Possibility and Benefits of MCDA Application for Decision Making Problems Support in Printing Activities

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Complex nature of the decisions made in a printing enterprise causes a need for the application of advanced decision making support tools that recommend effective decisions. Multi-criteria decision analysis approach constitutes such a tool. The results of a sample analysis confirm the applicability of the approach for management support.

Introduction

What a contemporary enterprise needs to survive in a dynamic complex surrounding environment is effective management. An enterprise adapts to external changes making constant decisions. Permanent changes in the surrounding environment cause that even simple, theoretically repeatable decisions, can be of a unique nature. On the other hand, there appear decisions which are clearly crucial for the future of an enterprise. Because of some important issues including uncertainties, appearing due to the changes in the surrounding environment, possible (and often considerable) consequences of decisions and the involvement of numerous resources, such decisions should be prepared carefully. To do it properly, decision makers should not rely on intuition only. What is needed here instead is the application of substantial decision support approaches, which would lead to more adequate decisions. On the other hand, the effects of decisions made in contemporary business world depend on numerous influences e.g. economic, social, environmental ones. So this is advisable to take into account parallel influence of all important issues. There is an approach especially useful when dealing with a multi-aspect nature of decision problems. The approach is called multi-criteria decision analysis (MCDA) or multi-attribute decision analysis (MADA). Methods implementing MCDA paradigm (Figueira et al., 2005) constitute a large set which is a strong basis for the choice of a method which is the most appropriate for the specific problem. For example, real complex decision problems often include not only tangible but also intangible issues. Particular methods applied for recommendation of the best decision alternative should be able to cope with the influence of intangible issues effectively.

A contemporary printing enterprise has similar survival problems like general businesses. There are different kinds of choice decisions which are often made. They deal with equipment and materials, staff, location of services, advertisement technique etc. They are also of complex multi-aspect nature so they are prone to the application of MCDA approach to arrive at effective decision recommendation. However, despite the long time existence of appropriate methods, they have not been extensively utilised yet. Such a phenomenon seems to result from a limited knowledge as to the availability of appropriate software that helps a lot in the application of multi-criteria decision support. The applied MCDA approach should be also fitted to a nature of a decision problem under consideration and integrated into the structure of a decision problem to deliver meaningful and acceptable results for decision makers.

A sample application of MCDA approach is presented in the paper. It deals with a preparation of recommendation for a decision maker with regard to a proper choice of printing equipment. Due to including both tangible and intangible issues and considering additional limitations the problem is not trivial. Therefore, the application shows its practical potential in case of a printing enterprise management. The results obtained make it possible to draw some interesting practical conclusions with regard to quality and rather sensational nature of external, commonly acknowledged, but, in our opinion, misleading sources of information.

Considered decision problem and goals of decision analysis

The problem pertains to a choice of a multi-functional printing equipment for a small-sized printing enterprise. There are many equipment models available in the market today. Models of leading manufacturers differ in some respects and are very similar in other. To make a justified choice, the initial selection of five equipment models proposed by experts of a recognised computer journal is taken into account. The models comprise so called choice alternatives. Five essential criteria of an equipment choice are taken into account: price, printing speed, accessories, operational costs and dimensions. Profiles of selected models are presented in tab.1. The models come from worldwide acknowledged manufacturers. The criteria have different nature. Some of them are clearly tangible (price, printing speed, operational costs—cost of standard page copy and dimensions) and there is one criterion which is clearly intangible (accessories). The tangible criteria have different meaning. Higher position of alternatives is obtained in case of higher scores for some criteria (printing speed) and in case of lower scores for other criteria (price, operational costs, dimensions). A nature of alternatives due to each criterion is identified in tab.1 using a cell background color (red colour pertains to the least preferable alternative, green colour denotes the most important alternative and grey colour is reserved for the intermediate alternatives). It is evident from the data gathered in tab.1 that there is no alternative which would be the best (dominating alternative) or the worst (dominated alternative) with regard to all considered criteria.

