A Multicriteria Multilevel Group Decision Method for Supplier Selection and Order Allocation

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ABSTRACT

Supplier selection is an integral part of supply chain management (SCM). It plays a prominent role in the purchasing activity of manufacturing and trading companies. Evaluation of vendors and procurement planning requires simultaneous consideration of tangible and intangible decision factors, some of which may conflict. A large body of analytical and intuitive methods has been proposed to trade off conflicting aspects of realism and optimize the selection process. In the large companies the fields of decision makers’ (DMs) expertise are highly distributed and DMs’ authorities are unequal. On the other hand, the decision components and their interactions are very complex. These facts restrict the effectiveness of using the existing methods in practice. The authors present a multicriteria decision analysis (MCDA) method which facilitates making supplier selection decisions by the distributed groups of experts and improves quality of the order allocation decisions. A numerical example is presented and applicability of the proposed algorithm is demonstrated in the Raiffeisen Westfalen Mitte, eG in Germany.

Keywords: Multi-Criteria Decision Analysis (MCDA), Multilevel Group Decision Making (MLGDM), Order Allocation, Supplier Selection, Supply Chain Management

INTRODUCTION

The formalization of complex decision problems requires comprehensive and accurate modeling of the problem environment, its elements and their interactions. Selection of the valid solution methods for such problems is a very challenging task. Fictitious simplifications of decision situations lead to management debacles and loss of profits. To avoid this, the research efforts should be focused on the flexible decision aiding framework which could enable problem-oriented modularization of the decision processes, their exhaustive analysis by a set of appropriate and consistent methods and generation of robust solutions. A variety of empirical studies have been conducted to improve decision making in teams. Still, the complex nature of decision groups has been left without proper attention in the analytical decision science. To fill this gap we first introduce notions of Multilevel Group Decision Making (MLGDM) to distinguish between the $\alpha$, $\beta$ and $\gamma$ decision makers (DMs). $\alpha$-voting power is
proposed to elicit DMs’ contribution to criteria prioritization; β-voting power is used to measure experts’ ability to evaluate performance of alternatives with respect to the set of direct decision criteria; γ-voting power index reflects the DMs’ expertise in evaluation of auxiliary decision components on indirect criteria.

Presented in this paper; the case study was completed in cooperation with Raiffeisen Westfalen Mitte eG (also referred to as Raiffeisen), an agricultural cooperative society operating in Germany, Nord-Rhein Westfalen, since the 18th century, with annual turnover exceeding 275 Mio. Euro in 2010. One of the largest trading companies of crops, animal feed and fertilizers also selling fuel oils is a significant aspect of the company’s strategy. We have developed a structured, multilevel group MCDA framework to aggregate multiple objective factors and group subjective expert judgments to enable the strategic evaluation of fuel oil suppliers and optimizing purchasing activity by aligning strategic priorities of the DMs with their daily decisions.

**PROPOSED ALGORITHM AND ITS APPLICATION**

Taking complex multicriteria decision, including purchasing, is a consequent multistage process. We designed the algorithm that includes 16 steps summarized below.

**1. Identify Overall Purpose of the Decision**

A first step of MCDA is to establish a clear goal pursued. Generally decision theory deals with three main types of problems: choice, ranking and classification (Zopounidis, 2002). Choice is selection of the most appropriate alternative or set of alternatives. Generally, organizations have two approaches to supplier selection. The first approach is to select the best single supplier, which can meet all the requirements (single sourcing). The second approach is to select an appropriate combination of suppliers (multiple sourcing) (Sanayei et al., 2008).

Ranking of suppliers is ordering of alternatives based on measuring of their contribution to the achievement of the stated decision objectives. Classification is division of alternatives into predefined homogeneous classes which are not necessarily ordered, on the other hand in sorting problems groups are ordered from the best to worst (Zopounidis, 2002). The proposed multilevel group framework is aimed at performing the following analytical functions:

- Derive consensus based rankings of suppliers in accordance with their strategic performance. Rankings serve as a legitimate and transparent foundation for establishment of partnership strategies, selection of long-term contractors and stimulation of supplier development.
- Classification of vendors into the groups reflecting their relative competitive advantages and disadvantages.
- Support Just-In-Time (JIT) purchasing decisions for trading activity based on market-rate prices taking into consideration compound strategic weights of vendors.

**2. Form Decision Making Group**

Once the goal is stated, a group comprised of the people responsible for the successful implementation of the decision must be formed. Zeleny (2010) asserts that any DM makes a decision either for himself or for others, therefore a distinction between the decision producer (or provider) and decision consumer (or customer) has to be drawn. According to the Crown copyright Multi-criteria analysis manual (Crown, 2009) there are two main types of DMs: stakeholders whose organization’s values should find expression in the decision, and key players who can make a useful and significant contribution to the MCDA and represent important perspectives on the subject of the analysis. Numerical reviews in the field of decision making have concluded that groups learn faster, make fewer errors, recall better, make better decisions, and are more productive, with a higher-quality product than individuals.
Baron et al., 1992; Davis, 1969; Johnson & Johnson, 2003; Laughlin & Early, 1982). The decision group may include:

- Board members and CEOs having clear understanding of the organization’s strategy;
- Subject matter experts at various levels having insight to evaluate organization environment, functional design of the company and specific areas of its activity, including purchasing;
- Representatives who can properly define what suppliers should be considered in the decision process;
- Experts who can provide reasonable estimates for proposed suppliers; and
- Operative managers who are deeply involved with the issue at hand and will implement the decision.

Group decision making does not mean that all team members have to be involved in every aspect of a decision; instead they are expected to process data and apply their individual expertise to contribute to the outcome (Saaty & Peniwati, 2008).

In the proposed decision analysis framework is considered a group of $K$ DMs ($k = 1, 2, ..., K$). In the study conducted for Raiffeisen was organized a decision group including a Raiffeisen’s board member and managers from purchasing department ($K = 3$).

3. Define, Describe and Structure a Finite Set of Decision Criteria

In modern management, one needs to consider many factors with the aim of developing a long-term supplier relationship (Muralidharan et al., 2006). Choosing the right suppliers involves much more than scanning a series of price lists, and choices will depend on a wide range of factors which involve both quantitative and qualitative (Ho et al., 2010). The multi-criteria decision models allow the integration of both objective and subjective criteria to produce an aggregate performance measure (Akarte et al., 2001). In the numerous scientific publications it is clearly indicated that vendor selection has a multi-objective nature implying that multiple conflicting criteria need to be considered in the supplier evaluation and selection process (Dickson, 1966; Weber et al., 1991). These criteria must be defined according to the corporate strategies and the company’s competitive situation (Sanayei et al., 2008). According to Bouyssou (1990), the criteria set must have two key qualities; be readable (i.e., include a number of criteria restricted enough so that it is possible to reason on this basis and eventually to model the inter and intra-criteria information required to perform an aggregation procedure) and be operational (i.e., be acceptable as a working basis for the study). Even Swaps method (Hammond et al., 1998) can be applied to simplify the complex decision and reduce the number of objectives in the consequences table.

In multi-criteria analysis decision factors can be grouped into contradictory categories. First classification approach for making trade-offs among various indicators was outlined by Benjamin Franklin in 1772 in his “Moral of prudential algebra” and is known as method of Pros and Cons (Hammond et al., 1998). Other classification schemes include opportunities and threats for evaluation of strategic courses of action (Tavana & Sodenkamp, 2010), division into benefits and costs (Triantaphyllou & Baig, 2005), internal strength and weaknesses along with external opportunities and threats (SWOT) (Tavana et al., 2010; Ghazinoory et al., 2011) or alternatively, consideration of existing benefits and opportunities and potential costs and risks (BOCR) (Saaty & Sodenkamp, 2010). Performance of alternatives on positive criteria has to be maximized and on negative criteria minimized. When the number of factors is large, typically more than a dozen, they may be arranged hierarchically (Saaty, 1977; Triantaphyllou, 2000) or as a feedback network (Saaty, 1996). Such structures allow for a systematic grouping of metrics in complex decision problems.

