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Implementation of multiple criteria decision analysis approaches in the supplier selection process: a case study

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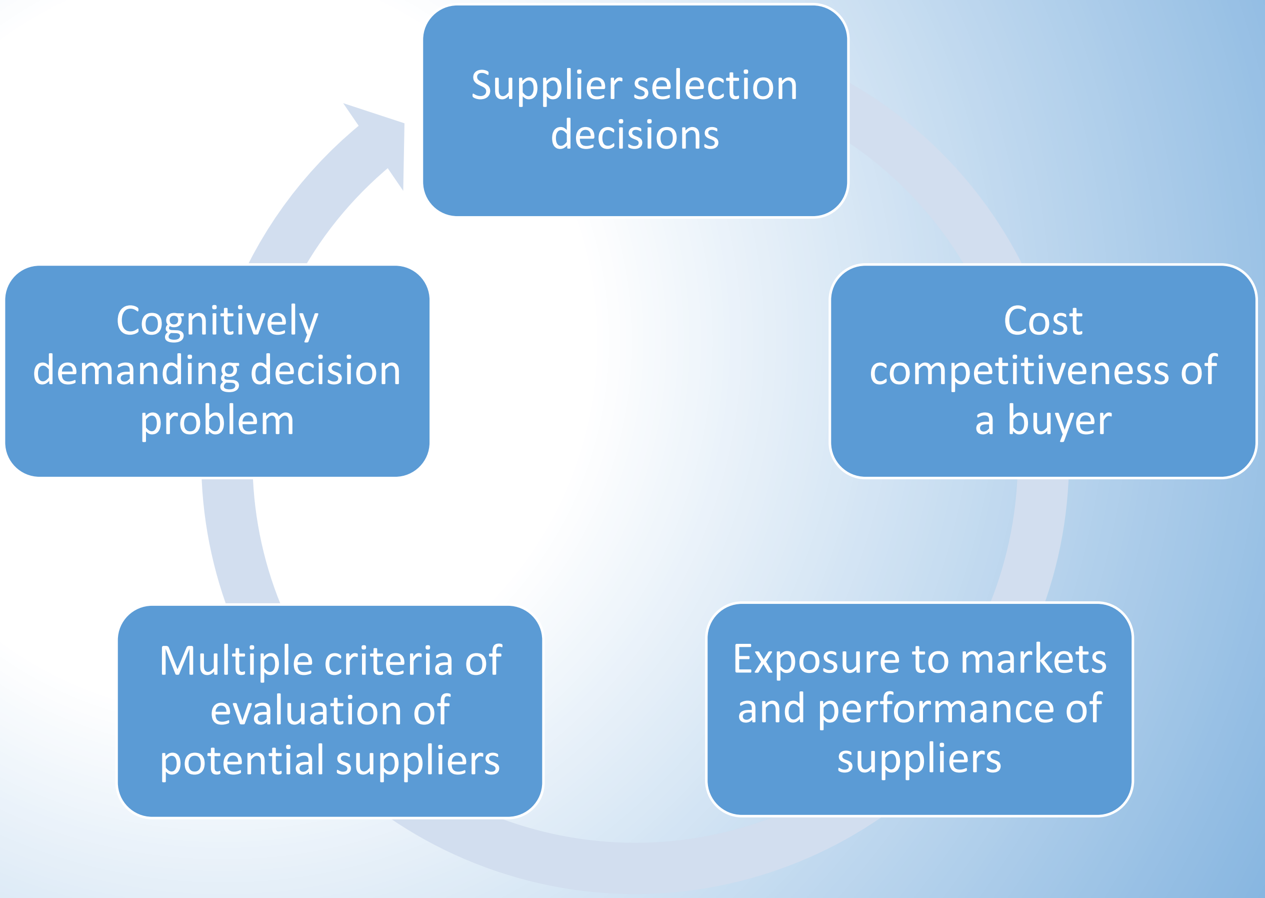
Summary of the presentation:

