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A comprehensive strategic approach for supplier management: selection, homogeneous clustering and negotiation

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Abstract: There is a popular saying that you should not put all your eggs in one basket. We believe that to some extent this adage can be applied to a manufacturer of goods vis-à-vis its suppliers in the sense that it is necessary to diversify the sources of origin of its raw materials or semi-finished products. To select its potential suppliers, the company sets its objectives first and then determines the criteria that must be used to evaluate any potential supplier. In this paper, we assume that the objectives (generally economic, social and environmental objectives), evaluation criteria and a list of suppliers are established by the company, and our goal acting as an analyst is to propose an evaluation framework for building a portfolio of supplier companies and/or clustering them into homogeneous categories for their appropriate treatment. To do this, we propose to apply a multi-criteria analysis method called bipolar analysis.

Keywords: suppliers selection; suppliers homogeneous clustering; bipolar analysis; BOCR analysis; synergistic aggregation.

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Biographical notes: Ayeley Philippe Tchangani received his Ingénieur degree (1995) from the Ecole Centrale de Lille, France, MSc (1995) and PhD (1999) from the Université des Sciences et Technologies de Lille, France in Control and Automation. After a Postdoctoral Fellowship at French South Africa Technical Institute in electronics (Pretoria, South Africa), he joins Université Toulouse III – IUT de Tarbes in 2001 where he is currently an Associate Professor. He holds a research position at Laboratoire Génie de Production (LGP) of Ecole Nationale d'Ingenieurs de Tarbes (ENIT) since 2003. His current research interests are in decision analysis, uncertainty modelling and risk assessment and management. Results of his researches appeared in a number of international refereed journals; a list of his publications is available at <http://publicationslist.org/tchangani>. He regularly serves as internal program committee (IPC) member of international conferences. He is a member of IEEE and MCDM societies.

1 Introduction and statement of the problem

Supply chain management is one of the fastest growing subject in management science, particularly in today globalised economy. Supply chain management include different activities such as purchasing management, transportation management, warehouse management, inventory management, strategic sourcing, and partners relationships management. One important issue raised by the globalisation of activities is how to identify and assess opportunities and risks related to these activities among which possible failure of quality of final product sold to customers. For long time, the primary concern in supply chain management, mainly in the selection of suppliers has been the costs of raw material that count up to 50 of the final price of a product in some industry such as automotive industry, see Weber and Current (1993), so that purchasing activity with suppliers selection has been considered as the capital decision, see Nydick and Hill (1992) and Mobolurin (1995), that determines the long term viability of the company, see Thomson (1990). But quality issues nowadays are becoming a real concern for companies; as a proof of this statement, let us mention the 2007 recall of Berko Electric Toe-Space Heaters made in the USA, the recall of backpack blowers made in Japan, the recall of toys and pet food made in China and recently largely mediatised problem of Fauteil or Bottes made in China that cause skin harms to their owners in France, to name few. Such events are very destabilising for companies that have their main market in developed countries where standards and norms as well as the public opinion are highly developed. Hence, along with classical criteria or attributes such as raw materials price and transportation price, companies must include another dimension related to the risk of quality failure and/or opportunity of quality improvement in their relationship with their suppliers. Along with quality failure of the final product, there may exist other sources including operational failure of the manufacturer process including packaging of the final product to be supplied to customers and/or transportation from manufacturer to customers conditions, quality failure of supplied components and part that can have origin in the failure of suppliers operations, transportation system from suppliers to manufacturer or from manufacturer to customers. Managing risk related to quality failure in supply chain on the manufacturer side is twofold: manage the upstream risk that is its relationship with its suppliers and the downstream risk related to customers. Other concerns in relation with sourcing and production location among others are oil price volatility and labour costs in emerging markets; a short discussion regarding these issues has been considered in Simchi-Levi et al. (2012). Relation with customers is mainly in one way that is customers desires act as constraints for manufacturer so that risk management strategy on this side will consist in warranties manufacturer will offer to customers. In this paper we will concentrate in analysing activities around the suppliers-manufacturer relationships with the manufacturer as the main partner. On the supplier's side, things are more complex as a certain common objectives of doing business may lead to cooperation strategies; two main approaches are used in this case: performance-based contracts and multi-sourcing and closer collaboration. Whereas, the first approach is a matter of the manufacturer who must select and diversify its partners, the second approach necessitates a collaboration of both the manufacturer and the supplier where each partner must act when considering the concerns of the other partner. These approaches can be considered sequentially where the manufacturer will first select a set of potential partners and then engage a close collaboration procedure with each selected partner. Of course the context that is the business environment of