Proposed here, the supplier evaluation model is based on the Pros&Cons classification method.
tion, where each class contains a three-level hierarchy of criteria. Let us define:

\[ M = \text{The total number of groups of factors;} \quad (m = 1, 2, \ldots, M) \]
\[ N = \text{The total number of decision criteria;} \quad (n = 1, 2, \ldots, N) \]
\[ L = \text{The total number of sub-criteria;} \quad (l = 1, 2, \ldots, L) \]
\[ C_{\text{Pros}} (C_{\text{Cons}}) = \text{The cluster “Pros” (“Cons”) including subjective and objective positive (negative) factors;} \]
\[ C_{\text{Pros}} (C_{\text{Cons}})_{m} = \text{The } m\text{-th group of factors within the Pros (Cons) cluster;} \quad (m = 1, 2, \ldots, M_{\text{Pros}}) \]
\[ M_{\text{Pros}} (M_{\text{Cons}}) = \text{The number of groups of factors within the Pros (Cons) cluster;} \]
\[ N_{\text{Pros}} (N_{\text{Cons}}) = \text{The number of attributes within the Pros (Cons) cluster;} \]
\[ L_{\text{Pros}} (L_{\text{Cons}}) = \text{The number of sub-criteria within the Pros (Cons) cluster;} \]
\[ N_{\text{Obj}} (N_{\text{Sub}}) = \text{The number of objective (subjective) decision criteria;} \]
\[ L_{\text{Obj}} (L_{\text{Sub}}) = \text{The number of objective (subjective) sub-criteria;} \]
\[ C_{\text{Pros}} (C_{\text{Cons}})_{n} = \text{The } n\text{-th factor within the } m\text{-th group of the Pros (Cons) cluster;} \quad (m = 1, 2, \ldots, M_{\text{Pros}}; \quad n = 1, 2, \ldots, N_{\text{Pros}}) \]
\[ C_{\text{Cons}} (C_{\text{Sub}})_{m} = \text{The } l\text{-th sub-factor of factor within the } m\text{-th group of the Pros (Cons) cluster;} \quad (m = 1, 2, \ldots, M_{\text{Cons}}; \quad n = 1, 2, \ldots, L_{\text{Cons}}) \]

Based on the reviews of vendor selection criteria (Dickson, 1966; Weber et al., 1991; Sen et al., 2008; Inemak & Tuna, 2009) and interviews with Raiffeisen representatives we identified 20 criteria \((N = 20)\) including 5 sub-factors \((L = 5)\) categorized into 6 groups \((M = 6)\) and arranged them into the hierarchy. The Pros category included 17 strategic criteria allocated among the six groups \((M_{\text{Pros}} = 6)\). The first group; Flexibility included three criteria \((N_{\text{Pros Flexibility}} = 3)\) one of which was comprised of three sub-criteria \((L_{\text{Pros Flexibility Product Mix}} = 3)\). The second group; Service included three criteria \((N_{\text{Pros Service}} = 3)\) one of which was divided into two sub-criteria \((L_{\text{Pros Service Good Communication System}} = 2)\). The other three groups included 2 to 5 criteria each one \((N_{\text{Pros Logistics}} = 3, N_{\text{Pros Relations}} = 5, N_{\text{Pros Financial}} = 2)\) without further division into sub-criteria. The Cons category included one tactical negative attribute and three strategic criteria allocated among the two groups \((M_{\text{Cons}} = 2)\), strategic criteria in the group of Risks \((N_{\text{Cons Risks}} = 3)\) and the tactical criterion Price belonged to the group Financial \((N_{\text{Cons Financial}} = 1)\).

The hierarchy of decision criteria for Raiffeisen’s fuel suppliers is visualized in Figure 1 and description of individual criteria is given in Table 1.

**4. Define Decision Alternatives**

The contemporary supply chain management is to maintain long term partnership with suppliers, and use fewer but reliable suppliers (Ho et al., 2010). Aissaoui et al. (2007) stated that today’s logistics environment requires a low number of suppliers as it is very difficult to manage high numbers. Therefore, inefficient candidates should be not included into the evaluation process. In Just-In-Time environment the majority of companies prefer to follow a strategy of a single supplier or at least with few suppliers (Ansari & Modarresss, 1986). Quarly (1998) presented the factors of determining the policy of a single or multi supplier selection. The elimination method is a useful approach for suppliers pre-selection. The idea is that suppliers who do not satisfy the minimum level of key criteria are not accepted for further consideration. Hammond et al. (1998) stated that one may simplify a complex decision by looking for the practical dominance in the consequences table. This method reduces the
number of alternatives and helps to focus only on highly competitive options.

We consider a set \( \{A_i\} \) of discrete elements \( A_i \) denoting alternatives (\( i = 1,2,\ldots,I; I \geq 2 \)).

The DMs from Raiffeisen selected eight suppliers (\( I = 8 \)) for the evaluation process: \( A_1 = GRG, A_2 = Atrian, A_3 = Certyoil, A_4 = Naronaft, A_5 = Vetic, A_6 = Petrolium Nord, A_7 = West Petrol Group \) and \( A_8 = POSF \).

5. Build Decision Hierarchy

Hierarchy is a fundamental tool of human thinking and the most common way to organize decision problems (Saaty & Peniwati, 2008). Saaty (1994) suggests using the hierarchy containing three basic levels of elements connected from the top to the bottom; goal on the top, decision criteria on the intermediate level and alternatives on the bottom, as shown in Figure 2.
Real decision problems usually have a more complex hierarchical structure than is depicted by Saaty and involve criteria that characterize alternatives not directly, but through some external objects. The main reason why such objects may have to be considered as a part of decision hierarchy is the impossibility in some cases to provide direct assessment of alternatives, according to a set of defined decision criteria due to reflection by those

