCOR model and the AHP method. *In*
50 Camarinha-Matos, L.M., Afsarmanesh, H. and Ortiz, A., eds. IFIP International Federation for Information Processing. *Collaborative*
51 *Networks and their breeding environments..* Boston, MA: Springer, 224, 99 – 108.
52
53 Camarinha-Matos L.M., Afsarmanesh H., 2003. Elements of a base VE infrastructure, *Computers in Industry*, 51, 139–163.
54
55 Cao^a H. and Gao Y., 2006. Penalty Guided Genetic Algorithm for Partner Selection Problem in Agile Manufacturing Environment.
56 *Intelligent Control and Automation, WCICA 2006*, Volume 1, 21-23 June 2006, 3276 – 3280.
57
58 Cao^b J., Ye F., Zhou G. and Huang H., 2004. A new method for VE partner selection and evaluation based on AHP and fuzzy theory. *The*
59 *8th International Conference on Computer Supported Cooperative Work in Design*, Volume 2, 26-28 May 2004, 563 – 566.
60

International Journal of Production Research

- 1
2
3 Cao^c J. and Zhou G., 2006. Partner Selection and Evaluation in Agile Virtual Enterprise Based upon TFN-AHP Model. *The 10th*
4 *International Conference on Computer Supported Cooperative Work in Design*, 3-5 May 2006, 1 – 6.
- 5
6 Cao^d J., Ye F. and Zhou G., 2006. A New Web-based Method for Partner Selection in the Agile Virtual Enterprise. *The Sixth World*
7 *Congress on Intelligent Control and Automation, WCICA 2006*. Volume 2, 21-23 June 2006, 6920 – 6924.
- 8
9 Carrera D.A. and Mayorga R.V., 2007. Supply chain management: a modular Fuzzy Inference System approach in supplier selection for
10 new product development. *Journal of Intelligent Manufacturing*. DOI 10.1007/s10845-007-0041-9.
- 11
12 Chen^a C-T., Lin C-T and Huang S-F., 2006. A fuzzy approach for supplier evaluation and selection in supply chain management.
13 *International Journal of Production Economics* 102, 289–301.
- 14
15 Chen^b, Q.X., Chen, X. and Lee, W.B., 2007. Qualitative search algorithms for partner selection and task allocation in the formulation of
16 virtual enterprise. *International Journal of Computer Integrated Manufacturing*, 2 (20), 115-.
- 17
18
19 Crispim, J. and Sousa, J.P., 2005. A multi-criteria decision support system for the formation of collaborative networks of enterprises. *In*
20 *Camarinha-Matos, L.M., Afsarmanesh, H. and Ortiz, A., eds. IFIP International Federation for Information Processing. Collaborative*
21 *Networks and their breeding environments*. Boston, MA: Springer, 224, 143 – 154.
- 22
23 Crispim, J. and Sousa, J.P., 2007. Multiple criteria partner selection in virtual enterprises. *In Camarinha-Matos, L.M., Afsarmanesh, H.,*
24 *Novais, P. and Analide, C., eds. IFIP International Federation for Information Processing. Establishing the Foundation of*
25 *Collaborative Networks*. Boston, MA, Springer. 243, 197-206.
- 26
27 Dai C. and Yang Y., 2005. The method integration model for partner selection in the virtual enterprise. *Proceedings of International*
28 *Conference ICSSSM '05 on Services Systems and Services Management*. Volume 1, 13-15 June 2005, 716 – 720.
- 29
30 Ding H., Benyoucef L. and Xie X., 2006. A simulation-based multi-objective genetic algorithm approach for networked enterprises
31 optimization. *Engineering Applications of Artificial Intelligence*, 19, 609–623.
- 32
33 Dotoli^a M., Fanti M.P., Meloni C. and Zhou M.C., 2005. A multi-level approach for network design of integrated supply chains.
34 *International Journal of Production Research* 43(20), 4267 – 4287.
- 35
36 Dotoli^b M., Fanti M. P., Meloni C. and Zhou M. C., 2006. Design and Optimization of Integrated E-Supply Chain for Agile and
37 Environmentally Conscious Manufacturing. *IEEE transactions on systems, man, and cybernetics—part a: systems and humans*, 36(1),
38 62-75.
- 39
40 Gao F., Cui G., Zhao Q. and Liu H., 2006. Application of Improved Discrete Particle Swarm Algorithm in Partner Selection of Virtual
41 Enterprise. *IJCSNS International Journal of Computer Science and Network Security*, 6 (3A), 208-212.
- 42
43 Gaonkar, R. and Viswanadham, N., 2004. A conceptual and analytical framework for the management of risk in supply chains. *IEEE*
44 *International Conference on Robotics and Automation, ICRA '04*. Volume 3, Apr 26-May 1, 2004, 2699 – 2704.
- 45
46 Glover F. and Laguna M., 1997. *Tabu search*. Boston, USA. Kluwer Academic Publishers.
- 47
48 Gülçin B., Orhan F. and Erdal N., 2007. Selection of the strategic alliance partner in logistics value chain. *International Journal of*
49 *Production Economics*, DOI:10.1016/j.ijpe.2007.01.016.
- 50
51 Hajidimitriou Y.A. and Georgiou A.C., 2002. A goal programming model for partner selection decisions in international joint ventures.
52 *European Journal of Operational Research*, 138 (3), 649-662.
- 53
54 Heavy, C., Byrne P.J., Liston P. and Byrne, J., 2006. Operational design in VO supply networks creation. *In Camarinha-Matos, L.M.,*
55 *Afsarmanesh, H. and Ollus, M., eds. IFIP International Federation for Information Processing. Network-Centric Collaboration and*
56 *Supporting Frameworks*. Boston, MA, Springer, 224, 381 – 388.
- 57
58
59
60