each partner will have a great influence on these strategies. Supply chain management issue has been considered in literature that being analysed below. The problem of inventory management policy of a manufacturing company of automotive components and to propose a new policy which would help to reduce the holding and ordering costs associated with the purchase of its raw materials has been considered in Sánchez et al. (2021). Sahaf et al. (2021) and Babazadeh and Ali (2021) show that parameters of the supply chain network design problem are uncertain ones due to the strategic nature of the problem (Babazadeh and Ali, 2021). Wang et al. (2022) combine supplier involvement with product attributes; it takes a problem-solving perspective to rethink suppliers' roles in new product development as problem-solvers rather than resource holders. Using insights from transaction cost and resource dependence theories, Zhang et al. (2020) explores how to balance coercive and non-coercive powers to enhance GSI and the mediating role of relationship commitment and the moderating role of relationship closeness. The purpose of the study carried in Adesanya et al. (2020) is to explore how tobacco manufacturing companies can improve their sustainability performance via effective supplier relationship management (SRM). The purpose of Green et al. (2019) is to develop and empirically assess comprehensive operations and supply chain management (SCM) model; the theorised model incorporates supply chain market orientation. The purpose of how Knowledge management capabilities (KMC) and corporate social responsibility (CSR) affect operational performance (OP) through supplier relationship management (SRM) in the context of the oil and gas industry has been considered in Shafiee and Tabaeecian (2021). A proactive approach to manage the supply chain risk (SCR) with minimal or no cost increases is proposed by Zohreh (2020). Martin (2017) analyses predictors and outcomes – including possible disadvantages – of a supplier's participation in supply chain finance practices. The notion of design reliability that is the ability to execute supply chains operations despite the disturbances caused by a disruption is considered in Singh (2016). Zabihi and Bafraei (2016) studied the coordination of two-echelon supply chains using stochastic demand that is dependent on retail price and time. Current literature review on resilience and agility in supply chain management from the perspective of risk management in business management in global environments and proposes two approaches to resilience and agility has carried out in Calvo et al. (2020). The nexus of relationships linking firm innovativeness, innovation magnitude, disruption severity, and supply chain resilience has been considered in Golgeci and Ponomarou (2013). Bustinza et al. (2013) addresses the problem of understanding how firms manage their product and service offerings, integrating supply chain management (SCM) and demand chain management (DCM) strategies.

The framework considered here is summarised as follows:

- the supplier is characterised by some attributes that constitute valuable information for manufacturer during selection process; his objectives that are concerns manufacturer must take into account during collaboration phase and actions or decisions he may set up to respond to manufacturer concerns
- the manufacturer have objectives that are balanced with suppliers attributes during selection process and constitute concerns supplier must consider during collaboration and decisions to set up in order to respond eventually to suppliers concerns.

Selection problem has been widely addressed in literature. In terms of mathematical tools to deal with supplier selection problem, multicriteria decision making (Zandkarimkhani et al., 2022; Zakeri et al., 2021), multi-objective problem approaches (Shadkam, 2021) with objectives such as delivery time, cost, quality, the rate of defective goods received, reliability, etc. have been widely considered in dedicated literature such as Zandkarimkhani et al. (2022). A methodological decision analysis model and the qualitative linear weighted point method (LWPM) has been proposed by Taifa et al. (2021) to develop the pertinent critical success decision criteria and virtually distribute the bulk orders equitably for supply chain management (Taifa et al., 2021). A supplier selection and order allocation multi-objective model in stochastic environment in which purchasing cost, percentage of delivered items with delay and percentage of rejected items provided by each supplier are supposed to be stochastic parameters following any arbitrary probability density function has been developed by Moheb-Alizadeh et al. (2017). Decision-making tool based on Taguchi loss function along with the analytical hierarchy process (AHP) to select an optimal supplier that helps firms evaluate and select suppliers based on multiple successful criteria such as quality, on time delivery, cost, service, range of product flexibility, innovation, and greenness has been proposed in Elsaleiby and Abuizam (2016). Group decision making with multi-attribute crisp and interval data and its application to supplier selection problem has been proposed by Azadfallah (2018). Supplier selection problem has been also addressed through extended TOPSIS method by Azadfallah (2016); the same author (Azadfallah, 2020) addressed the question of modelling emotional feelings (particularly, regret factor) with application in supply chain management. The paper citeCho19 suggests that evaluating the sustainability performance of suppliers is much more critical in developing countries. A hybrid algorithm for supplier evaluation and demand allocation among the suppliers has been developed in Yadav and Samuel (2021).

This paper is mainly concerned by selection and negotiation processes. Indeed, we consider that from a prospective search process, a manufacturer has identified a list of potential suppliers from which he will select a short list of suppliers with which he wants to work. Short list selection process is typically a multi-criteria/multi-objectives decision-making problem that will be considered in BOCR analysis framework, see Tchangani (2015) and Tchangani and Pérès (2010); BOCR stands for a decision process that evaluates available options, given an objective, in terms of benefit (B) and opportunity (O) by aggregating certain (respectively uncertain) attributes that support (work towards the achievement of the objective) this objective on one side and cost (C) and risk (R) by aggregating certain (respectively uncertain) attributes that reject (work against the achievement of the objective) that objective.