	Choice Alternatives	1	2	3	4	5
	Appliance model name	Color Image Runner C3220 **Canon**	Aficio 3235C **Ricoh**	Work Centre Pro C2636 **xerox**	ARC262MSP **SHARP**	X762e **Lexmark**
Nr.	Feature					
1	Price [PLN]	56689	34500	45700	34200	24800
2	Printing speed [page per minute]	32	17.3	18.1	32	23
3	Accessories	modules: folding and brochure completion, scan and copy resolution: 600 dpi, printing resolution 2400 dpi, image rotation, paper feeder capacity: 5000 sheets, appliance identification: mark inscription advanced access control, LCD control panel	modules: brochure completion, punching and sewing modules, duplex printing, one-point text printing, printing stop mode, paper size-based adaptation, image rotation, access control, data scrambling, safe data overwrite module, single and multiline fax machine	modules: continuous sewing, punching, creation of complete folded and sewed brochures, title page printing and applying, duplex printing, paper size selection, image rotation, appliance identification mark inscription, access control, single and multiline fax machine	modules: brochure completion and punching modules, modes: book, spread, duplex printing, paper size-based adaptation, up to 4 pages on a single sheet, image rotation, contrast control, access control	paper feeder: 1100 sheets, single line fax machine
4	Single copy cost [PLN]	0.50	0.74	0.92	0.84	0.99
5	Dimensions: width/depth/height [mm]	876x787x1181	914x692x1257	1460x889x1276	660x698x1168	959x609x1181
	Consumption of floor area [m^2]	0.7	0.63	1.28	0.46	0.58

Table 1
Data describing set of considered choice alternatives

The main goal of the decision analysis is to deliver the final choice recommendation for a decision maker. It is also intended to include some additional repercussions pertaining to a price value. Both the influence of an admissible price limit and the influence of the attitude towards the price on the final decision recommendation should be considered. Collected data and stated goals fully justify the need for the application of the advanced decision support tool for the preparation of decision recommendation.