- ✓ Introduction
- ✓ Methodology of the research
- ✓ Initial dataset
- ✓ Simple additive weighting (SAW) model
- ✓ Weighted goal programming (WGP) model
- ✓ Analytic Hierarchy Process (AHP) model
- ✓ Results and conclusions
- ✓ References

Supplier selection is a complex decision problem, affecting competitive position of a buyer and involving multiple criteria evaluation of possible supply alternatives:

- ❑ Quantitative financial (cost-related) criteria
- ❑ Quantitative non-financial criteria
- ❑ Qualitative criteria
- ❑ Standards and legal requisites



The research of the supplier selection problem counts with a panoply of multiple criteria decision analysis (MCDA) approaches, applied solely or within integrated models:

Mathematical approaches

- Analytic Hierarchy Process
- Analytic Network Process
- Data envelopment analysis
- Mixed integer programming
- Goal programming
- TOPSIS

Statistical approaches

- Cluster analysis
- Multiple regression
- Discriminant analysis
- Principal component analysis
- Factor analysis

Artificial Intelligence

- Fuzzy set theory
- Case-based reasoning
- Neural networks
- Expert systems
- Genetic algorithm

The growth of theoretical research on the subject does not imply *per se* a linkage with the purchasing practice: “**It is apparent that the validity and success of all the developments of MCDA research are measured by the number and quality of the decisions supported by MCDA methodologies**.” (Figueira, Greco, & Ehrgott, 2005)

Boer and van der Wegen (2003), and Bruno et al. (2012), formulated the following issues reflecting the possible gap between supplier selection research and practice:

- Lack of empirical evidence of usefulness of MCDA models.
- Tendency to use illustrative examples.
- Lack of attention to end-user impact, perception, and integration with existing practice and procedures.

The methodology of case study with experiment was adopted in the present research. It followed the design of de Boer and van der Wegen (2003): **a comparison of a decision situation in which a formal decision tool was applied with a situation in which this was not the case**.

- Three approaches were applied to a recent and relevant purchasing situation:
  - Simple additive weighting – SAW model
  - Weighted goal programming - WGP model
  - Analytic hierarchy process – AHP model.
- The feedback of decision makers, concerning decision analysis, modelling process and comparison of outputs, was analyzed.

The case studied was of a specialized Portuguese textile group, possessing its own trademark but also working for world-known labels.

Purchasing represents +/- 40% of total cost of production, with yarn, the main raw material, weighting 80-85% of purchasing costs.

The Group is working for the top price segment, and the quality of the final products is a part of its marketing strategy.

Information about relevant criteria of supplier selection is provided by:

- Internal clients - Production and Quality areas
- External expertise in textile quality control - USTER® Technologies AG (2016).

The explored purchasing decision was choosing a supplier of cotton yarn on *Title NE50/1*, to be delivered monthly, in six orders of 5000 kg each.

The initial dataset included performance of 5 suppliers (A, B, C, D, E) on the set of relevant criteria:

Criteria	Value	Target/limits	A	B	C	D	E
Hairiness, max	5	4.5	4	4	4.5	5.09	3.5
Contamination, per kg, max	5	0.5	0.5	0.5	0.5	0.5	0.5
Thick places (+50%), max	4	22	22	42	21.3	22	6
Title (NE)	3	50+/-0.5	50	50	50.66	49.5	50
Coefficient of variation (CV%), max	3	1.4	1.2	1.4	0.97	1.2	1.2
Thin places (-50%), max	3	6	5	5	2.5	3	1
Neps (+200%), max	3	76	40	94	55.3	86	22
Twist (1/m)	3	[3.5 - 4]	3.7	3.75	3.52	3.75	4
Unit price, €/kg, max	2	4.6	4.6	4.6	4.8	4.5	4.85
Availability for order, kg	1	30000	yes	yes	yes	yes	yes