Negotiation process is a multi-agent decision-making problem where the suited paradigm is game theory. Classically, game theory framework has been established with pure competition assumption whereas in practice (mainly in our supplier chain management problem) players that are actually partners may have interest to cooperate. Main issues in classical cooperative game theory have concerned how to share the created value from cooperation; to this purpose some power indices such as Shapley index are introduced; in supply chain literature this index is used, for instance, by Pan (2010) to share value from reduction of CO₂ emission when enterprises form a pool for their logistics activities. In Talluri (2002), a model to evaluate alternative bids in buyer-seller negotiation and selection process is formulated. Satisficing game theory is a well suited tool to tackle cooperation problem because it highlights bipolar

nature of human decision making, that is given an alternative, one evaluates its positive aspects and its negative aspects separately and then balance them. Satisficing notion has been already considered in supply chain management literature; for instance, He and Khouja (2011) and Shi and Chen (2007) employed this notion in supplier-retailer contracts evaluation. But one must notice that satisficing notion considered in these publications differ from that being considered in this paper in the sense that satisficing in this paper is a point of view that highlights bipolarity of attributes with regard to objectives whereas in the former publications satisficing is related to the attainment of a threshold of a certain indicator. Collaborative planning between supply chain partners based on a negotiation scheme using integer programming method has been considered in Dutek and Stadtler (2005). A three successive steps negotiation procedure has been proposed in Tsurui et al. (2017) to manage relationships between a supplier and a retailer. The investigation of how relatively weaker manufacturers respond to the dominance of stronger suppliers and/or customers is an important issue as shown by Tao et al. (2022). The use of subcontractors' specific knowledge of on-site processes such that productivity and efficiency are enhanced is considered in Grenzfurter and Gronalt (2021). The study carried in Vlachos and Dyra (2020) shows that all multi-sourcing triads achieved efficient coordination via network configuration showing varying degrees of collaboration and integration.

The remainder of this paper is organised as follows: in the second section the problem of selecting a short list of suppliers by a manufacturer is considered with a recall of relevant basics of a single decision maker satisficing game theory; the third section presents the negotiation procedure with a prior recall of multi persons satisficing game; the fourth section considers an illustration and section five concludes the paper.

2 Proposed model

The problem considered here is in fact much more widespread than the title suggests, namely the formation of portfolios of suppliers of a manufacturing company. Indeed, the problem here is to select a sub-set or even to form categories of individuals in the broad sense in order to satisfy certain objectives of the decision maker. Thus we assume that the decision maker has at his disposal a set, possibly very large, of potential units (here potential suppliers) that can meet his expectations and the analyst's work is to find a way or mechanism to select the best ones. But to decide, it is necessary to measure the adequacy between the potential units and the decision maker's objectives; the adequacy can be assessed through the attributes characterising each unit. Therefore, formally, the problem considered here is organised around the following elements:

- a set U of n units potentially capable of satisfying the decision maker is constituted;
- each unit of the set U is characterised by a set A of m attributes that we consider numerically evaluated.

It is therefore necessary to design an algorithm to select a number n^* ($p \leq n^*$) of units or to group these units into k classes. Finally, since each unit is characterised by a numerical vector of m attributes, it can be confused with its attribute vector $x \in R^m$ from which the analyst must design his selection or grouping algorithm. But among

the attributes characterising a unit, there are always some that go in the direction of the decision maker (the stronger their assessment, the better for the decision maker) and others that go in the opposite direction (the weaker their assessment, the better). The aggregation of these two types of attributes for the final evaluation of the unit can be problematic because of the simultaneous combination or weighting of positive and negative aspects. To overcome this possible incomparability, we propose to aggregate separately the positive and the negative aspects, which we refer to as bipolar analysis. Set A of the attributes is therefore divided into positive attributes whose evaluations form a vector $x_p \in R^{m_p}$ and negative attributes with evaluation $x_n \in R^{m_n}$ ($m_p + m_n = m$); x_p and x_n are considered to be normalised (they are positive and sum to 1 over U). The grouping of attributes into homogeneous categories calls for synergistic aggregation in that the simultaneous contribution of two attributes of the same nature is more important than the sum of the contributions. Moreover, in general, the attributes of the same category do not have the same relative importance and analysts and/or decision makers are often able to weight them; let us suppose that we have available the weighting vector ω_p of positive attributes and the weighting vector ω_n of negative attributes; vectors that we consider in a normalised form. A synergistic aggregation operator under these conditions that we use here is the Choquet integral associated with a weighted cardinal fuzzy measure (WCFM) (Tchangani, 2013). Each suppliers u will be ultimately characterised by its positive normalised aggregated $\mu_p(u)$ score and negative one $\mu_n(u)$ that are given by equation (1).