International Journal of Production Research

- Herrera F., Martínez L. and Sánchez P.J., 2004. Decision Aiding Managing non-homogeneous information in group decision making. *European Journal of Operational Research* 166 (1), 115-132.
- Herrera F., Lopez E., Rodríguez M.A., 2002. A linguistic decision model for promotion mix management solved with genetic algorithms. *Fuzzy Sets and Systems*, 131, 47 – 61.
- Huang^a H. and Chen J., 2005. A partner selection method based on risk evaluation in virtual enterprises. *International Conference on Services Systems and Services Management, ICSSSM '05*. Volume 1, 13-15 June 2005, 608 – 612.
- Huang^b X. G., Wong y. S., Liu z. J. and Qiu z. M., 2005. Critical-path-analysis-based dynamic component supplier optimization. *International Journal of Computer Integrated Manufacturing*, 18(8), 702 – 709.
- Huang^c, X., Wong, Y. and Wang, J., 2004. A two-stage manufacturing partner selection framework for virtual enterprises. *International Journal of Computer Integrated Manufacturing*, 17, 294 – 304.
- Ho, G. T. S., Lee, C. K. M., Lau, H. C. W. and Ip, A. W. H., 2006. A hybrid intelligent system to enhance logistics workflow: An OLAP-based GA approach. *International Journal of Computer Integrated Manufacturing*, 19 (1), 69-78.
- Ip^a W.H., Huang M., Yung K.L. and Wang D., 2003. Genetic algorithm solution for a risk-based partner selection problem in a virtual enterprise. *Computers and Operations Research*, 30 (2), 213-231.
- Ip^b W.H., Yung K.L. and Wang D., 2004. A branch and bound algorithm for sub-contractor selection in agile manufacturing environment. *International Journal of Production Economics*, 87 (2), 195-205.
- Jarimo, T. and Pulkkinen, U., 2005. A Multi-criteria mathematical programming model for agile virtual organization creation. In Camarinha-Matos, L.M., Afsarmanesh, H. and Ortiz, A., eds. IFIP International Federation for Information Processing. *Collaborative Networks and their breeding environments*. Boston, MA: Springer, 224, 127 – 142.
- Jarimo, T., Salkari, I. and Bollhalter, S., 2006. Partner Selection with Network Interdependencies: An Application. In Camarinha-Matos, L.M., Afsarmanesh, H. and Ollus, M., eds. IFIP International Federation for Information Processing. *Network-Centric Collaboration and Supporting Frameworks*. Boston, MA, Springer, 224, 389 – 396.
- Kahraman C., Cebeci U. and Ulukan Z., 2003. Multi-criteria supplier selection using fuzzy AHP. *Logistics Information Management*, 16 (6), 382-394.
- Kang K., Zhang J. and Xu B., 2007. Optimizing the Selection of Partners in Collaborative Operation Networks in Advanced Intelligent Computing Theories and Applications with Aspects of Artificial Intelligence. *Lecture Notes in Computer Science*, 4682, 836-850.
- Kim T-Y, Lee S., Kim K. and Kim C-H., 2006. A modeling framework for agile and interoperable virtual enterprises. *Computers in Industry* 57, 204–217.
- Ko C. S., Kim T. and Hwang H., 2001. External partner selection using tabu search heuristics in distributed manufacturing. *International Journal of Production Research*, 39 (17), 3959-3974.
- Li Y. and Liao X., 2007. Decision support for risk analysis on dynamic alliance. *Decision Support Systems* 42, 2043– 2059.
- Liao, X-W and Tang, H-W., 2003. An evidential reasoning approach for partner selection in dynamic alliance. *Computer Integrated Manufacturing System (China)*, 9 (1), 57-62.
- Lin C-W R. and Chen H-Y S., 2004. A fuzzy strategic alliance selection framework for supply chain partnering under limited evaluation resources. *Computers in Industry* 55, 159–179.
- Lin H-Y, Hsu P-Y and Sheen G-J., 2007. A fuzzy-based decision-making procedure for data warehouse system selection. *Expert Systems with Applications*, 32, 939–953.