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Description</th>
<th>Measurement Unit</th>
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<tbody>
<tr>
<td>Volume Flexibility</td>
<td>Supplier’s capabilities and readiness to increase/decrease the ordered quantities at short notice</td>
<td>Subjective scale (SS)</td>
</tr>
<tr>
<td>Rush Order Processing</td>
<td>Possibility to purchase and deliver the products within a short time</td>
<td>SS</td>
</tr>
<tr>
<td>Product Mix</td>
<td>Purchased quantities of other products during the period</td>
<td>Thousand litres</td>
</tr>
<tr>
<td>Business Hours</td>
<td>Number of business hours during the week</td>
<td>Hours</td>
</tr>
<tr>
<td>Information Exchange</td>
<td>Information and forecasts regarding situation in the industry, market trends and other relevant information e.g., advertising tactic</td>
<td>SS</td>
</tr>
<tr>
<td>Number of Contact Persons</td>
<td>Number of contact persons authorized to take orders and to reply to inquiries</td>
<td>Integer number</td>
</tr>
<tr>
<td>Responsiveness</td>
<td>Speed of reaction and professionalism of contact persons</td>
<td>SS</td>
</tr>
<tr>
<td>Number of Loading Points</td>
<td>Number of disposable loading stations</td>
<td>Integer number</td>
</tr>
<tr>
<td>Quick Loading</td>
<td>Possibility to load the goods quickly on the supplier’s terminals</td>
<td>SS</td>
</tr>
<tr>
<td>Process Flexibility</td>
<td>Well organized loading process on the stations; training programs for the drivers</td>
<td>SS</td>
</tr>
<tr>
<td>Past Businesses</td>
<td>Quantities of the product at hand purchased during the period</td>
<td>Euro</td>
</tr>
<tr>
<td>Stabilized Relationship</td>
<td>Long lasting relationships without pronounced negative incidents or contradictions in the past</td>
<td>SS</td>
</tr>
<tr>
<td>Supplier’s Attitude</td>
<td>Friendly and individual treatment; relationships beyond the business</td>
<td>SS</td>
</tr>
<tr>
<td>Supplier’s Desire to Cooperate</td>
<td>Supplier’s attempts for sustainable partnership</td>
<td>SS</td>
</tr>
<tr>
<td>Trust</td>
<td>The expectations that the supplier’s future behaviour will remain within the framework of common values and moral obligations</td>
<td>SS</td>
</tr>
<tr>
<td>Bad Experience</td>
<td>Negative incidents in the past, such as breaches of contracts or supplier defaults</td>
<td>SS</td>
</tr>
<tr>
<td>Bad Reputation in Industry</td>
<td>The supplier is not respected by its customers, suppliers or other groups of interests</td>
<td>SS</td>
</tr>
<tr>
<td>Supplier’s Acquisition Difficulties</td>
<td>Probability of lack of product in stock e.g., due to bad weather (frost, drought or flood)</td>
<td>SS</td>
</tr>
<tr>
<td>Terms of Payment</td>
<td>Maximal provided payment period</td>
<td>Days</td>
</tr>
<tr>
<td>Credit Limit</td>
<td>The amount guaranteed by the supplier is high enough to satisfy your demand for its product</td>
<td>SS</td>
</tr>
<tr>
<td>Price</td>
<td>Bid price of the product for 100 Litres</td>
<td>Euro</td>
</tr>
</tbody>
</table>
criteria of different aspects of the engaged services, facilities or other external objects and not of alternatives themselves. We shall further call these external elements **auxiliary decision objects (ADOs)**. The indicators specifying performance of the ADOs will be called **indirect criteria** ($C^*$). The attributes describing alternatives immediately will be referred to as **direct criteria**. In Figure 3 is shown a decision hierarchy including ($M-1$) direct criteria connected to the alternatives, one indirect criterion describing the ADOs and relationships between the alternatives and the ADOs.

Correspondence between the ADOs and alternatives must be established in accordance with Table 2 to enable tracking the influences of indirect criteria on alternatives.

Raiffeisen’s suppliers do not own centralized facilities for warehousing and shipment of fuels. Instead, each supplier leases space on the large loading terminals. Moreover, several competing suppliers can use service of the same loading stations. The eight suppliers under consideration share services of five ($T=5$) loading terminals situated in Dortmund, Gelsenkirchen, Hamm, Lünnen and Üntrop. These stations differ on two criteria from the group **Logistics**: **Quick loading** ($C_{3,2}^{Pros}$) and **Process flexibility** ($C_{4,3}^{Pros}$). The layout of suppliers on the loading stations is profiled in Table 3.

Evaluated suppliers, shared by them external facilities, criteria and dependencies among these elements yield the decision hierarchy exhibited in Figure 4.

### 6. Identify the DM’s Alpha-Voting Power for Assessment of Criteria

We assume that some DMs have more authority, expertise, knowledge, or skills. Therefore each voting member of the decision team is assigned a voting power which is meant to reflect his or her potential ability to influence the decision outcome. Bodily (1979) indicated that these weights may be assigned either through mutual agreement of the decision team members or by a “super decision maker” (benevolent dictator).

Top managers, CEOs or board members may not be too deeply involved with the daily (purchasing) decisions and evaluation of alternatives (vendors). But they usually have better vision of strategic priorities and objectives of their organization and its functional units than lower level employees.

We introduce a coefficient $\alpha$ standing for **Alpha voting power** to designate the relative DMs’ impacts on the establishment of strategic priorities expressed by importance weights of the goals, objectives and criteria. The DMs responsible for criteria evaluation will be further called **$\alpha$-level DMs**.
We consider $K^\alpha$ $\alpha$-level DMs, each with a positive $\alpha$-voting power index $\pm \alpha_k$, where

$$\sum_{k=1}^{K^\alpha} \alpha_k = 1, \quad (k^\alpha = 1, 2, ..., K^\alpha).$$

In the study conducted for Raiffeisen the strategy group responsible for evaluation of criteria included three $\alpha$-level DMs ($K^\alpha = 3$) with following $\alpha$-voting power coefficients: $\alpha_1 = 0.5$, $\alpha_2 = 0.3$ and $\alpha_3 = 0.2$.

**7. Elicit Importance Weights of Criteria**

This step includes the assessment of the relative importance of identified criteria by the group of $\alpha$-level DMs. The weight elicitation problem in general is one of the most difficult problems in MCDA, because MCDA methods are supported by mathematical models and therefore the preferences need to be expressed in mathematical

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**Table 2. Matrix of connections between the alternatives and ADOs**

<table>
<thead>
<tr>
<th>ADO, St</th>
<th>Set of linked alternatives, ${Ai(St)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S1$</td>
<td>${Ai(S1)}$</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>$St$</td>
<td>${Ai(St)}$</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>$ST$</td>
<td>${Ai(ST)}$</td>
</tr>
</tbody>
</table>
Three factors are usually considered to obtain the weights: the variance degree of criteria, the independency of criteria and the subjective preference of the DMs (Tervonen et al., 2007). A number of approaches have been proposed to define criteria weights. Equal weights method (Dawes & Corrigan, 1974) requires minimal knowledge of the DM’s priorities and minimal DM’s input and treat all criteria as equally important. The simple multi-attribute rating technique (SMART) (Edwards, 1977) is based on the idea of ranking the importance of the changes in criteria from the lowest to the highest (best) levels, Edwards and Barron (1994) presented an improved version of this method called SMARTER which uses centroid method to find the final rankings. SWING (von Winterfeld & Edwards, 1986) is a direct algebraic decomposed procedure based on the ranking and scoring of criteria on a 100-point scale. Simos (Figueira & Roy, 2002) is a method where the user associates a “playing card” with each criterion, then the user ranks the cards in ascending order, according to the importance he/she wants to ascribe to the criteria; the white cards are used to determine the distance between successive criteria, from which the numerical attribute values are derived. The objective weighting methods use the distance metrics and include TOPSIS (Technique for order preference by similarity to ideal solution) (Hwang & Yoon, 1981), entropy (Srdjevic et al., 2009).

### Table 3. Allocation of suppliers among the loading stations

<table>
<thead>
<tr>
<th>Loading Stations, St</th>
<th>Suppliers, {Ai(St)}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Üntrop, t=1</td>
<td>Atrian, Certoil, GRG, Petroleum Nord, POSF</td>
</tr>
<tr>
<td>Hamm, t=2</td>
<td>GRG, Vetic</td>
</tr>
<tr>
<td>Lünnen, t=3</td>
<td>Certoil, GRG, Naronaft, Petroleum Nord, POSF</td>
</tr>
<tr>
<td>Dortmund, t=4</td>
<td>All</td>
</tr>
<tr>
<td>Gelsenkirchen, t=5</td>
<td>Atrian, GRG, West Petrol Group</td>
</tr>
</tbody>
</table>

### Figure 4. Hierarchy for evaluation of Raiffeisen’s fuel oil suppliers
al., 2004), principal component analysis etc. Combination of the objective and subjective weights is implemented in the additive and multiplicative synthesis (Wang et al. 2009).

The AHP is a subjective weighting method that relies on the pairwise comparisons to determine the weights of every decision criterion. The AHP was proposed by Saaty (1977). In the AHP pairwise comparisons are performed using 1 to 9 Fundamental Scale (Saaty & Sodenkamp, 2008).