$$\mu_p(u) = \frac{C_{\omega_p}^{wcfm}(x_p(u))}{\sum_{v \in U} \{C_{\omega_p}^{wcfm}(x_p(v))\}} ; \mu_n(u) = \frac{C_{\omega_n}^{wcfm}(x_n(u))}{\sum_{v \in U} \{C_{\omega_n}^{wcfm}(x_n(v))\}} \tag{1}$$

Given a numerically valued n dimension vector θ with a relative importance vector ω , Choquet integral of x associated to a weighted cardinal fuzzy measure with relative importance vector ω is give by equation (2), see Tchangani (2013).

$$C_{\omega}^{wcfm}(\theta) = \sum_{k=1}^n \{ \varphi(A_k) (\theta_{\sigma(k)} - \theta_{\sigma(k-1)}) \} \tag{2}$$

where $\varphi(A_k)$ is a weighted cardinal fuzzy measure of subset A_k given by equation (3)

$$\varphi(A_k) = \left(\frac{n - (k - 1)}{n} \right) \left(\sum_{j \in A_k} \omega_j \right) \tag{3}$$

and A_k is defined as equation (4).

$$A_k = \{ \sigma(k), \sigma(k + 1), \dots, \sigma(n) \} \tag{4}$$

where σ is a permutation over x as given by equation (5).

$$\theta_{\sigma(1)} \leq \theta_{\sigma(2)} \leq \dots \leq \theta_{\sigma(n)}; \theta_{\sigma(0)} = 0 \tag{5}$$

From the measures $\mu_p(u)$ and $\mu_n(u)$ as well as column normalised characterisation x_p and x_n , several practical supply chain or suppliers management problems of a company

can be formulated and solved. This may include, for example, the selection of a limited number of suppliers, which we call a ‘suppliers short list selection’ or *SSLS* for short; it may also be necessary to group potential suppliers into homogeneous classes in order to determine their main common characteristics for appropriate treatment (proposals for improving certain indicators or production processes), we will refer to this latter as homogeneous clustering of suppliers or *HCS* in short. The following sections present the formulation and resolution of these problems.

2.1 *SSLS problem*

In this case, let us assume that the managers of the company in question would like to select a number n^* (with $n^* \leq n$) of suppliers from the initial list U when trying to maximise the ratio between the positive and negative aspects. Let us designate by $\alpha(u)$ a binary index indicating if the supplier u is selected or not, defined by equation (6).

$$\alpha(u) = \begin{cases} 1 & \text{if } u \text{ is selected} \\ 0 & \text{if not} \end{cases} \tag{6}$$

then the selection problem can be formulated as a linear programming problem in binary numbers given by equation (7).

$$\left\{ \begin{array}{l} \max_{u \in U} \left\{ \sum_{u \in U} \left(\frac{\mu_p(u)}{\mu_n(u)} \right) \alpha(u) \right\} \\ \sum_{u \in U} \alpha(u) = n^* \\ \alpha(u) \in \{0, 1\} \end{array} \right. \tag{7}$$

There is a lot of software available to solve this kind of problem among which the *intlinprog* function of the MATLAB optimisation toolbox.

2.2 *HCS problem*

In the case of a homogeneous grouping of suppliers, several homogeneity criteria may be used. The most obvious of the criteria seems to be distance (or dissimilarity) or proximity (or similarity) between suppliers in the attributes space; but it will still be necessary to find the right expression for all these indicators. Several notions of these indicators exist in the literature; but in our sense these indicators can only be of interest if they are calculated between homogeneous attributes, i.e., attributes of the same category evaluated on the same scale. The grouping of the attributes into positive and negative attributes respectively carried out in the previous section therefore allows us to formulate by categorical homogeneity by weighting through ω_p and ω_n vectors x_p and x_n and re-normalising by raw to obtain y_p and y_n that allows us to avoid the difficulties mentioned above. Normalisation therefore makes it possible to treat the vectors y_p and y_n as a probability distribution over the sets R^{m_p} and R^{m_n} respectively. A measure of dissimilarity (or similarity by taking the complement to 1) between two distributions well accepted in the literature is the Kullback-Leibler divergence (Kullback and Leibler,

1951). Thus, from the vectors x_p and x_n we determine two symmetric matrices of similarity (symmetry in the space of positive and negative attributes respectively) between suppliers as given by equations (8)–(9)

$$S_p(u, v) = 1 - \frac{1}{2} (D_p^{KL}(y_p(u)//y_p(v)) + D_p^{KL}(y_p(v)//y_p(u))) \quad (8)$$

$$S_n(u, v) = 1 - \frac{1}{2} (D_n^{KL}(y_n(u)//y_n(v)) + D_n^{KL}(y_n(v)//y_n(u))) \quad (9)$$

where the divergence D^{KL} between two distributions P and Q over a discrete set Ψ is given by equation (10).