International Journal of Production Research

- 1
2
3 Ma, X., Han, J., Wei, Z. and Wang, Y., 2007. An improved adaptive Genetic Algorithm in Optimization of Partner Selection. *Eighth ACIS*
4 *International Conference on Software Engineering, Artificial Intelligence, Networking, and Parallel/Distributed Computing, SNPD*
5 *2007*. Volume 3, 30 July 2007- 1 Aug. 2007, 455 – 460.
6
7
8 Mikhailov L., 2002. Fuzzy analytical approach to partnership selection in formation of virtual enterprise. *Omega* 30, 393 – 401.
9
10 Ren, F., Zhang, M. and Bai, Q., 2007. A Fuzzy-Based Approach for Partner Selection in Multi-Agent Systems. *6th IEEE/ACIS International*
11 *Conference on Computer and Information Science, ICIS 2007*, 11-13 July 2007, 457 – 462.
12
13 Ma, X., Han, J., Wei, Z. and Wang, Y., 2007. An improved adaptive Genetic Algorithm in Optimization of Partner Selection. *Eighth ACIS*
14 *International Conference on Software Engineering, Artificial Intelligence, Networking, and Parallel/Distributed Computing, SNPD*
15 *2007*. Volume 3, July 30 2007-Aug. 1 2007, 455 – 460.
16
17 Ng W.L., 2007. An efficient and simple model for multiple criteria supplier selection problem. *European Journal of Operational Research*,
18 DOI:10.1016/j.ejor.2007.01.018.
19
20 Sha D.Y. and Che Z.H., 2005. Virtual integration with a multi-criteria partner selection model for the multi-echelon manufacturing system.
21 *International Journal of Advance Manufacturing Technology*, 25, 793–802.
22
23 Sari B., Sen T. and Kilic S. E., 2007. AHP model for the selection of partner companies in virtual enterprises. *International Journal of*
24 *Advance Manufacturing Technology*. DOI 10.1007/s00170-007-1097-6.
25
26 Shih H-S., Wang C-H. and Lee E. S., 2004. A multiattribute GDSS for aiding problem-solving. *Mathematical and computer modelling* 39,
27 1397-1412.
28
29 Tang Q., Fang X. and Xiang-Bo L., 2006. Multiobject Decision-Making Model for Virtual Enterprise Partners Selection. *International*
30 *Conference on Machine Learning and Cybernetics*, Aug. 2006, 1790 – 1795.
31
32 Viswanadham, N. and Gaonkar, R.S., 2003. Partner selection and synchronized planning in dynamic manufacturing networks. *IEEE*
33 *Transactions on Robotics and Automation*, 19 (1), 117 – 130.
34
35 Xia W. and Wu Z., 2007. Supplier selection with multiple criteria in volume discount environments. *Omega* 35, 494 – 504.
36
37 Xu S., Shen L., Zhai J., Yang Z. and Li Y., 2006. Research on Virtual Logistic Enterprises Partners Selection Method Based on CLIQUE.
38 *10th International Conference on Computer Supported Cooperative Work in Design*, May 2006, 1 – 5.
39
40 Zeng Z., Li^a Y., Li^b S. and Zhu W., 2005. A New Algorithm for Partner Selection in Virtual Enterprise. *Sixth International Conference on*
41 *Parallel and Distributed Computing, Applications and Technologies, PDCAT 2005*. 05-08 Dec. 2005, 884 – 886.
42
43 Zhao^a F-Q, Zhang Q-Y. and Yang Y-H., 2006. A Hybrid Self-Adaptive PSO Algorithm and its Applications for Partner Selection in
44 Holonic Manufacturing System (HMS). *International Conference on Machine Learning and Cybernetics*, Aug. 2006, 2536 – 2541.
45
46 Zhao^b H., Jiang K., Cao W. and Yu Z., 2006. A Novel Partner Selection Algorithm Based on GA and Fussy Decision-Making in
47 Manufacturing Extended Enterprise. *The Sixth World Congress on Intelligent Control and Automation, WCICA 2006*.
48 Volume 2, 21-23 June 2006, 6934 – 6938.
49
50 Zhao^c F., Hong Y. and Dongmei W., 2004. A Novel Genetic Algorithm for Partner Selection Problem in Virtual Enterprise. *Proceedings of*
51 *the 2004 International Conference on Intelligent Mechatronics and Automation Chengdu*, August 26-31China, 2004, 477 – 482.
52
53 Zhao^d F., Hong Y. and Dongmei W., 2006. A multi-objective optimization model of the partner selection problem in a virtual enterprise and
54 its solution with genetic algorithms. *International Journal of Advanced Manufacturing Technology*, 28, 1246–1253.
55
56 Wang^a D., Yung K. L. and Ip W. H., 2001. A Heuristic Genetic Algorithm for Subcontractor Selection in a Global Manufacturing
57 Environment. *IEEE transactions on systems, man, and cybernetics—part c: applications and reviews*, 31 (2), 189.
58
59
60