Based on the pairwise comparison, matrices weights of criteria can be derived. The geometric aggregation rule should be used to avoid the controversies associated with rank reversal (Dyer, 1990; Harker & Vargas, 1990; Saaty, 1990b). After that, Consistency Ratio must be calculated to assure accuracy and logicality of provided subjective judgments.

The tree of attributes together with criteria weights reflects the DMs’ value system for decision at hand. Figure 5 illustrates a formal scheme of assigning criteria weights by the α-level DMs.

Three α-level DMs in the Raiffeisen study used the AHP and Super Decisions software / (http://www.superdecisions.com) independently to derive individual weights of criteria groups \( w^{\alpha}_{m} \), criteria \( w^{\alpha}_{mn} \) and sub-criteria \( w^{\alpha}_{nml} \). Tables 4 and 5 profile criteria importance weights for two DMs on objective and subjective criteria respectively.

8. Identify DMs’ Beta-Voting Power for Evaluation of Alternatives on Subjective Direct Criteria

Once the set of decision alternatives is generated, the DMs’ will make their assessment based upon subjective direct criteria should be selected and differentiated according to their ability to evaluate the alternatives. Performance values of alternatives on the objective criteria do not depend on the DMs’ opinion. We propose to call the DMs responsible for evaluation of alternatives on the subjective direct criteria β-level DMs. The DMs may vary in the sense of knowing decision alternatives to different extents and having experience to evaluate them rationally. In contrast to the Alpha-voting power indices \( a^{\alpha}_{k} \) that indicate relative authority or influence of the DMs in the process of objectives or criteria weighting and establishment of strategic priorities, the Beta-voting power \( \beta^{k}_{i} \) specifies the DMs’ relative ability to assess performance of alternatives on the direct subjective criteria. Methods of awarding the Alpha voting power indices \( a^{\alpha}_{k} \) can be also implemented to establish the Beta voting power components \( \beta^{k}_{i} \).

Numerical values \( \beta^{k}_{i} \) for two Raiffeisen’s β-level DMs \( K^{\beta} = 2 \) are reflected in Table 6.

9. Collect Objective Data

The next step is collection of the hard data describing performance of alternatives on qualitatively and objectively measurable criteria. The performance values for the set of objectively measurable factors do not depend on the DM’s judgments and are equal for each individual. The units of measurement have to be identical for all the alternatives with respect to the same criterion. Let’s denote;

\[
p^{\text{Pros}}_{ml}^{(i)} \quad (p^{\text{Cons}}_{ml}^{(i)}) \quad \text{Performance value of the } i\text{-th alternative on the objectively measurable Pros (Cons) } l\text{-th sub-criterion of the } n\text{-th criterion within the } m\text{-th group; }
\]

\[
i = 1, 2, \ldots , I; \quad l = 1, 2, \ldots , L_{mn};
\]

\[
m = 1, 2, \ldots , M; \quad n = 1, 2, \ldots , N_{m}
\]

\[
p^{\text{Pros}}_{mn}^{(i)} \quad (p^{\text{Cons}}_{mn}^{(i)}) \quad \text{Performance value of the } i\text{-th alternative on the objectively}
\]
measurable \( n \)-th criterion within the \( m \)-th group, if \( n \) does not contain sub-criteria; \((i = 1, 2, \ldots, I; m = 1, 2, \ldots, M; n = 1, 2, \ldots, N_m)\)

Performance values of Raiffeisen’s suppliers on the objective criteria are shown in Table 7.

10. Develop Scoring System for Subjective Criteria and Assign Scores to Alternatives on Direct Soft Criteria

Intangible (soft) criteria can be defined in several ways with scales varying both in definition and in number of options. The type of scale, with one definition on each end of the scale, gives the respondent space for subjective judgment while a scale with clearly defined alternatives can result in more objective answers according to the predefined alternatives. (Hartley & Betts, 2010) A Likert scale is commonly used in questionnaires to measure qualitative facts. Rensis Likert invented the scale with the purpose of using it within psychology and it can be designed as a 5-, 7- or a 10-point scale. Typical for a Likert scale is that the respondents specify their level of agreement to a statement. By using the Likert scale, the respondents can express their strength of feeling on a scale consisting of response categories.

Muralidharan et al. (2002) suggest guidelines for comparing supplier attribute. That is a five-point rating scale with predefined descriptions of each alternative. Judging whether a supplier has met the company’s expectations, or not is not always an easy task if there are no clear statements declaring what the company’s expectations are (Muralidharan, Anantharaman, & Deshmukh, 2002). We adopted this scale to the 10 grading points which is shown in Table 8.

The rating scale in Table 8 is appropriate for the Pros criteria where the higher values are preferred to the lower ones. For the Cons criteria the scale values should be inverted so that 1 is considered as the best value with minimal negative impact and 10 as the worst value with maximal negative impact, as specified in Table 9.

The scale grades for Pros should be maximized and for Cons minimized. The performance scores for the set of subjectively
Table 4. Weights of objective criteria derived with the AHP

<table>
<thead>
<tr>
<th>Groups, $C_m$</th>
<th>Group weights, $w^e_m$</th>
<th>Criteria, $C_{mn}$</th>
<th>Criteria weights, $w^{e_o}_{mn}$</th>
<th>Sub-criteria, $C_{mnl}$</th>
<th>Sub-criteria weights, $w^{e_o}_{mnl}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DM 1</td>
<td>DM 2</td>
<td>DM 1</td>
<td>DM 2</td>
<td>DM 1</td>
</tr>
<tr>
<td>1. Flexibility</td>
<td>0.100</td>
<td>0.060</td>
<td>1.3. Product Mix</td>
<td>0.249</td>
<td>0.194</td>
</tr>
<tr>
<td></td>
<td></td>
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</tr>
<tr>
<td>2. Service</td>
<td>0.090</td>
<td>0.070</td>
<td>2.3. Good Communication System</td>
<td>0.302</td>
<td>0.181</td>
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</tr>
<tr>
<td>3. Logistics</td>
<td>0.060</td>
<td>0.050</td>
<td>3.1. Number of Loading Points</td>
<td>0.241</td>
<td>0.146</td>
</tr>
<tr>
<td>4. Relations</td>
<td>0.130</td>
<td>0.080</td>
<td>4.1. Past Businesses</td>
<td>0.146</td>
<td>0.103</td>
</tr>
<tr>
<td>6. Financial</td>
<td>0.310</td>
<td>0.360</td>
<td>6.1. Term of Payment</td>
<td>0.320</td>
<td>0.300</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5. Weights of subjective criteria derived with the AHP