$$D^{KL}(P//Q) = \sum_{\psi_i \in \Psi} \left(P(\psi_i) \log \left(\frac{P(\psi_i)}{Q(\psi_i)} \right) \right) \quad (10)$$

The total symmetry $S(u, v)$ between two suppliers u and v is obtained by equation (11) where the parameter δ ($0 \leq \delta \leq 1$) can be used to manage the preference of decision makers.

$$S(u, v) = \delta S_p(u, v) + (1 - \delta) S_n(u, v) \quad (11)$$

3 Some hints for negotiation

Once the short list and/or the clustering of suppliers into homogeneous categories has been made, it may be necessary to enter into negotiation to establish a mutually beneficial partnership contract with each individual supplier (possibly collectively). To this end, each partner, i.e., the company looking for suppliers and each supplier, engages in a kind of negotiation in which each partner takes its decisions taking into account the other's concerns. For example, the company's concerns may lead the supplier to consider the options of:

- 1 undergo a deep amelioration of his production process confirmed by certification process such ISO certification for instance, this will necessitate a great financial and human investment.
- 2 just improve existing procedure by ameliorating its documentation process to keep an easy traceability of potential mistakes for example.
- 3 keep actual situation.

And those of the suppliers oblige the company to consider options such as:

- 1 sign an exclusive long term contract with the supplier
- 2 sign an exclusive short term contract
- 3 sign a simple contract not exclusive nor long term (see for instance Tchangani et al., 2012).

We typically find ourselves in a game problem that we propose to analyse using satisficing games approach. We position the problem in the bilateral case, i.e., the company in front of each supplier or a group of suppliers. So we are dealing with a two-player game where cooperation is allowed so that each party knows the options of the other given by the following sets $D_c = \{d_1^c, d_2^c, \dots, d_{n_c}^c\}$ for the company and $D_s = \{d_1^s, d_2^s, \dots, d_{n_s}^s\}$ for the supplier(s).

The establishment of a mutually beneficial contract is therefore equivalent to selecting a pair of options $d^* = (d_i^c, d_j^s) \in D = D_c \times D_s$ that is satisfactory to both parties. We propose to analyse this problem within the framework of satisficing game theory (Stirling, 2003), which considers the evaluation of options by two measures: a selectability measure (μ_S) that roughly aggregates the positive aspects of the option and a rejectability measure (μ_R) that accounts for the negative aspects of the option. Each partner will therefore evaluate its options by these two measures, for example by carrying out a BOCR analysis of its options vis-à-vis the other's options; this process will therefore lead the company to determine the measures $(\mu_S^c(d_i^c)/\mu_R^c(d_i^c), \forall d_i^c \in D_c)$ and the supplier to establish its own $(\mu_S^s(d_j^s)/\mu_R^s(d_j^s), \forall d_j^s \in D_s)$. These measures should have a probability structure (this can always be obtained by normalisation) that is they verify equation (12).

$$\sum_{d_j^s \in D_s} \mu_{\times}^*(d_j^s) = 1 \tag{12}$$

where $*$ stands for c or s and \times for S or R . The joint measures of selectability μ_S and rejectability μ_R of a pair of options (d_i^c, d_j^s) are defined by equation (13).

$$\mu_S(d_i^c, d_j^s) = \mu_S^c(d_i^c)\mu_S^s(d_j^s) \quad \text{and} \quad \mu_R(d_i^c, d_j^s) = \mu_R^c(d_i^c)\mu_R^s(d_j^s) \tag{13}$$

From the previous defined measures the negotiation process can goes as following:

- Each partner defines its satisficing set as giving by equations (14) and (15)

$$\Sigma_{q_c}^c = \{d_i^c \in D_c : \mu_S(d_i^c) \geq q_c \mu_R(d_i^c)\} \tag{14}$$

and

$$\Sigma_{q_s}^s = \{d_j^s \in D_s : \mu_S(d_j^s) \geq q_s \mu_R(d_j^s)\} \tag{15}$$

where q_c is the boldness or caution index of the company and q_s that of supplier;

- Define the joint satisficing set at the boldness index $q = \min(q_c, q_s)$ as given by equation (16)

$$\Sigma_q = \{d \in D = D_c \times D_s : \mu_S(d) \geq q \mu_R(d)\} \tag{16}$$

- Determine the compromise set of (the set of all decision vectors d that are jointly satisficing at boldness index $q = \min(q_c, q_s)$ where the component d_i^c or d_j^s is satisficing for decision maker c or s denoted C_c or C_s is called the compromise set of company c or supplier s) each partner as given by equations (17) and (18); this set is known to be non-empty in any conditions (Stirling, 2003).