International Journal of Production Research

- 1
2
3 Wang^b Y-M and Parkanc C., 2006. A general multiple attribute decision-making approach for integrating subjective preferences and
4 objective information. *Fuzzy Sets and Systems* 157, 1333 – 1345.
- 6 Wang^c T-C. and Chen Y-H., 2007. Applying consistent fuzzy preference relations to partnership selection. *Omega* 35, 384 – 388.
- 8 Wang^d, J. and Lin, H. -Y., 2006. A fuzzy hybrid decision-aid model for selecting partners in the design chain. *International Journal of*
9 *Production Research*, 44 (10), 2047 – 2069. DOI: 10.1080/00207540500354028.
- 11 Wu N. and Su P., 2005. Selection of partners in virtual enterprise paradigm. *Robotics and Computer-Integrated Manufacturing*, 21 (2), 119-
12 131.
- 14 Yang C., Xue H. and Ding J., 2006. A Adaptive Genetic Algorithm for Selecting Partners in Virtual Enterprise. *The Sixth World Congress*
15 *on Intelligent Control and Automation, WCICA 2006*. Volume 2, 21-23 June 2006, 6826 – 6830.
- 17 Ye F. and Li Y., 2005. Multi-attribute decision-making model for virtual enterprise partners selection under uncertain information condition.
18 International Conference on Services Systems and Services Management, ICSSSM '05. Volume 2, 13-15 June 2005, 1162 – 1165.
- 20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Table 1: Research Context/Methods Organization

Method	Research context	Virtual enterprise/ dynamic alliance	Manufacturing	Supply chain
Heuristic algorithms				
Genetic algorithm		Ma et al. (2007)	Cao ^a and Gao (2006)	
+ <i>particle swarm optimization</i>			Zhao ^a et al. (2006)	
+ <i>fuzzy set theory</i>		Tang et al. (2006) Zhao ^c et al. (2004) Ip ^a et al. (2003) Zhao ^d et al. (2006)	Wang ^a et al. (2001) Zhao ^b et al. (2006)	Lin and Chen (2004) Wang ^d and Lin (2006)
+ <i>Dempster-Shafer theory</i>		Yang et al. (2006)		
+ <i>On-Line Analytical Processing</i>				Ho et al. (2006)
+ <i>AHP and MAUT</i>				Sha and Che (2006)
Tabu search			Ko et al. (2001)	
+ <i>2-tuple fuzzy linguistic representation model</i>		Crispim and Sousa (2005)		
+ <i>TOPSIS</i>		Crispim and Sousa (2007)		
<i>ACO (Ant colony optimization) + AHP</i>		Kang et al. (2007)		
Particle swarm optimization		Gao et al. (2006)		
Local search algorithm		Chen ^b et al. (2007)		
Exact algorithms				
Integer programming model		Ip ^b et al. (2004) - B&B		Dotoli ^b et al. (2006)
+ <i>2-phase improvement algorithm</i>			Wu and Su (2005)	
+ <i>AHP and MAUT</i>			Sha and Che (2005)	
Mixed-integer programming model		Jarimo and Pulkkinen (2005)	Viswanadham and Gaonkar (2003)	Gaonkar and Viswanadham (2004)
Multi-objective mixed-integer programming model		Jarimo et al. (2006)		
Nonlinear integer programming with Branch-and-Bound algorithm (B&B)		Zeng et al. (2005)		
Fuzzy goal programming + PROMETHEE				Araz et al. (2007)
Weighted linear program				Ng (2007)
Goal programming model				Hajidimitriou and Georgiou (2002)
Fuzzy set theory				
+ <i>Evidential reasoning</i>		Li and Liao (2007) Liao and Tang (2003)		
+ <i>AHP</i>		Cao ^b et al. (2004) Cao ^c and Zhou (2006) Mikhailov (2002)		Kahraman et al. (2003)
+ <i>clustering</i>		Dai and Yang (2005)		
+ <i>critical path analysis</i>		Huang ^b et al. (2005)		
Fuzzy Comprehensive Evaluation		Huang ^a and Chen (2005)		
Consistent fuzzy preference relations		Wang ^c and Chen (2007)		
Fuzzy Inference System				Carrera and Mayorga (2007)
Fuzzy Topsis				Chen ^a et al., (2006)
Fuzzy decision-making model		Ye and Li (2005) Ren et al. (2007)		Lin et al. (2007)
Analytic hierarchy process (AHP)				
AHP		Sari et al. (2007)		
+ <i>multi-objective mixed integer programming</i>				Xia and Wu (2007)
+ <i>TOPSIS</i>				Gülçin et al. (2007)
+ <i>SCOR model</i>		Bettencourt and Rabelo (2005)		
Others				
Simulation optimization methodology		Kim et al. (2006)	Heavy et al. (2006)	Ding et al. (2006)
CLIQUE cluster analysis				Xu et al. (2006)
Two-stage manufacturing partner selection framework			Huang ^c et al. (2004)	
Multi-level approach: First level: candidate selection; Second level: network design; Third level: solution evaluation and validation				Dotoli ^a et al. (2005)