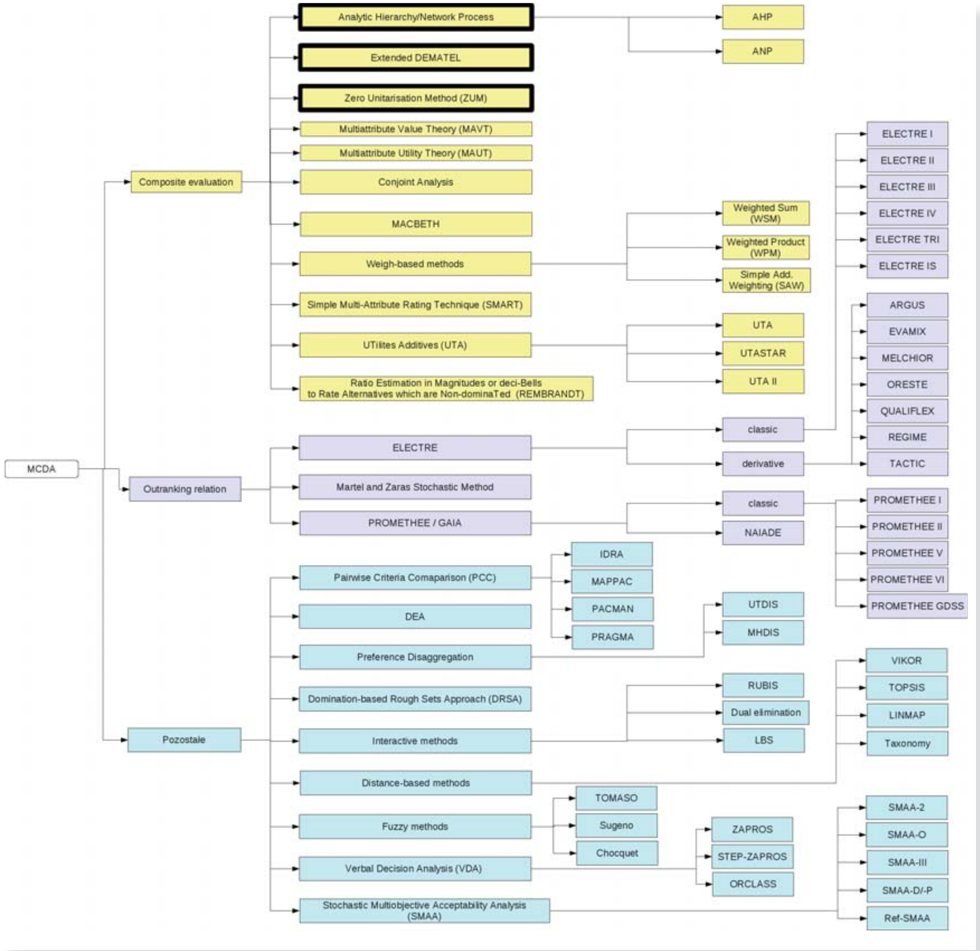


Fig. 1
Sample tree of MCDA methods

[1] [@:] http://www.superdecisions.com/~saaty.

[2] International Symposium on AH/NP ISAHP 2009. Pittsburgh, USA, 28 June–1 August 2009. [@:] http://www.isahp.com.

MCDA approach

Introduction

The notion of multi-criteria decision analysis comes from the sixties in the last century. The approach deals with sets of predefined decision alternatives and makes it possible to attain different goals: the choice of the best alternative or a small subset of close alternatives, classification (sorting) of alternatives and obtaining rankings of alternatives. It comprises a part of a wider concept called multi criteria decision making (MCDM) which also includes cases where decision alternatives are not predefined but result from the analysis taking into account several conditions which must be obeyed by profiles of alternatives.

Despite a long history the development of MCDA approach is still under way. There appear new methods constantly and the old methods undergo constant improvement. The usefulness of the methods is verified all the time in both theoretical analysis and practical applications. There are a lot of methods which implement the approach. They differ both in implementation details and the scope of application. A sample tree for MCDA methods is presented in fig.1.

Decision analysis using a multi-criteria approach generally includes the following steps:

1. definition of decision analysis goal(s);
2. initial selection of non-dominated decision alternatives;
3. identification of alternatives parameters allowing to attain analysis goal(s);
4. final realisation of the goal.

Analytic Hierarchy Process (AHP) method (Saaty 1980) is applied as a basic MCDA approach for the solution of the considered decision problem. Two other methods, namely: extended Decision Making Trial and Evaluation Laboratory (DEMATEL) (Fontela and Gabus, 1976; Dytczak and Ginda, 2008) and Zero Unitarisation Method (ZUM) (Kukuła, 2000) are utilised as auxiliary means for the validation of the results delivered by AHP. Description of the methods follows below.