$$C_c = \{d = (d_i^c, d_j^s) \in \Sigma_q \quad \text{and} \quad d_i^c \in \Sigma_{q_c}^c\} \tag{17}$$

and

$$C_s = \{d = (d_i^c, d_j^s) \in \Sigma_q \text{ and } d_j^s \in \Sigma_{q_s}^s\} \tag{18}$$

- Form the satisficing imputation set N_q (N_q contains joint decision that provides benefit to the group while ensuring that each decision makers preferences are not compromised) given by equation (19).
- If N_q is empty then no compromise is possible and one of partner must lower its standards (by reducing for instance its boldness index) in order to reach a compromise.

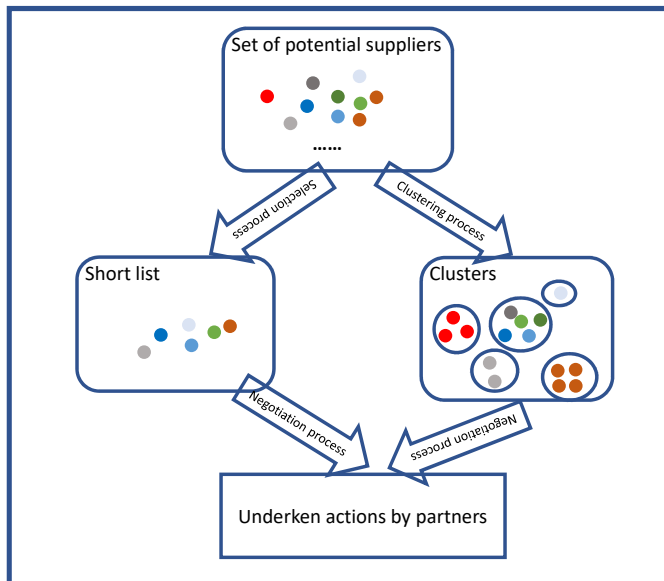
$$N_q = C_c \cap C_s \tag{19}$$

- Once a non-empty satisficing imputation set N_q is reached one can select a joint imputation decision within this set using some criterion; for instance that given by equation (20)

$$d^* = \arg \left\{ \max_{d \in N_q} \left\{ \frac{\mu_S(d)}{\mu_R(d)} \right\} \right\} \tag{20}$$

All the elements forming the basis of the idea of this paper are summarised in Figure 1

Figure 1 Graph summarising the developed model (see online version for colours)



4 Applications

4.1 Case study in selection and clustering

4.1.1 Description

This application is adapted from data of a problem considered by Araz and Ozkarahan (2007) and cited in Nemery (2008). A manufacturing company, in the field of electronic industry, would like to develop strategic partnerships with a set of (hopefully) innovative suppliers. Integration of the right suppliers in concurrent engineering teams is an important factor for success, see Araz and Ozkarahan (2007). For this purpose, the company would like to evaluate its suppliers (and some emergent ones) in order to distinguish them. The purpose is obviously not to rank the suppliers. A ranking of the suppliers may not be adapted since for example the worst supplier may be completely in line with the need of the company. On the other hand, the best supplier may not be adapted at all for the company. In this situation, new suppliers need to be found. For these reasons the company wants to compare the suppliers according to some norms or reference profiles which will be representative of their strategy and needs; that is nominally classifying potential suppliers into predefined classes or categories. Therefore, classes and attributes characterising suppliers are discussed in the following.

4.1.1.1 Classes or categories

Company has identified four classes or categories described as following:

- c_1 : suppliers for strategic partnerships
- c_2 : promising suppliers that must be supported via supplier development programs
- c_3 : suppliers for competitive partnerships: they have to be considered for competitive partnerships for some products
- c_4 : suppliers to be pruned: they should no longer be considered for the partnership in any level.

4.1.1.2 Attributes or criteria

The company uses ten attributes described below to evaluate potential suppliers:

- a_{01} : support in product structural design
- a_{02} : support in process design and engineering
- a_{03} : design revision time
- a_{04} : prototyping time
- a_{05} : level of technology
- a_{06} : quality performance
- a_{07} : financial strength
- a_{08} : cost reduction performance

- a_{09} : delivery performance
- a_{10} : ease of communication.

All attributes, except of a_3 and a_4 (small is better), have to be maximised (high is better) and the preference parameters are given in Table 1. The values of the parameters are determined by the interaction with the concurrent design team.