Table 2: Criteria on which the partner selection is based

Criteria		Article
Risk factors		Ye and Li (2005) Huang ^a and Chen (2005) Jarimo and Pulkkinen (2005) Li and Liao (2007) Zhao ^b et al. (2006)
	+ due date and performance	Yang et al. (2006) Zhao ^c et al. (2004) Zhao ^a et al. (2006)
Operational costs	+ time to market + performance	Gaonkar and Viswanadham (2004) Viswanadham and Gaonkar (2003)
	+ financial costs	Ip ^b et al. (2004)
	+ transportation costs	Ko et al. (2001)
	+ due date	Cao ^a and Gao (2006)
	+ processing time	Wang ^a et al. (2001) Wu and Su (2005)
	+ service level	Ding et al. (2006)
	+ processing time + efficiency	Huang ^b et al. (2005)
	+ completion time of subprojects + due date	Zeng et al. (2005)
	+time + credit	Ma e tal. (2007)
	+ reaction time + risk factor	Gao et al. (2006)
Multiple criteria expressed by:	fuzzy numbers	Cao ^b et al. (2004) Cao ^c and Zhou (2006) Wang ^d and Lin (2006) Kahraman et al. (2003)
	interval pairwise comparisons	Wang ^c and Chen (2007)
	verbal judgements transformed in scale (1-9)	Sha and Che (2005) Kang et al. (2007)
	numerical scale (1-5; 1-9;...)	Hajidimitriou and Georgiou (2002) Huang ^c et al. (2004) Cao ^b et al. (2004) Cao ^d et al. (2006) Mikhailov (2002)
	operational performance indices	Dotoli ^a et al. (2005) Dai and Yang (2005) Sha and Che (2006) Ho et al. (2006)
	linguistic terms and performance ratio measures	Araz et al. (2007)
	linguistic terms	Lin et al. (2007) Gülçin et al. (2007) Carrera and Mayorga (2007) Chen ^a et al. (2006) Ren et al. (2007)
	linguistic terms, numerical and interval numbers	Crispim and Sousa (2005) Crispim and Sousa (2007)
	quantitative information: numbers and percentages	Xu et al. (2006) Xia and Wu (2007) Bettencourt and Rabelo (2005) Tang et al. (2006) Dotoli ^b et al. (2006) Jarimo et al. (2006) Ng (2007) Sari et al. (2007) Lin and Chen (2004) Liao and Tang (2003)
	success probability, processing time, and inefficient candidate	Ip ^a et al. (2003) Zhao ^d et al. (2006)
	number of enterprises, number of redundant basic capability units, and number of basic capability units useful to the manufacturing requirement	Chen ^b et al. (2007)

Table 3: Projects data

Project 1							Project 2						
Activities (code)	Resources	Precedent activities	Duration	Earliest start time	Latest finish time	Quantity of resources	Activities (code)	Resources	Precedent activities	Duration	Earliest start time	Latest finish time	Quantity of resources
A	7	-	36	0	106	400	G	4	-	99	10	159	362
B	8	-	62	0	97	604	H	2	-	56	10	202	206
C	3	-	67	0	122	528	I	9	-	30	10	202	135
D	5	A	16	36	122	275	J	6	G	41	109	202	116
E	4	B	25	62	122	368	L	8	G	44	109	202	221
F	8	C,E,D	43	87	165	304	K	9	H,I,L,J	32	153	234	282