Analytic Hierarchy Process

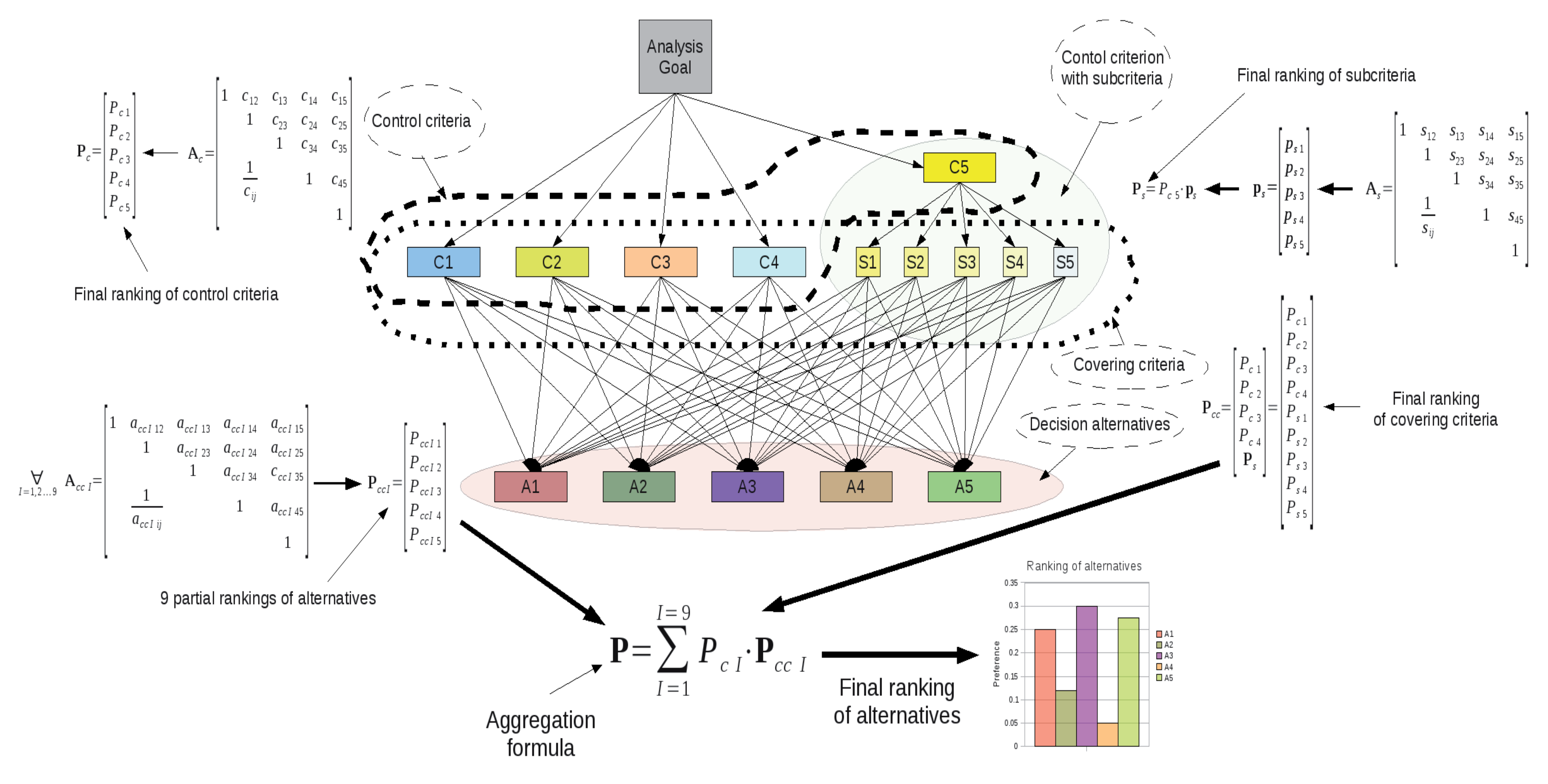
Overall order of alternatives is derived using AHP method. The method is a particular case of more general, although much younger approach called Analytic Network Process—ANP (Saaty, 1996). One of inherent strengths of AHP and ANP methods is the ability to cope with problems including intangible aspects (Saaty et al., 2003; Saaty, 2005). The ability made it possible to utilise both approaches for numerous diverse decision making problems. AHP is the older approach. Therefore, it has been more widely utilised in the past. For example, a survey of recent AHP applications can be found in a paper by Vaiadya and Kumar (Vaidya and Kumar, 2006). ANP has got a long record of application as well. To learn more about areas of AHP and ANP applications, materials presented in the WWW by AHP/ANP founder—prof. T.L. Saaty can be consulted[1] . AHP and ANP are subjects of dedicated[2] and general international symposiums and seminars e.g. (York, 2008).

Both AHP and ANP methods require the structuring of a decision problem into a set of related items including analysis goals, criteria and decision alternatives. A basic difference between AHP and ANP comes from a considered form of relations. The ANP is based on a notion of a feedback while the AHP relies on a simple linear hierarchical relation between the considered items. To make use of AHP/ANP, the particular decision problem should be expressed by a control structure. The structure is a feedback network in case of ANP application and linear hierarchy in case of AHP application.