- All criteria were quantitative, measured in different scales (or indexes).
- All data was treated deterministically, with possibility to carry out laboratorial samples quality testing.
- ***Contamination*** criterion was redundant for this particular case, but it was agreed to keep it in analysis.
- In this case it was decided to order from only **one source**, to guarantee the lot´s homogeneity; ***Availability*** criterion must be transformed into a capacity constraint.
- Here, neither logistic performance nor qualitative criteria were relevant for the decision makers.
- For the 7 of the remaining 9 criteria, minimization is the sense of optimization, i.e. "**less is the better**".
- There were 2 dual-side criteria, in which "**exact is the better**": ***Title (NE)*** and ***Twist***.
- ***Twist*** criterion seemed like interval of acceptance (as initially formulated), but it was really dual-side target value. The value of 3.8 was defined as a target, with values of 3.5 and 4.0 as rejection levels.

Linearity assumed, **the 1st step of the SAW model** was normalization of the suppliers' performance, starting with one-side criteria:

For maximization: $$r_{ij} = \frac{s_{ij}}{max\ s_{ij}} \quad (1)$$

For minimization: $$r_{ij} = \frac{min\ s_{ij}}{s_{ij}} \quad (2)$$

Where s_{ij} was the performance of supplier *i* on criteria *j*, *i* = 1, 2, …, *m*, and *j* = 1, 2, …, *n*.; resulting in scores r_{ij}.

- For normalization of the performance data on two dual-side criteria - ***Title (NE)*** and ***Twist***, triangular linear function was applied.
- Having alternative(s) matching the exact target value, the resulting scores are already normalized in the same sense as in the equations (1-2); otherwise the equation (1) is applied.

Only one of the 5 alternatives actually fulfils all the limits - supplier A. Though, the nature of the *target/upper limits* was not clear: are they **rejection or aspiration levels**? Rescreening performed, it was decided:

- **To drop the supplier B**, which exceeds largely rejection levels on ***Thick places*** and ***Neps*** criteria.
- The supplier E, which does not meet ***Price*** criterion, was kept in the analyses.
- The suppliers C and D were kept in the analysis, but zero score were assigned to these alternatives on criteria where original rejection levels were matched or exceeded.
- For ***Thin places*** criterion the indifference level equal to "3" was established.

Performance data normalization scheme decided, **the 2nd step of the SAW model** was defining the criteria weights, representing the relative importance of every criterion.

The criteria relative weights are positive and sum to "1".

The vector w_j of the criteria relative weights was obtained with AHP. The pairwise comparison matrix and resulting weights are shown here.

	Criteria	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	w_j
(1)	Hairiness	1.00	1.00	2.00	4.00	4.00	4.00	4.00	4.00	5.00	**0.2430**
(2)	Contamination	1.00	1.00	2.00	4.00	4.00	4.00	4.00	4.00	5.00	**0.2430**
(3)	Thick places	0.50	0.50	1.00	3.00	3.00	3.00	3.00	3.00	4.00	**0.1610**
(4)	Title (NE)	0.25	0.25	0.33	1.00	1.00	1.00	1.00	1.00	3.00	**0.0645**
(5)	CV%	0.25	0.25	0.33	1.00	1.00	1.00	1.00	1.00	3.00	**0.0645**
(6)	Thin places	0.25	0.25	0.33	1.00	1.00	1.00	1.00	1.00	3.00	**0.0645**
(7)	Neps	0.25	0.25	0.33	1.00	1.00	1.00	1.00	1.00	3.00	**0.0645**
(8)	Twist	0.25	0.25	0.33	1.00	1.00	1.00	1.00	1.00	3.00	**0.0645**
(9)	Unit price	0.20	0.20	0.25	0.33	0.33	0.33	0.33	0.33	1.00	**0.0303**

The **Consistency Ratio (C.R.) was equal to 0.0143** (i.e., almost consistent).