Table 4: Description of attributes

attributes (Objectives)	<i>c1</i>	<i>c2</i>	<i>c3</i>	<i>c4</i>	<i>c5</i>	<i>c6</i>	<i>c7</i>	<i>c8</i>
<i>example</i>	<i>attitude toward uncertainty/risk</i>	<i>productivity</i>	<i>Price (per unit)</i>	<i>production capacity</i>	<i>market entrance capability</i>	<i>partnership experience</i>	<i>Cost (per unit)</i>	<i>technical expertise</i>
type	linguistic	numerical	interval	interval	linguistic	numerical	numerical	linguistic
max (+) / min (-)	+	+	-	-	+	+	-	+
cardinality (for linguistic)	7	-	-	-	3	-	-	7
weight(%)	20	23	2	7	19	13	14	2

For Peer Review Only

Table 5: Non-dominated alternatives

Project 1 <i>Activities</i>							Project 2 <i>Activities</i>						
	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>		<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>
VE1	83	81	48	68	39	81	VE1	39	10	27	17	27	81
VE2	35	22	41	79	75	22	VE2	75	59	27	4	27	22
VE3	21	97	14	26	75	97	VE3	75	59	109	86	109	97
VE4	21	81	14	13	102	81	VE4	77	36	25	51	25	81
VE5	35	71	30	31	47	71	VE5	57	2	110	4	110	71
VE6	74	44	48	55	57	44	VE6	57	2	110	34	110	44
VE7	42	44	41	79	39	44	VE7	39	98	27	56	27	44
VE8	7	44	30	13	75	44	VE8	75	80	110	17	110	44
VE9	100	97	48	90	104	97	VE9	108	98	110	99	110	97
VE10	21	44	41	79	39	44	VE10	39	33	27	56	27	44

Or Peer Review Only

Table 6: Example of fuzzy sets

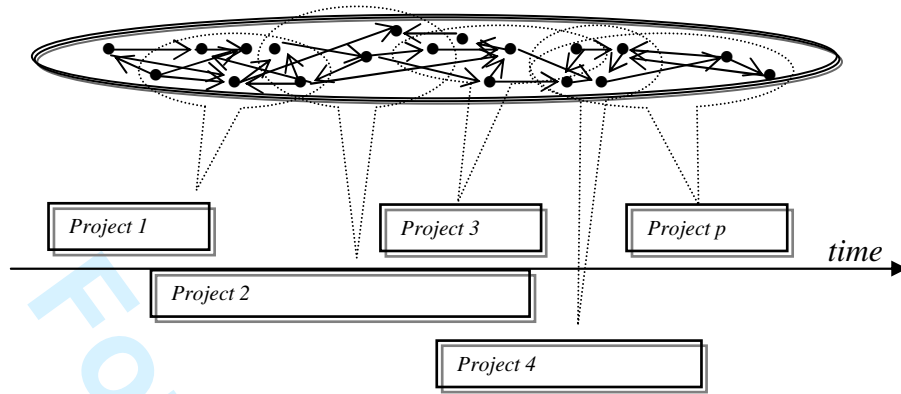
Fuzzy sets for Project 0, 1st alternative, Criterion 7 - partnership experience											
#	activity 1	#	activity 2	#	activity 3	#	activity 4	#	activity 5	#	activity 6
[1]	0.00000000	[1]	0.00000000	[1]	0.00000000	[1]	0.00000000	[1]	0.00000000	[1]	0.00000000
[2]	0.00000000	[2]	0.00000000	[2]	0.00000000	[2]	0.00000000	[2]	0.00000000	[2]	0.00000000
[3]	0.00000000	[3]	0.00000000	[3]	0.54901963	[3]	0.00000000	[3]	0.00000000	[3]	0.00000000
[4]	0.00000000	[4]	0.14370811	[4]	0.45098040	[4]	0.00000000	[4]	0.00000000	[4]	0.14370811
[5]	0.00000000	[5]	0.85629189	[5]	0.00000000	[5]	0.086925283	[5]	0.00000000	[5]	0.85629189
[6]	0.37151715	[6]	0.00000000	[6]	0.00000000	[6]	0.91307473	[6]	0.00000000	[6]	0.00000000
[7]	0.62848282	[7]	0.00000000	[7]	0.00000000	[7]	0.00000000	[7]	1	[7]	0.00000000