In case of the best equipment model selection problem there is not any need for including feedback between the considered analysis goal, criteria and possible alternatives. Thus, a linear control hierarchy will do in case of a decision making problem under consideration. The assumed control hierarchy is presented in fig.2 (dashed rectangle embraces a group of criteria complementing the price criterion).

To find the order of the criteria and alternatives a concept of a pairwise comparison is utilised. The comparison is related to the relation between criteria or alternatives considered in a pair wise manner. The concept is well suited to psychological aspects, that is the ways people make decisions. Considered criteria are compared with regard to relation of importance between them and included alternatives are compared with regard to choice preference. The alternatives are compared in case of each

Fig. 7
Illustration of AHP application rules



This illustration has been printed on the central pages of this journal because of its size. It is referred to on page 42.

criterion separately. Several partial alternative rankings (each pertaining to one criterion only) are obtained this way. The final ranking of alternatives is derived thanks to the aggregation of partial alternative rankings. It is assumed that the importance of each partial ranking is proportional to the rank of underlaying criterion. Therefore, the final ranking of criteria is required to obtain the overall ranking of alternatives. Both partial rankings of alternatives and final ranking of criteria are obtained using the same approach. The approach is based on a concept of a full set of pairwise comparisons of items comprising a group of criteria or alternatives. Criteria occupy a single bottommost level in the considered control hierarchy (fig.2). However, they can appear on several levels of the hierarchy. In such a case they constitute the whole hierarchy of more general and more specific criteria. The bottommost level criteria are called covering criteria. They influence the ranking of alternatives directly. There are five covering criteria in the problem under consideration.

Every possible combination of items forming a group is included while making pairwise comparisons. Typically, a discrete qualitative 9-point judgement scale is applied for making the judgements. Odd levels of scale are applied in case of sure expert judgements. The levels have the following meaning:

- 1—equal importance of both compared criteria (or equal preference for both alternatives),
- 3—a slight advantage of the first compared criterion (or the first compared alternative),
- 5—a noticeable advantage of the first criterion (or the first alternative),
- 7—a big advantage of the first criterion or (the first alternative),
- 9—an extreme advantage of the first criterion or (the first alternative).

Opposite relations are assessed using a simple reciprocal rule:

- 1/3 denotes a slight advantage of the second compared criterion (or the second alternative),
- 1/5 means a noticeable advantage of the second criterion (or the second alternative),
- 1/7 expresses a big advantage of the second criterion (or the second alternative),
- 1/9 denotes an extreme advantage of the second criterion (or the second alternative).

Even scale levels and their reciprocals are utilised in case of expert's hesitation when making judgements:

- 2 (½) corresponds to an intermediate state between equality and slight advantage (or disadvantage),
- 4 (¼) refers to an intermediate state between slight and noticeable advantage (or disadvantage),
- 6 (1/6) relates to an intermediate state between noticeable and big advantage (or disadvantage),
- 8 (1/8) pertains to an intermediate state between big and extreme advantage (or disadvantage).

Scales of other kinds (e.g. of continuous nature) can be applied as well (Dong et al., 2008). However, that is not recommended by the AHP founder. Every utilised AHP scale should be of a universal nature. The universal nature means the ability to cope well with both tangible and intangible items.

A full set of judgements for a group of items makes it possible to obtain a judgement matrix A. The judgement matrix is quadratic. Its size equals to a number of items (n) constituting a group. The i-th row of the matrix consists of judgements pertaining to relations which include the i-th item as the first in pairwise comparisons. The j-th row of the matrix includes judgements pertaining to relations which include the j-th item as the second in the comparisons. Thus, a component of A which occupies the i-th row and j-th column (aij) contains a judgement corresponding to the assessment of relation appearing between the i-th item and j-th item of a group. The reciprocity rule makes the following formula valid in case of judgement matrix:

$$a_{ji} = \frac{1}{a_{ij}}. \qquad (1)$$

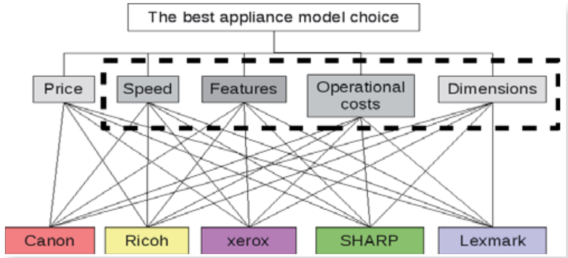


Fig. 2
Control hierarchy for the considered problem

The matrix consists of n^2 components. However, thanks to the reciprocity rule, only a part of components should be assessed to complete the matrix. The main diagonal components pertain to the comparisons of items against themselves. Therefore, they contain judgements equal to one. Matrix components below the main diagonal correspond to opposite relations (see eqn.1). Thus, the assessment of the components above the main diagonal (j>i) will do to obtain a complete set of matrix components. There are n(n−1)/2 components over the main matrix diagonal. So, a number of required comparisons equals n(n−1)/2.

The judgement matrix comprises the basis for obtaining actual order for a group of items. The order is given by a normalised priority vector. Components of the vector are priorities pertaining to the rank of the assessed items. Derivation of a priority vector is called prioritisation. There are several prioritisation techniques available (Srdjevic, 2005). The founder of AHP recommends a prioritisation technique based on the application of right-hand eigenvector p (Saaty, 2003) corresponding to maximal eigenvalue λ_{max} of a judgement matrix A (2):

$$\mathbf{Ap} = \lambda_{max}\mathbf{p}. \qquad (2)$$

However, other techniques can be applied with this regard e.g. additive normalisation, weighted least squares, logarithmic-least squares, logarithmic goal programming, fuzzy preference programming and rising matrix A to powers. The above mentioned techniques differ in complexity and accuracy of delivered results. An average normalisation technique constitutes a less time consuming and resource-consuming approach because it requires the application of only elementary operations like adding, multiplying, dividing. The technique relies on a concept of arithmetic mean corresponding to the contents of rows of a column-wise normalised judgement matrix. On the other hand, other techniques rely on more complex operations. For example, rising judgement matrix to a powers requires calculation of a sequence of matrix powers. The sequence ends when the assumed accuracy of the priority vector estimation is attained.

The subjective nature of expert's opinions results in a need for addressing a problem of judgement inconsistency. Inconsistency is related to a set of judgements pertaining to a group of items and related judgement matrix. AHP allows a certain a level of inconsistency when making judgements. Each existing prioritisation technique delivers means for validation of judgements consistency. For example, in the case of the right-hand eigenvector technique following formula is utilised for the consistency check:

$$c.r. = \frac{\lambda_{max} - 1}{(n-1) \cdot r.i.(n)} < 0.10, \qquad (3)$$

where: c.r. denotes consistency ratio and r.i. is random inconsistency index which relies only on a number of items (n) comprising considered group.

In the case c.r. is not less than 0.10, judgements must be rearranged appropriately to obtain a proper value of consistency. The additive normalisation technique makes use of eqn.3 and approximated eigenvalue λ_{max} instead of the accurate one.

Despite inevitable subjective expert opinions, AHP is a proven tool as to arriving at justified decision recommendation. Allowance for including a subjective expert's attitude helps a lot to cope with intangibility which is an inherent issue of real-life problems arising in different areas of activities including business, law, sports, government missions, arts, finance analysis and science. Real intangibility means a lack of ability to measure intensity of features. There are also cases when measurement is possible but due to issues with a lack of time needed for the measurement or measurement process complexity it would be more convenient to utilise less time-consuming and easier methods. Both kinds of intangibility can be addressed in a similar way.

The applicability of AHP for coping with intangible issues is illustrated using following examples. The examples pertain to the application of different human senses. Additive normalisation method based on a column-wise normalisation of judgement matrices is utilised for the derivation of the priority vector in the examples.