Table 1 Raw data of of illustrative application

Suppliers (u_i)	Attributes (a_j)									
	a_{01}	a_{02}	a_{03}	a_{04}	a_{05}	a_{06}	a_{07}	a_{08}	a_{09}	a_{10}
u_{01}	84	83	12	7	85	85	80	85	95	90
u_{02}	72	78	7	5	70	70	80	75	95	90
u_{03}	70	82	7	7	80	85	89	65	90	95
u_{04}	70	68	20	25	75	70	60	90	70	90
u_{05}	70	95	15	5	95	50	95	95	80	95
u_{06}	90	85	30	32	85	60	70	77	80	85
u_{07}	80	75	15	7	80	95	70	84	90	80
u_{08}	86	90	10	5	85	85	92	75	99	90
u_{09}	92	85	30	26	90	60	92	75	90	90
u_{10}	70	65	25	28	60	60	75	70	60	60
u_{11}	75	85	30	32	65	50	90	80	89	60
u_{12}	92	90	8	5	90	90	85	92	99	90
u_{13}	72	75	27	10	80	70	80	70	89	80
u_{14}	55	60	28	32	70	85	60	65	70	60
u_{15}	95	90	8	5	90	90	85	85	98	90
u_{16}	95	95	8	7	95	95	95	92	95	90
u_{17}	70	75	24	12	85	80	84	70	86	80
u_{18}	80	70	10	7	85	60	80	60	95	90
u_{19}	95	90	7	7	95	85	85	95	97	95
u_{20}	60	70	30	30	60	60	80	70	60	80
u_{21}	90	90	15	5	80	90	80	75	99	90
u_{22}	70	60	30	15	60	50	60	75	70	65
weights (ω_j)	0.15	0.10	0.10	0.10	0.08	0.15	0.05	0.12	0.10	0.05

4.1.2 Results

Due to the limited space, only the main lines of the results will be given. Since the attributes are all positive except a_3 and a_4 , the vectors x_p and x_n are composed of the normalised values per column of the initial data of attributes $\{a_{01}, a_{02}, a_{05}, a_{06}, a_{07}, a_{08}, a_{09}, a_{10}\}$ and attributes $\{a_{03}, a_{04}\}$ respectively; weighting vectors ω_p and ω_n are obtained corresponding components of initial weighting vector ω and are given by equations (21) and (22).

$$\omega_p = [0.1923, 0.1282, 0.1026, 0.1923, 0.0641, 0.1282, 0.1282, 0.0641] \tag{21}$$

$$\omega_n = [0.5, 0.5] \tag{22}$$

The vectors y_p and y_n by normalising by rows x_p and x_n weighted by their weighting vectors ω_p and ω_n as shown by equation (23).

$$y_p(u)[j] = \frac{\omega_p(j)x_p(u)[j]}{\sum_{k=1}^{m_p=8} \omega_p(k)x_p(u)[k]}; \quad y_n(u)[j] = \frac{\omega_n(j)x_n(u)[j]}{\sum_{k=1}^{m_n=2} \omega_n(k)x_n(u)[k]} \quad (23)$$

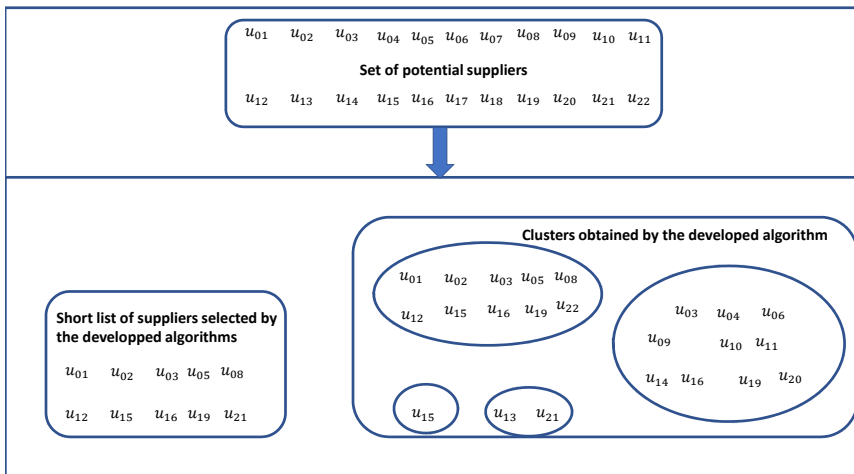
After this process we obtain vectors μ_p and μ_n as well as similarity matrix S that we do not show here because of limited place.