<table>
<thead>
<tr>
<th>Groups, $C_m$</th>
<th>Group weights, $w^s_m$</th>
<th>Criteria, $C_{mn}$</th>
<th>Criteria weights, $w^{s_o}_{mn}$</th>
<th>Sub-criteria, $C_{mnl}$</th>
<th>Sub-criteria weights, $w^{s_o}_{mnl}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DM 1</td>
<td>DM 2</td>
<td>DM 1</td>
<td>DM 2</td>
<td>DM 1</td>
</tr>
<tr>
<td>1. Flexibility</td>
<td>0.100</td>
<td>0.060</td>
<td>1.2. Rush Order Processing</td>
<td>0.342</td>
<td>0.455</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.1. Volume Flexibility</td>
<td>0.409</td>
<td>0.351</td>
</tr>
<tr>
<td>2. Service</td>
<td>0.090</td>
<td>0.070</td>
<td>2.3. Good Communication System</td>
<td>0.302</td>
<td>0.181</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.2. Information Exchange</td>
<td>0.526</td>
<td>0.649</td>
</tr>
<tr>
<td>3. Logistic</td>
<td>0.060</td>
<td>0.050</td>
<td>3.2. Quick Loading</td>
<td>0.446</td>
<td>0.541</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3.3. Process Flexibility</td>
<td>0.313</td>
<td>0.313</td>
</tr>
<tr>
<td>4. Relations</td>
<td>0.130</td>
<td>0.080</td>
<td>4.2. Stabilized Relations</td>
<td>0.209</td>
<td>0.262</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.3. Supplier’s Attitude</td>
<td>0.187</td>
<td>0.118</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.4. Supplier’s desire to cooperate</td>
<td>0.165</td>
<td>0.131</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.5. Trust</td>
<td>0.293</td>
<td>0.386</td>
</tr>
<tr>
<td>5. Risks</td>
<td>0.310</td>
<td>0.380</td>
<td>5.1. Bad Experience</td>
<td>0.566</td>
<td>0.614</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5.2. Bad Reputation in Industry</td>
<td>0.183</td>
<td>0.119</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5.3. Supplier’s Acquisition Difficulties</td>
<td>0.251</td>
<td>0.267</td>
</tr>
<tr>
<td>6. Financial</td>
<td>0.310</td>
<td>0.360</td>
<td>6.1. Credit Limit</td>
<td>0.076</td>
<td>0.04</td>
</tr>
</tbody>
</table>
measurable attributes are different for the $K^\beta$ 
$\beta$-level DMs. Let's denote:

$$p_{(\text{Pros})^i_{nml}}^{\beta i} \cdot p_{(\text{Cons})^i_{nml}}^{\beta i}$$

Performance score of the $i$-th alternative on the subjectively measurable $l$-th Pros (Cons) sub-criterion of the $n$-th criterion within the $m$-th group assigned by $K^\beta$ the $\beta$-level DM; 
($i = 1, 2, ..., I; k^\beta = 1, 2, ..., K^\beta; l = 1, 2, ..., L_{ml}; m = 1, 2, ..., M; n = 1, 2, ..., N_m$)

In Figure 6 is illustrated the process of assigning subjective scores to alternatives on one direct criterion by the $\beta$-level DM.

### 11. Evaluate Auxiliary Decision Objects on Indirect Criteria

Analogously to the direct criteria that reflect to what extent alternatives meet the requirements expressed by means of quantitative and qualitative decision factors, indirect criteria help to
distinguish between the ADOs. The same as direct criteria, indirect ones can be objective (factual) or subjective (judgmental) merits. Factual data characterizing the ADOs has to be identified uniquely for each ADO and does not depend on the DMs’ judgments. To formulate this step algebraically lets define:

\[
p_{\text{Pros}}^\text{Obj}_{n,m,l} (p_{\text{Cons}}^\text{Obj}_{n,m,l} ) \text{Performance value of the } t\text{-th ADO on the objectively measurable } l\text{-th } \text{Pros (Cons) sub-criterion of the } n\text{-th criterion within the } m\text{-th group ( } t = 1,2,\ldots,T; \ l = 1,2,\ldots,L_{mn}; \ m = 1,2,\ldots,M; \ n = 1,2,\ldots,N_m )
\]

\[
p_{\text{Pros}}^\text{Obj}_{n,m} (p_{\text{Cons}}^\text{Obj}_{n,m}) \text{Performance value of the } t\text{-th ADO on the objectively measurable } n\text{-th } \text{Pros (Cons) criterion within the } m\text{-th group, if } n \text{ does not contain sub-criteria } ( t = 1,2,\ldots,T; \ m = 1,2,\ldots,M; \ n = 1,2,\ldots,N_m )
\]

In contrast to the tangible characteristics, intangible indirect indicators reflect the DMs’ opinions. Decision team responsible for evaluation of the ADOs should include individuals having appropriate expertise and knowledge. Members of this group do not necessarily have to be criteria evaluators (\(\alpha\)-level DMs), nor alternative assessors (\(\beta\)-level DMs). The DMs responsible for estimation of the ADOs on subjective indirect criteria will be called \(\gamma\)-level DMs. \(\gamma\)-level DMs may vary in the sense of experience or authority to evaluate performances of particular ADOs. The relative ability of \(\gamma\)-level DMs to assess performance of the ADOs on indirect subjective criteria will be called \(\gamma\)-voting power. We consider \(K\) \(\gamma\)-level DMs, each with a positive \(\gamma\)-voting power index \(\gamma^t_{k}\), where

\[
\sum_{k=1}^{K} \gamma^t_{k} = 1 \ ( k = 1,2,\ldots,K; \ t = 1,2,\ldots,T ).
\]

<table>
<thead>
<tr>
<th>Point</th>
<th>Grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Exceptional</td>
<td>Demonstrates substantially excellent performance, and has been at least in the excellence category for last 12 months</td>
</tr>
<tr>
<td>7</td>
<td>Excellence</td>
<td>Exceeds company’s and customers’ expectations, demonstrates extra effort</td>
</tr>
<tr>
<td>5</td>
<td>Good</td>
<td>Meets the company’s expectations</td>
</tr>
<tr>
<td>3</td>
<td>Acceptable</td>
<td>Meets company’s minimum requirements</td>
</tr>
<tr>
<td>1</td>
<td>Poor</td>
<td>Does not meet company’s and customers’ minimum acceptable level</td>
</tr>
<tr>
<td>2,4,6,8,9</td>
<td></td>
<td>Annectent grades</td>
</tr>
</tbody>
</table>

Table 8. Rating scale for supplier evaluation on the Pros criteria

<table>
<thead>
<tr>
<th>Point</th>
<th>Grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Poor</td>
<td>Does not meet company’s and customers’ minimum acceptable level</td>
</tr>
<tr>
<td>7</td>
<td>Acceptable</td>
<td>Meets company’s minimum requirements</td>
</tr>
<tr>
<td>5</td>
<td>Good</td>
<td>Meets the company’s expectations</td>
</tr>
<tr>
<td>3</td>
<td>Excellence</td>
<td>Exceeds company’s and customers’ expectations, demonstrates extra effort</td>
</tr>
<tr>
<td>1</td>
<td>Exceptional</td>
<td>Demonstrates substantially excellent performance, and has been at least in the excellence category for last 12 months</td>
</tr>
<tr>
<td>2,4,6,8,9</td>
<td></td>
<td>Annectent grades</td>
</tr>
</tbody>
</table>

Table 9. Rating scale for supplier evaluation on the Cons criteria
In order to evaluate the ADOs on subjective Pros and Cons a scoring system has to be developed. For this purpose a 10-point verbal scale with respective numerical values given in Table 8 can be applied for Pros, and an inverse 1 to 10 scale from the Table 9 can be adapted for indirect Cons. Once the scale for subjective scores has been defined evaluation of the ADOs can begin. To formalize the process let us define:

\[ p_{\text{Pros mn}}^{\text{Sbj tl}}(\gamma) \]  
Performance score of the \( t \)-th ADO on the subjectively measurable \( n \)-th Pros (Cons) indirect criterion within the \( m \)-th group assigned by the \( k^{\gamma} \)-the \( \gamma \)-level DM; \( t = 1,2,...,T; \ k^{\gamma} = 1,2,...,K^{\gamma}; \ m = 1,2,...,M; \ n = 1,2,...,N^{\gamma}_m \)

The group of two purchasing managers (\( \gamma \)-level DMs, \( K^{\gamma} = 2 \)) was formed to evaluate five shared loading stations of Raiffeisen’s suppliers on the subjective indirect criteria Quick loading (\( C_{3,2}^{\text{Pros}} * \)) and Process flexibility (\( C_{3,3}^{\text{Pros}} * \)). The \( \gamma \)-voting power indices and performance scores assigned to the loading points are given in Table 10.