The third step of the SAW model was to make weighted sum calculations:

	Criteria	Ideal vector	A	C	D	E	AHP weights	SMART weights
(1)	Hairiness	3.50	0.8750	0.7778	0.0000	1.0000	0.2430	0.1779
(2)	Contamination	0.50	1.0000	1.0000	1.0000	1.0000	0.2430	0.1779
(3)	Thick places	6.00	0.2727	0.2817	0.2727	1.0000	0.1610	0.1383
(4)	Title (NE)	50.00	1.0000	0.0000	0.0000	1.0000	0.0645	0.0988
(5)	Coefficient of variation	0.97	0.8083	1.0000	0.8083	0.8083	0.0645	0.0988
(6)	Thin places	3.00	0.6000	1.0000	1.0000	1.0000	0.0645	0.0988
(7)	Neps	22.00	0.5500	0.3978	0.0000	1.0000	0.0645	0.0988
(8)	Twist	3.80	0.8000	0.0800	1.0000	0.0000	0.0645	0.0711
(9)	Unit price	4.50	0.9783	0.9375	1.0000	0.9278	0.0303	0.0395
Total score (AHP weights), %			**77.17**	**66.56**	**49.85**	**92.09**		
Total score (SMART weights), %			75.91	63.49	50.50	90.71		

- An alternative set of criteria weights was calculated with SMART (Simple multi-attribute rating technique): different vectors of the criteria relative weights had no significant impact on the final scores.
- **Total scores of alternatives in percentage display the proximity of the supply alternatives to the ideal solution, in accordance with the preferences of the decision-makers.**
- Supplier D, the less costly one, was clearly a worst performing option.
- Supplier E, the most expensive one, was considered as the best alternative.
- Supplier A, the only one which did not violate initial target/upper limits, was the second best alternative.

✓ **The way in which the data was structured and visualized, was innovative to the decision makers.**
✓ **The process of structuring the decision process was found to be revealing and useful.**
✓ **The obtained final scores of the suppliers were consistent with the decision makers´ experience.**

Dropped one source strategy, in this or future buying decisions, the SAW model output might not be efficient.

Considered underlying philosophy of satisfying multiple objectives, and without evidence of different priorities levels, **weighted goal programming model** was chosen.

Model indices, parameters and decision variables were stated as follows:	
i	set of suppliers, $\forall i \in \{1, \dots, 4\}$
j	set of criteria, $\forall j \in \{1, \dots, 9\}$
k_j	set of goals to achieve on criteria j
s_{ij}	performance of supplier *i* on criterion *j*
d	buyer´s demand
c_i	supplier´s *i* capacity
w_j	relative weights of criteria *j*, assigned by the decision makers
x_i	**decision variable of order quantity, allocated to supplier *i***
n_j	underachievement deviational variable on criterion *j*
p_j	overachievement deviational variable on criterion *j*

Also used as normalization constant for the elements of the achievement function

Performance of the suppliers given in the initial dataset, without normalization

The vector of criteria relative weights, already obtained with AHP

Objective function was expressed as follows:

$$min\ a = \frac{w_1 \times p_1}{k_1} + \frac{w_2 \times p_2}{k_2} + \frac{w_3 \times p_3}{k_3} + \frac{w_4(n_4 + p_4)}{k_4} + \frac{w_5 \times p_5}{k_5} + \frac{w_6 \times p_6}{k_6} + \frac{w_7 \times p_7}{k_7} + \frac{w_8(n_8 + p_8)}{k_8} + \frac{w_9 \times p_9}{k_9}$$

Subject to:
$\sum x_i = d,\ \forall i \in \{1, \ldots, 4\}$
$c_i \geq d,\ \forall i \in \{1, \ldots, 4\}$
$\sum x_i s_{ij} + n_j - p_j = k_j,\ \forall i \in \{1, \ldots, 4\},\ \forall j \in \{1, \ldots, 9\}$
$n_j, p_j \geq 0,\ \forall j \in \{1, \ldots, 9\}$
$x_i \geq 0$ and binary, $\forall i \in \{1, \ldots, 4\}$