4.1.2.1 SLS problem

In the case of SLS problem, solving the problem defined by equation (7) using *intlinprog* function of MATLAB for $n^* = 10$, we obtain the subset of the selected suppliers of equation (24).

$$\{u_{01}, u_{02}, u_{03}, u_{05}, u_{08}, u_{12}, u_{15}, u_{16}, u_{19}, u_{21}\} \quad (24)$$

Figure 2 Results of selection and clustering processes for the considered application (see online version for colours)



4.1.2.2 HCS problem

In the case of grouping suppliers into homogeneous classes without this having a value of comparison with the original study (Araz and Ozkarahan, 2007; Nemery, 2008) that produced the data used, the division into four classes of suppliers in this problem using the MATLAB clusterdata function leads to the results given by equations (25)–(28).

$$C_1 = \{u_{01}, u_{02}, u_{03}, u_{05}, u_{08}, u_{12}, u_{15}, u_{16}, u_{19}, u_{22}\} \quad (25)$$

$$C_2 = \{u_{03}, u_{04}, u_{06}, u_{09}, u_{10}, u_{11}, u_{14}, u_{16}, u_{19}, u_{20}\} \quad (26)$$

$$C_3 = \{u_{05}\} \quad (27)$$

$$C_4 = \{u_{13}, u_{21}\} \quad (28)$$

4.2 Illustrative academic example of negotiation

Suppose that after establishing a short list given by equation (24), the company decides to enter into negotiations with each supplier for a mutually beneficial contract. Suppose, as outlined above, that the consideration of each other’s concerns led both partners to consider the following options:

- *Supplier’s options:*

- d_1^s undergo a deep amelioration of his production process confirmed by certification process such ISO certification for instance, this will necessitate a great financial and human investment
- d_2^s just improve existing procedure by ameliorating its documentation process to keep an easy traceability of potential mistakes for example
- d_3^s keep actual situation.

- *Supplier’s options:*

- d_1^c sign an exclusive long term contract with the supplier
- d_2^c sign an exclusive short term contract
- d_3^c sign a simple contract not exclusive nor long term.

Let us assume that after bipolar evaluation of the options, for example by pairwise comparison of the options of one conditional on the choice of the other, both partners arrive at the selectability and rejectability measures given in Table 2 (see Tchangani et al., 2012 for details of the pairwise comparison calculations).

Table 2 Illustrative negotiation data

Company			Supplier		
Options	μ_S^c	μ_R^c	Options	μ_S^s	μ_R^s
d_1^c	0.3230	0.4233	d_1^s	0.4170	0.4565
d_2^c	0.3262	0.3621	d_2^s	0.3468	0.3370
d_3^c	0.3508	0.2145	d_3^s	0.2363	0.2065

For a common boldness or caution index equal to 1 ($q_c = q_s = 1$), we obtain the following sets (negotiation materials), equations (29)–(34)

$$\Sigma_1^c = \{d_3^c\} \tag{29}$$

$$\Sigma_1^s = \{d_2^s, d_3^s\} \tag{30}$$

$$\Sigma_1 = \{(d_1^c, d_3^s), (d_2^c, d_3^s), (d_3^c, d_2^s), (d_3^c, d_3^s)\} \tag{31}$$

$$C_c = \{(d_3^c, d_2^s), (d_3^c, d_3^s)\} \tag{32}$$

$$C_s = \Sigma_1 \tag{33}$$

$$N_1 = C_c \cap C_s = C_c = \{(d_3^c, d_2^s), (d_3^c, d_3^s)\} \tag{34}$$

As the imputation set is not empty, the mutual most beneficial d^* selected using the criterion of equation (20) is given by equation (35).

$$d^* = (d_3^c, d_3^s) \quad (35)$$

meaning that, given actual situation, it is better to sign a simple contract for company and supplier keep its actual manufacturing process.

5 Conclusions

A problem of defining a framework within which suppliers of a given company can be managed in several ways was the subject of this paper. Management can consist of selecting a short list of suppliers from a potentially large set of suppliers or dividing a company's potential suppliers into homogeneous classes for appropriate treatment. To do this, they must be evaluated according to several attributes; in terms of defining and evaluating supplier attributes or, in general, a company's partners for a specific purpose, this company is generally able to list the attributes and both the way and the scale of evaluation. It is precisely this problem that has been considered in this paper as important sub-problems, either the selection of a short list of potential suppliers or their repartition into homogeneous classes. In this paper we first proposed to divide the attributes into two sub-classes according to whether their contribution to the objective is positive or negative; this allows for their comparison in order to make them much easier to compare. Indeed, it is not easy for a decision maker or an expert to compare two attributes that go in opposite directions towards the same objective. The solutions provided are either to aggregate the attributes often in their category and use this evaluation to determine a short list of suppliers by maximising the ratio of positive to negative aspects or to use this evaluation to construct a similarity matrix that is used to divide suppliers into homogeneous classes using classical machine learning approaches and tools such data clustering function (*clusterdata*) of MATLAB. An application of the proposed approach to a real problem shows undeniable potentialities. In future work, instead of using existing algorithms on the similarity matrix, we believe it should be possible to design more efficient clustering algorithms from this similarity matrix. The other contribution of this paper is the ideas (to be further developed in future work) presented for the negotiation process between a company and its supplier on a win-win basis.

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