12. Normalize All Objective Performances and Subjective Scores to Obtain Identical Measurement Units

Next, we normalize variables with multiple measurement scales to assure uniformity. The literature reports on several normalization methods. The selection of a specific normalization method must be based on the problem characteristics and model requirements (Tavana & Sodenkamp, 2010). In this study, we use the

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approach where the normalized value is the quotient of the initial value divided by the sum of the values of all alternatives/ADOs on that criterion. Normalized objective performances on direct, as well as on indirect Pros and Cons criteria can be defined by the expressions (1) - (4):

\[ p'(Pr_{\text{Obj}})_{\text{mn}} = \frac{\sum_{i} p(Pr_{\text{Obj}})_{\text{mn}}}{\sum_{i} p(Pr_{\text{Obj}})_{\text{mn}}} \]  

(1.a)

\[ p'(Pr_{\text{Obj}})_{\text{ml}} = \frac{\sum_{i} p(Pr_{\text{Obj}})_{\text{ml}}}{\sum_{i} p(Pr_{\text{Obj}})_{\text{ml}}} \]  

(1.b)

\[ p'(Con_{\text{Obj}})_{\text{mn}} = \frac{\sum_{i} p(Con_{\text{Obj}})_{\text{mn}}}{\sum_{i} p(Con_{\text{Obj}})_{\text{mn}}} \]  

(2.a)

\[ p'(Con_{\text{Obj}})_{\text{ml}} = \frac{\sum_{i} p(Con_{\text{Obj}})_{\text{ml}}}{\sum_{i} p(Con_{\text{Obj}})_{\text{ml}}} \]  

(2.b)

\[ p'(Pr_{\text{Obj}})_{\text{mnl}} = \frac{\sum_{i} p(Pr_{\text{Obj}})_{\text{mnl}}}{\sum_{i} p(Pr_{\text{Obj}})_{\text{mnl}}} \]  

(3.a)

\[ p'(Pr_{\text{Obj}})_{\text{mtl}} = \frac{\sum_{i} p(Pr_{\text{Obj}})_{\text{mtl}}}{\sum_{i} p(Pr_{\text{Obj}})_{\text{mtl}}} \]  

(3.b)

\[ p'(Con_{\text{Obj}})_{\text{mnl}} = \frac{\sum_{i} p(Con_{\text{Obj}})_{\text{mnl}}}{\sum_{i} p(Con_{\text{Obj}})_{\text{mnl}}} \]  

(4.a)

\[ p'(Con_{\text{Obj}})_{\text{mtl}} = \frac{\sum_{i} p(Con_{\text{Obj}})_{\text{mtl}}}{\sum_{i} p(Con_{\text{Obj}})_{\text{mtl}}} \]  

(4.b)

Table 10. Voting power and scores of Raiffeisen γ-level DMs

<table>
<thead>
<tr>
<th>Shared loading facilities, ( \gamma )</th>
<th>Dortmund, ( t=1 )</th>
<th>Gelsenkirchen, ( t=2 )</th>
<th>Hamm, ( t=3 )</th>
<th>Lünnen, ( t=4 )</th>
<th>Üntrop, ( t=5 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \gamma )-level DMs, ( k^\gamma )</td>
<td>( DM_1, k^\gamma = 1 )</td>
<td>( DM_2, k^\gamma = 2 )</td>
<td>( DM_1, k^\gamma = 1 )</td>
<td>( DM_2, k^\gamma = 2 )</td>
<td>( DM_1, k^\gamma = 1 )</td>
</tr>
<tr>
<td>( \gamma )-voting power</td>
<td>0.5</td>
<td>0.5</td>
<td>0.7</td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Quick loading, ( C_{32}^{12} )</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Process flexibility, ( C_{33}^{12} )</td>
<td>10</td>
<td>10</td>
<td>3</td>
<td>5</td>
<td>7</td>
</tr>
</tbody>
</table>

Normalized subjective scores on direct and on indirect Pros and Cons criteria can be defined by the expressions (5) - (8):

\[ p'(Pr_{\text{Obj}})_{\text{mn}} = \sum_{i} p(Pr_{\text{Obj}})_{\text{mn}} \]  

(5.a)

\[ p'(Pr_{\text{Obj}})_{\text{ml}} = \sum_{i} p(Pr_{\text{Obj}})_{\text{ml}} \]  

(5.b)

\[ p'(Con_{\text{Obj}})_{\text{mn}} = \sum_{i} p(Con_{\text{Obj}})_{\text{mn}} \]  

(6.a)

\[ p'(Con_{\text{Obj}})_{\text{ml}} = \sum_{i} p(Con_{\text{Obj}})_{\text{ml}} \]  

(6.b)

\[ p'(Pr_{\text{Obj}})_{\text{mnl}} = \sum_{i} p(Pr_{\text{Obj}})_{\text{mnl}} \]  

(7.a)

\[ p'(Pr_{\text{Obj}})_{\text{mtl}} = \sum_{i} p(Pr_{\text{Obj}})_{\text{mtl}} \]  

(7.b)

\[ p'(Con_{\text{Obj}})_{\text{mnl}} = \sum_{i} p(Con_{\text{Obj}})_{\text{mnl}} \]  

(8.a)

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After the normalization process, we use an integration procedure to combine the following elements into one pair of values for Pros and Cons of each decision alternative:

- Voting power coefficients $\alpha_k$, $\beta_k$, and $\gamma_k$;
- $K^\alpha$ sets of $M$ criteria group weights ($w_m$), $N$ attribute weights ($w_n$) and $L$ sub-criteria weights ($w_l$);
- $N^{Obj}$ and $L^{Obj}$ normalized performances of I alternatives and T ADOs on the direct and indirect objective Pros and Cons criteria ($p^{(Pros)}_{\text{Obj} \mid i}$, $p^{(Cons)}_{\text{Obj} \mid i}$, $p^{(Pros)}_{\text{Obj} \mid n}$, $p^{(Cons)}_{\text{Obj} \mid n}$, $p^{(Pros)}_{\text{Obj} \mid m}$, $p^{(Cons)}_{\text{Obj} \mid m}$) and $p^{(Pros)}_{\text{Obj} \mid t}$ and $p^{(Cons)}_{\text{Obj} \mid t}$;
- $K^\beta$ sets of normalized scores of I alternatives on the direct subjective Pros and Cons criteria ($p^{(Pros)}_{\text{Obj} \mid i}$, $p^{(Cons)}_{\text{Obj} \mid i}$, $p^{(Pros)}_{\text{Obj} \mid n}$, $p^{(Cons)}_{\text{Obj} \mid n}$, $p^{(Pros)}_{\text{Obj} \mid m}$, $p^{(Cons)}_{\text{Obj} \mid m}$) and $p^{(Pros)}_{\text{Obj} \mid t}$ and $p^{(Cons)}_{\text{Obj} \mid t}$; and
- $K^\gamma$ sets of normalized scores of T ADO’s on the indirect subjective Pros and Cons criteria ($p^{(Pros)}_{\text{Obj} \mid i}$, $p^{(Cons)}_{\text{Obj} \mid i}$, $p^{(Pros)}_{\text{Obj} \mid n}$, $p^{(Cons)}_{\text{Obj} \mid n}$, $p^{(Pros)}_{\text{Obj} \mid m}$, $p^{(Cons)}_{\text{Obj} \mid m}$) and $p^{(Pros)}_{\text{Obj} \mid t}$ and $p^{(Cons)}_{\text{Obj} \mid t}$.