The formulation allowed minimization of the unwanted deviations from the defined goals on the 9 relevant criteria:

- Unwanted deviation variables were multiplied by the weighting vector w_j of criteria importance.
- Unwanted deviation variables were divided by the set of goals as normalization constants.
- **For the dual-side criteria, the sums of negative and positive deviations were minimized.**

- With **initial set of targets/limits used as first set of goals**, the solution was to order to the supplier A – it was consistent with the fact that supplier *A* was the only one not violating the initial set of targets.
- **Switching to more rigorous set of targets on the 9 criteria** (4, 0.5, 22, 50, 1.2, 3, 55.3, 3.8, 4.6), or to the ideal vector as set of targets, the solution was to order to supplier E - consistent with the SAW model.
- Next, **the binary condition of decision variables x_i and capacity constraint were relaxed**, with the same target setting. The solution found was to split the order between all suppliers in the following proportions:
- In the variant of the multiple sourcing, the achievement function value decreased 7.47 times, the total cost of solution was reduced from 145500€ to 141043€ (i.e., less 3.06%).
- This way, different policy scenarios - single and multiple sourcing strategies - and "supplier A" variant, might be visualized and compared, with sensitivity analysis facilitated, **providing an analysis tool for the decision makers**.

Supplier	Order
A	0,399
C	0,102
D	0,125
E	0,374

In the final stage of the case the decision makers commented that ***Title*** **(*NE*)** dual-side criterion - a density index - might be seen as asymmetric:

- Some yarn lot with the index less than 50 is thicker, thus provoking greater material consumption.
- The value function on this criterion might be seen as non-linearly decreasing to the right of the target value.

AHP is a decision making technique able to aggregate tangibles and intangibles factors, so as non-linearity.

The AHP single technique model with three levels was elaborated: **supplier selection level as the overall objective, criteria level and alternatives level.**

- The vector of relative weights of the criteria was already calculated for the previous models.
- **The next step was to compare the supply alternatives to each other with respect to all criteria**.

Comparisons on one-side criteria were based on the performance data of *i*th supplier on *j*th criterion.

Example: performance of the suppliers according to the ***Hairiness*** criterion.

Suppliers	A	C	D	E	Suppliers weight
A	1.000	1.125	1.273	0.875	0.262
C	0.889	1.000	1.131	0.778	0.233
D	0.786	0.884	1.000	0.688	0.206
E	1.143	1.286	1.454	1.000	0.299

Performance of the alternatives on the dual-side criteria was assessed on the 1 to 9 scale.

Example: pairwise comparison matrix and suppliers' weights for the ***Title (NE)*** criterion.

The C.R. was equal to 0.00599 - consistent matrix.

Suppliers	A	C	D	E	Suppliers weight
A	1.000	5.000	7.000	1.000	0.425
C	0.200	1.000	2.000	0.200	0.094
D	0.143	0.500	1.000	0.143	0.056
E	1.000	5.000	7.000	1.000	0.425

Performance of the suppliers according to the relevant criteria assessed, known the criteria weights, follows resulting AHP model calculations:

The output slightly differs from the one of the SAW model - AHP model maintained inherent values of the alternatives on the criteria even when the specifications´ limits were matched or surpassed.

	Criteria	Criteria weights	A	C	D	E
(1)	Hairiness	0.2430	0.2619	0.2328	0.2059	0.2994
(2)	Contamination	0.2430	0.2500	0.2500	0.2500	0.2500
(3)	Thick places	0.1610	0.1493	0.1542	0.1493	0.5473
(4)	Title (NE)	0.0645	0.4251	0.0938	0.0561	0.4251
(5)	Coefficient of variation	0.0645	0.2360	0.2920	0.2360	0.2360
(6)	Thin places	0.0645	0.1034	0.2069	0.1724	0.5172
(7)	Neps	0.0645	0.2496	0.1805	0.1161	0.4538
(8)	Twist	0.0645	0.3221	0.0704	0.5371	0.0704
(9)	Unit price	0.0303	0.2545	0.2439	0.2602	0.2414
		Total weights of suppliers	**0.242**	**0.204**	**0.215**	**0.339**
		Scores of suppliers, %	**71.54**	**60.20**	**63.40**	**100.00**

The final interview was dedicated to the decision makers´ feedback and analysis of the models´ perceived value.