Table 7: Closeness coefficients / ranking of the alternatives

Project 1					Project 2				
Rank	VE	\bar{d}_i^+	\bar{d}_i^-	\bar{R}_i	Rank	VE	\bar{d}_i^+	\bar{d}_i^-	\bar{R}_i
1	4	306.394	16.5643	0.05128	1	3	307.100	15.2357	0.04726
2	3	307.585	14.6141	0.04535	2	2	308.035	14.9483	0.04628
3	1	308.198	14.5867	0.04519	3	1	308.248	14.3540	0.04449
4	8	307.644	14.5391	0.04512	4	7	308.392	14.2846	0.04426
5	9	307.804	14.5092	0.04501	5	4	308.263	14.1921	0.04401
6	2	307.913	13.9505	0.04334	6	5	308.451	13.8885	0.04308
7	7	308.742	13.0287	0.04049	7	0	308.835	12.9139	0.04013
8	0	308.631	12.9402	0.04024	8	6	308.952	12.5320	0.03898
9	5	308.548	12.8897	0.04010	9	9	308.841	12.4384	0.03871
10	6	309.021	12.8263	0.03985	10	8	309.093	12.2121	0.03800

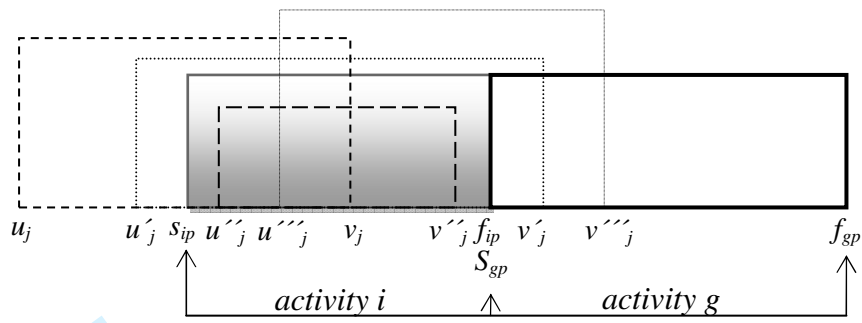
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Figure 1: Multiple projects in a network and VEs



For Peer Review Only

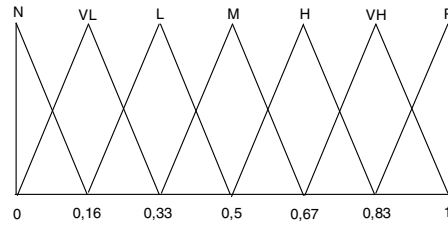
Figure 2: Time window constraint with several hypotheses



For Peer Review Only

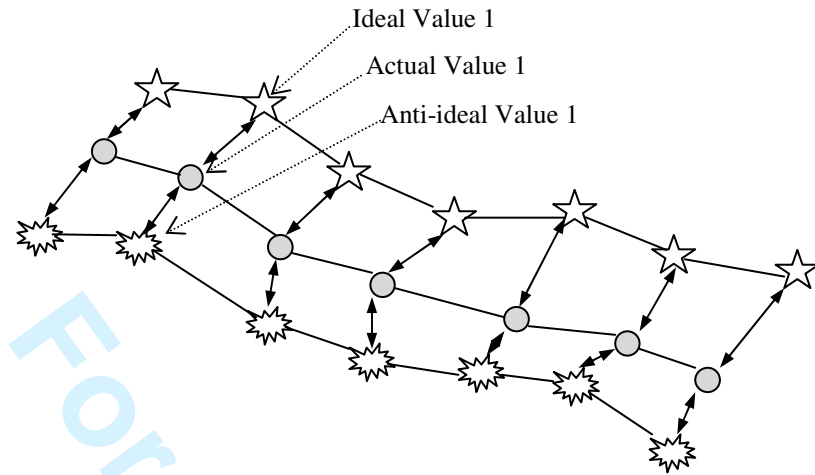
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Figure 3: A set of seven terms