14.1. Combination of the Group Criteria Weights

For the first step of the integration procedure it is necessary to find combined among the $\alpha$-level DM’s, weights of criteria groups ($w_m$), criteria ($w_n$) and sub-criteria ($w_l$).

$$w_m = \sum_{k' = 1}^{K^\alpha} (\alpha_{k'} \cdot w_{m}^{k'}) \quad (9.a)$$

$$w_n = \sum_{k' = 1}^{K^\alpha} (\alpha_{k'} \cdot w_{n}^{k'}) \quad (9.b)$$

$$w_l = \sum_{k' = 1}^{K^\alpha} (\alpha_{k'} \cdot w_{l}^{k'}) \quad (9.c)$$

14.2. Prioritization of the ADOs

In the second step of the integration procedure we calculate the group rankings of the ADO’s in order to incorporate this information into the decision matrix later for evaluation of the alternatives.

Aggregated group Pros and Cons of the each ADO must be derived taking into account $\gamma$-voting power indices $s_i^\gamma$, using formulas (10)-(11) respectively:

$$p^{(Pros)}_{\text{Obj} \mid t} = \sum_{k' = 1}^{K^\gamma} \gamma_{k'} \cdot p^{(Pros)}_{\text{Obj} \mid t} \quad (10.a)$$

$$p^{(Cons)}_{\text{Obj} \mid t} = \sum_{k' = 1}^{K^\gamma} \gamma_{k'} \cdot p^{(Cons)}_{\text{Obj} \mid t} \quad (11.a)$$

We use weighed-sum aggregation method and equations (12)-(13) to calculate the total...
Pros \(p_{(Pros)}^y\) and Cons \(p_{(Cons)}^y\) scores of \(T\) ADOs.

\[
p_{(Pros)}^y \sum_{m} \left( w_{mn} \left( \sum_{j} p_{(Pros)}_{mnj}^y \right) \right) + \sum_{j} p_{(Pros)}_{mnj}^y + \sum_{\alpha} p_{(Pros)_{mn\alpha}^y} + \sum_{\beta} p_{(Pros)_{mn\beta}^y}
\]

\[
p_{(Cons)}^y \sum_{m} \left( w_{mn} \left( \sum_{j} p_{(Cons)}_{mnj}^y \right) \right) + \sum_{j} p_{(Cons)}_{mnj}^y + \sum_{\alpha} p_{(Cons)_{mn\alpha}^y} + \sum_{\beta} p_{(Cons)_{mn\beta}^y}
\]

In the Raiffeisen study integrated group rankings of the five shared loading terminals were obtained using formulas (10) and (12), the results are shown in Table 13.

### 14.3. Derive Values of the Alternatives on the Indirect Criteria

Once positive and negative ratings of all ADO’s have been calculated, impacts of indirect criteria on the decision alternatives have to be measured taking into consideration correspondence between the ADO’s and alternatives as defined in Table 2. To calculate performance level of decision alternatives \(Ai\) on the indirect criteria \(C^*\) for contradictory classes Pros and Cons formulas 14(a) and 14(b) can be applied.

### Table 11. Normalized performances of alternatives on objective criteria

<table>
<thead>
<tr>
<th>Groups of criteria, (C^*_{m})</th>
<th>Criteria, (C_{mn})</th>
<th>Sub-criteria, (C_{mn\alpha})</th>
<th>Alternative suppliers, (A^i)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>GRG</td>
</tr>
<tr>
<td>1. Flexibility</td>
<td>1.3. Product Mix</td>
<td>1.3.1. Heating Oil</td>
<td>0.380</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.3.2. Gasoline</td>
<td>0.090</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.3.3. Motor Oil/Lubricants</td>
<td>0.229</td>
</tr>
<tr>
<td>2. Service</td>
<td>2.1. Business Hours</td>
<td></td>
<td>0.238</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.3. Good Communication System</td>
<td>0.127</td>
</tr>
<tr>
<td>3. Logistics</td>
<td>3.1. Number of Loading Points</td>
<td></td>
<td>0.217</td>
</tr>
<tr>
<td>4. Relations</td>
<td>4.1. Past Businesses</td>
<td></td>
<td>0.403</td>
</tr>
<tr>
<td>6. Financial</td>
<td>6.1. Term of Payment</td>
<td></td>
<td>0.125</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.3. Price</td>
<td>0.126</td>
</tr>
</tbody>
</table>

### Table 12. Normalized scores of the loading stations

<table>
<thead>
<tr>
<th>Indirect criteria, (C^*_{mn})</th>
<th>Casual loading facilities, (i)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dortmund, t=1</td>
</tr>
<tr>
<td>DM1</td>
<td></td>
</tr>
<tr>
<td>DM2</td>
<td></td>
</tr>
<tr>
<td>Quick loading, (C_{q})*</td>
<td>0.278</td>
</tr>
<tr>
<td>Process flexibility, (C_{p})*</td>
<td>0.303</td>
</tr>
</tbody>
</table>

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respectively. The numbers obtained can then be incorporated into the process of alternatives evaluation together with direct criteria.

\[ p(\text{Pros})_{mn}^i = \frac{\sum_{t=1}^{T^i} p(\text{Pros})_{mn}^t}{T^i} \]  

(14.a)

\[ p(\text{Cons})_{mn}^i = \frac{\sum_{t=1}^{T^i} p(\text{Cons})_{mn}^t}{T^i} \]  

(14.b)

where \( T^i \) stands for number of ADOs related to alternative \( i \).

Raiffeisen’s loading point information and suppliers’ integrated group performance scores on the indirect criteria are collected in Table 14.

14.4. Calculate Group Weights of the Alternatives on Each Criterion

The normalized subjective group scores on direct factors must be merged with \( \beta \)-voting power magnitudes to derive consensus bases rankings of alternatives.

\[ p(\text{Pros})_{mnl}^i = \sum_{k=1}^{K^3} \beta_{k}^i \cdot p(\text{Pros})_{mn}^i \]  

(15.a)

\[ p(\text{Cons})_{mnl}^i = \sum_{k=1}^{K^3} \beta_{k}^i \cdot p(\text{Cons})_{mn}^i \]  

(15.b)

14.5. Combine All Direct Pros and Cons Weights For Each Alternative

Then we apply the weighed-sum aggregation to calculate combined objective and subjective

Pros ( \( p(\text{Pros})^i \) ) and Cons ( \( p(\text{Cons})^i \) ) of \( I \) alternatives on the direct criteria.

\[ p(\text{Pros})_{m}^i = w_m \cdot (\sum_{n} p(\text{Pros})_{mn}^i) + \sum_{n} p(\text{Pros})_{mnl}^i + \sum_{n} p(\text{Pros})_{mnl}^i \]  

(17)

\[ p(\text{Cons})_{m}^i = w_m \cdot (\sum_{n} p(\text{Cons})_{mn}^i) + \sum_{n} p(\text{Cons})_{mnl}^i + \sum_{n} p(\text{Cons})_{mnl}^i \]  

(18)

14.6. Find a Pair of Total Pros and Cons for Each Alternative

On the final step of our integration procedure the total Pros ( \( p(\text{Pros})^i \) ) and Cons ( \( p(\text{Cons})^i \) ) values are calculated for each alternative as added weighed estimates on the direct and indirect criteria:

\[ p(\text{Pros})^i = \sum_{m=1}^{M} (w_m \cdot (p(\text{Pros})_{m}^i + p(\text{Pros})_{mnl}^i)) \]  

(19)

\[ p(\text{Cons})^i = \sum_{m=1}^{M} (w_m \cdot (p(\text{Cons})_{m}^i + p(\text{Cons})_{mnl}^i)) \]  

(20)