- The **SAW model** was seen as very enriching approach: **it forced to make a scrutinized analysis of the decision problem**; the correct implementation was not as straightforward as it might be expected.
- The **goal programming** proved to be a sophisticated concept. Its capacity to handle multiple source (product, period) purchasing decisions was noted. However, such complex problems should not be a starting point of implementation.
- AHP was integrated with SAW and GP models, and applied as a single technique. **AHP was seen as very universal, intuitive approach, less work-intensive and time consuming as it might appear**.
- The decision models were developed with Excel and Solver of Excel; control calculations were made with free decision software BeSmart2. Such approach allowed to avoid time and money investment in this – initial and experimental - stage.

- Structuring and visualization of the supplier selection problem was found practically useful, giving mathematical tools to analyse multiple criteria - especially USTER® parameters - in the aggregated manner.
- Such concepts as rejection and aspiration levels, compensatory and non-compensatory decision rules, quantitative and qualitative data, sensitivity analysis, non-linearity and asymmetry were seen as valuable contributes to practical decision making skills of the managers.
- The decision modelling outcome was considered acceptable and consistent with the decision makers´ experience, provided a tool of internal/external supply-related analysis and communications.
- Modelling a typical and important, but not very complex, decision process was crucial to capture attention and interest of the managers to the implementation of the MCDA approaches.

In the context of the present research, MCDA-based decision modelling showed to be a useful tool when supplier selection decisions imply trade-offs between feasible alternatives possessing different properties.

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Células de Variável

Célula	Nome	Final Valor	Reduzido Custo	Objetivo Coeficiente	Permissível Aumentar	Permissível Diminuir
$B$3:$W$3						
$B$3	X1	0,399379864	0	0	0,235073199	0,612685689
$C$3	X2	0,102140078	0	0	0,27816778	0,342726039
$D$3	X3	0,124635214	0	0	0,243823897	0,458762862
$E$3	X4	0,373844844	0	0	0,374786829	0,545386826

Table 12. Criteria relative weigths with SMART technique

Criteria	Points	Criteria weight W_i
(1) Hairiness	45	0.1779
(2) Contamination	45	0.1779
(3) Thick places	35	0.1383
(4) Title (NE)	25	0.0988
(5) CV%	25	0.0988
(6) Thin places	25	0.0988
(7) Neps	25	0.0988
(8) Twist	18	0.0711
(9) Unit price	10	0.0.395

$$\begin{bmatrix} 1 & 1 & 2 & 4 & 4 & 4 & 4 & 4 & 5 \\ 1 & 1 & 2 & 4 & 4 & 4 & 4 & 4 & 5 \\ 0.5 & 0.5 & 1 & 3 & 3 & 3 & 3 & 3 & 4 \\ 0.25 & 0.25 & 0.33 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0.25 & 0.25 & 0.33 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0.25 & 0.25 & 0.33 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0.25 & 0.25 & 0.33 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0.25 & 0.25 & 0.33 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0.2 & 0.2 & 0.25 & 0.33 & 0.33 & 0.33 & 0.33 & 0.33 & 1 \end{bmatrix} \times \begin{bmatrix} 0.2430 \\ 0.2430 \\ 0.1610 \\ 0.0645 \\ 0.0645 \\ 0.0645 \\ 0.0645 \\ 0.0645 \\ 0.0303 \end{bmatrix} = \begin{bmatrix} 2.2504 \\ 2.2504 \\ 1.4934 \\ 0.5888 \\ 0.5888 \\ 0.5888 \\ 0.5888 \\ 0.5888 \\ 0.2753 \end{bmatrix}$$

Thank you for the attention!