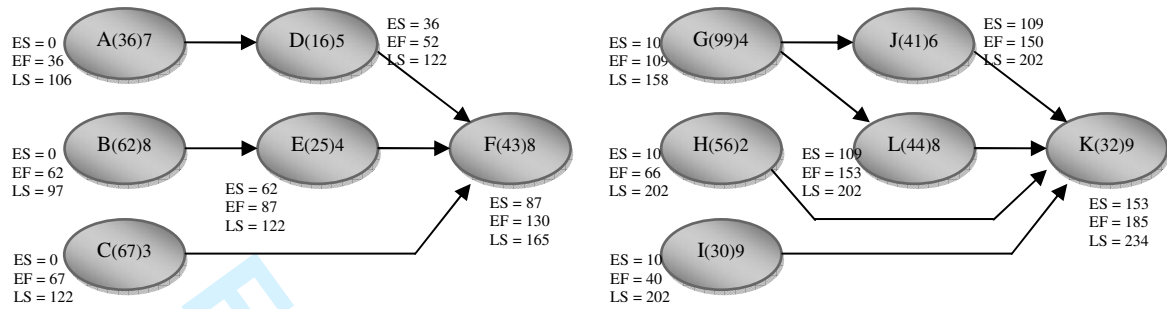
For Peer Review Only

Figure 4: TOPSIS



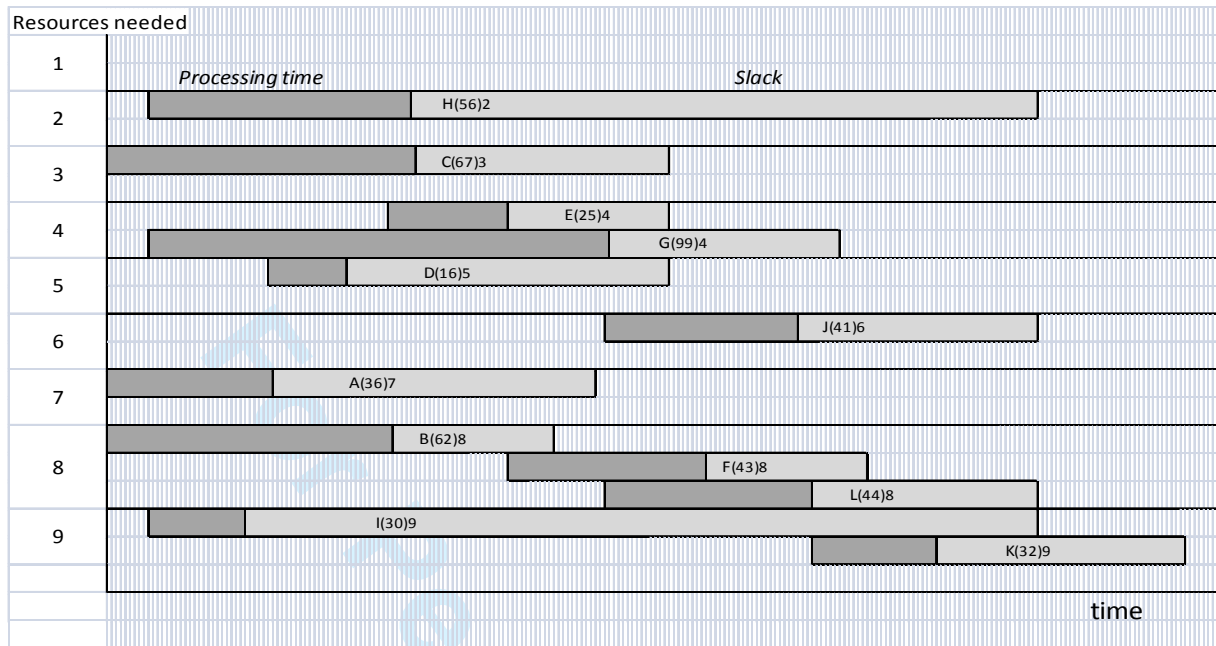
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Figure 5: Sequence graphs for projects 1 and 2



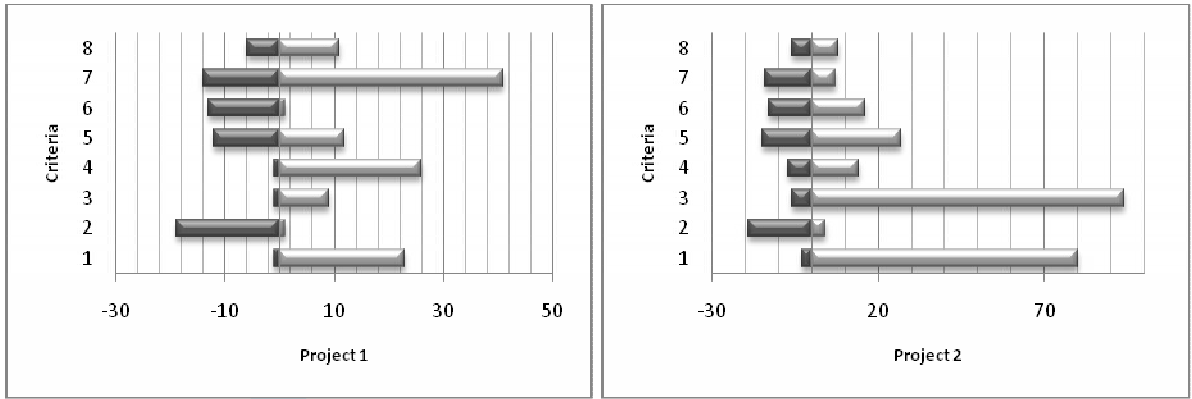
For Peer Review Only

Figure 6: Gantt chart of projects 1 and 2



Peer Review Only

Figure 7: Projects 1 and 2 - stability interval



Or Peer Review Only

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60