The Pros and Cons of Raiffeisen’s suppliers are presented in Table 15.
Zeleny (1982) suggested using the Euclidean measure to compare alternatives among themselves and with the ideal one. This approach was implemented in numerous researchers (Tavana & Sodenkamp, 2010; Tavana et al., 2010) and by practitioners. The ideal Pros value \( p_{Pros}^* \) is the highest Pros weight among the set of \( \{ p_{Pros}(i) \} \) and ideal Cons value \( p_{Cons}^* \) is the lowest Cons weight among the set of \( \{ p_{Cons}(i) \} \). To find the Euclidean distance of each alternative from the ideal one we extract the quadratic root of summarized squared differences between the ideal and the \( i \)-th indices of the Pros and Cons. Lets define:

\[
E'(p_{Pros}) = \sqrt{(p_{Pros} - p_{Pros}^*)^2 + (p_{Cons} - p_{Cons}^*)^2}
\]

(22)

We then sort alternatives \( A_i \) from the best to the worst one based on the values \( E_i \) and form a set \( \{ A^{Ord}_i \} \). \( A_i \) indicates that \( i \)-th alternative has \( r \)-th rank in the ordered set \( \{ A^{Ord}_i \} \), where \( r = 1, \ldots, I \).

The highest Pros value among the set of Raiffeisen’s suppliers is \( p_{Pros}^* = 0.056 \), whereas the lowest Cons value is \( p_{Cons}^* = 0.015 \). The Raiffeisen fuel oil suppliers’ distances to the ideal point, together with ranks based on Euclidean distance are shown in Table 16.

### 16. Choose the Optimal Alternative(s) and Assign Order Quantities

To solve the choice decision problem the maximal efficiency can be achieved if the alternative \( A_{r=1} \) with the highest rank will be selected. In purchasing management this kind of supplier selection is called single sourcing and it is used if one supplier can satisfy all the buyer’s needs.

If decision goal is formulated in terms of selection of several best options, the required number \( Q (Q \leq I) \) of alternatives must be defined by the decision group. The desire of purchasing managers to split orders among

---

Table 14. Suppliers’ loading stations information

<table>
<thead>
<tr>
<th>Suppliers, ( A_i )</th>
<th>GRG, ( i=1 )</th>
<th>Atrian, ( i=2 )</th>
<th>Certyoil, ( i=3 )</th>
<th>Naronaft, ( i=4 )</th>
<th>Vet, ( i=5 )</th>
<th>Petroleum Nord, ( i=6 )</th>
<th>West Petrol Group, ( i=7 )</th>
<th>POSF, ( i=8 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Loading Stations, ( p )</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Loading stations, ( St )</td>
<td>Dortmund, Gelsenkirchen, Hamm, Lünnen, Üntrop</td>
<td>Dortmund, Gelsenkirchen, Hamm, Lünnen, Üntrop</td>
<td>Dortmund, Hamm, Lünnen, Üntrop</td>
<td>Dortmund, Hamm</td>
<td>Dortmund, Hamm</td>
<td>Dortmund, Hamm, Lünnen, Üntrop</td>
<td>Dortmund, Hamm, Lünnen, Üntrop</td>
<td></td>
</tr>
<tr>
<td>Total scores on indirect criteria, ( p_{Pros}^* )</td>
<td>0.161</td>
<td>0.171</td>
<td>0.174</td>
<td>0.173</td>
<td>0.188</td>
<td>0.174</td>
<td>0.180</td>
<td>0.174</td>
</tr>
</tbody>
</table>
vendors may arise for a variety of reasons, including inability of suppliers to satisfy all of the buyer’s requirements or intentionally creating an environment of competitiveness. In such case, \( Q \) first elements from the ordered set \( \{ A^{Ord} \} \) must be selected to assure highest efficiency of \( Q \) alternatives. The selected alternatives are \( A^i_q \) with \( q = 1, \ldots, Q \).

Raiffeisen follows the policy of risks minimization and multiple sourcing. To purchase fuels the DMs select three \( Q = 3 \) vendors with highest ranks \( r \). These are GRG (\( A^1 \)), Vetic (\( A^5 \)) and POSF (\( A^8 \)). Then order quantities \( o^q (q = 1, \ldots Q) \) have to be allocated among the selected suppliers proportionally to the normalized relative weights \( w^i_q \) of selected alternatives within set \( \{ Q \} \).

\[
w^i_q = \frac{E^i_q}{\sum_{q=1}^{Q} E^i_q}
\]

(23)

where \( E^i_q \) is Euclidean distance for the \( q \)-th selected alternative and \( E^i_q = E^i \).

Assuming that \( d \) is demand of the product to purchase, the order quantities for vendors are:

\[
o^q = w^i_q \cdot d
\]

(25)

Normalized weights of the suppliers selected by Raiffeisen, and assigned to them order quantities for \( d = 72 000 \) (liters) are presented in Table 17.

**CONCLUSION**

The research presented in this study promotes explicit and comprehensive modeling of extremely complex decisions and systematic evaluation and selection of alternatives based on their contribution made throughout the organization. When real decision processes do not fit into the typical hierarchy “goals-criteria-alternatives” due to involvement of the external

<table>
<thead>
<tr>
<th>Table 15. Suppliers’ overall Pros and Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suppliers, ( A^i ) Merits</td>
</tr>
<tr>
<td>Pros, ( p(Pros)^i )</td>
</tr>
<tr>
<td>Cons, ( p(Cons)^i )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 16. Suppliers’ distances to the ideal and final ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier, ( A^i )</td>
</tr>
<tr>
<td>Euclidean Distance, ( E^i )</td>
</tr>
<tr>
<td>Rank, ( r )</td>
</tr>
</tbody>
</table>

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services or other intermediate units, connections between the decision elements become more intricate and standard methods are no longer applicable. We demonstrate a supplier selection problem including indirect influences of decision criteria on the vendors and formulate appropriate step-by-step assessment framework. All relevant objective information, together with the expert judgments regarding criteria importance; performance scores of alternatives and auxiliary objects are captured consistently in the evaluation procedure. Principal distinction is drawn between the three types of DMs; strategy determination group (α-level DMs), alternatives evaluation group (β-level DMs) and ADOs assessment group (γ-level DMs). Moreover, different grades of DMs influence inherent to real decision teams are expressed by voting power coefficients and then included into the aggregation procedure, aimed to reveal consensus based supplier priorities. Sensitivity analysis can be performed in order to understand impacts of particular parameters on the final result and to examine robustness of the proposed solution.

Systematic holding of non-anonymous assessment sessions with our method makes significant contributions to the decision process transparency. Moreover, the MLGDM process can be used as a tool for DMs’ learning and dynamic monitoring of strategic and tactical purchasing decisions on different organizational layers.

ACKNOWLEDGMENTS

The authors would like to thank the anonymous reviewers and the editor for their insightful comments and suggestions. All the suppliers’ names are changed to protect their anonymity. The data presented in this study is significantly reduced to allow a meaningful illustration of the method.

REFERENCES


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Table 17. Selected suppliers and order quantities

<table>
<thead>
<tr>
<th>Selected suppliers, $A_q$</th>
<th>GRG, $q=1$</th>
<th>Vetic, $q=2$</th>
<th>POSF, $q=3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euclidean distances, $E_q$</td>
<td>0,000</td>
<td>0,006</td>
<td>0,015</td>
</tr>
<tr>
<td>Normalized weighs, $w_q$</td>
<td>0,500</td>
<td>0,357</td>
<td>0,143</td>
</tr>
<tr>
<td>Order quantities, $o_q$</td>
<td>36 000</td>
<td>25 704</td>
<td>10 296</td>
</tr>
</tbody>
</table>


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