The first example involves the application of eyesight and deals with the assessment of relative sizes of geometrical figures[3] . Five figures are considered. The figures, judgement matrix and the obtained priority vector for figure areas is presented in fig.3. The initial row of the

[3] The idea borrowed from the WWW. [@:] http://www.superdecisions.com/~saaty.

judgement matrix pertains to pairwise comparisons of circle A area against area of itself (identity: judgement equal to 1), triangle B (an extreme advantage: 9), square C (the same area or a little advantage: 2), rhomb D (a slight or noticeable advantage: 4) and rectangle E (a noticeable advantage: 5). The second row contains judgements corresponding to comparisons of triangle B area against area of circle A (reciprocal of judgement 9 in the first row—a noticeable disadvantage: 1/9), itself (identity: 1), square C (a noticeable disadvantage: 1/5), rhomb D (a slight disadvantage: 1/3) and rectangle E (equality or a slight disadvantage: 1/2). The third row pertains to comparisons of square C area against area of circle A (reciprocal of judgement 2 in the first row—equality or a slight disadvantage: 1/2), triangle B (reciprocal of judgement 2 in the first row—a noticeable advantage: 5), itself (identity: 1), rhomb D (equality or a slight advantage: 2) and rectangle E (a slight advantage: 3). The fourth row contains judgements with regard to comparison of rhomb D area with areas of other figures. The judgements appearing in the first three columns are reciprocals of values appearing in the fourth column (cells in rows 1–3). Value in the fourth cell of the row is equal to 1 (comparison of the rhomb area against itself) and value in the last cell of the row corresponds to comparison of rhomb D area against area of rectangle E (equality or a slight advantage: 2). The first four cells of the last row of the judgement matrix are given by reciprocals of values appearing in the last column (cells in rows 1–4) and the last cell contains judgement 1 (due to comparison of rectangle area against itself). A set of judgements is consistent enough because consistency ratio c.r. due to eqn. 3 is equal to 0.007<0.10 (n=5, λ_{max}=5.033, r.i.=1,12). Estimated areas are very close to actual values given using boldface characters.

It is worth mentioning that there are other examples available through the WWW which correspond to other uses of eyesight e.g. pertaining to the order of items with regard to colour intensity.

Other senses can be successfully applied for deriving orders of items too. The following example corresponds to a problem of touch-based paper thickness estimation. A kind of printing paper is considered. The paper is available in 5 distinct thickness levels pertaining to basis weight of 90, 170, 240, 130 and 60 g/m^2. The results obtained are compared to real relative paper thickness given using bold face characters (fig.4).

The third example is devoted to the application of audition. Three different sound sources are considered: rustle of leaves (10 dB), calm street (30 dB), office noise (50dB), loud music inside (80 dB), motorcycle without a silencer (100 dB). The results obtained agree sufficiently well with the results of measurements presented using boldface characters (fig.5).

There are also some interesting examples available which demonstrate AHP potential for decision making support in case of complex real-life problems. One of them pertains to a market survey. The survey deals with determination of drink consumption structure in the USA[4] . The following drink categories were defined: coffee, wine tea, beer, sodas, milk and water. About two hundred consumers were randomly selected and interviewed to get information about their drink preferences. AHP is equipped with suitable tools to deal with group decision making, so it is possible to derive a single priority vector pertaining to the opinions delivered by the whole population of survey participants. The priority vector can be obtained using different group decision making-aware techniques. For example, a single judgement matrix aggregating all participants opinions can be defined. Such matrix can be immediately utilised for deriving the priority vector. The results obtained are presented in fig.6. The results are very close to official results (boldface characters) delivered by more thorough but very expensive statistical research. Thus, AHP can serve as a validation tool and it can also be applied as a replacement of more time-consuming and resource-consuming research approaches.

The application of a number of criteria more than one makes decision analysis more complicated. The division of considered criteria into more general and detailed criteria is often applied when addressing complex decision problems. Additionally, there is a kind of limitation pertaining to a number of items which make up a group. This number should be not larger than 9 (and preferably not smaller than 5). Such limitation corresponds to human capacity for processing information at once (Miller, 1956).

For each group of items a full set of judge-

[4] The example available in the WWW. [@:] http://www.superdecisions.com/~saaty.

Fig. 3
Data and results obtained in the case of the figure's area experiment

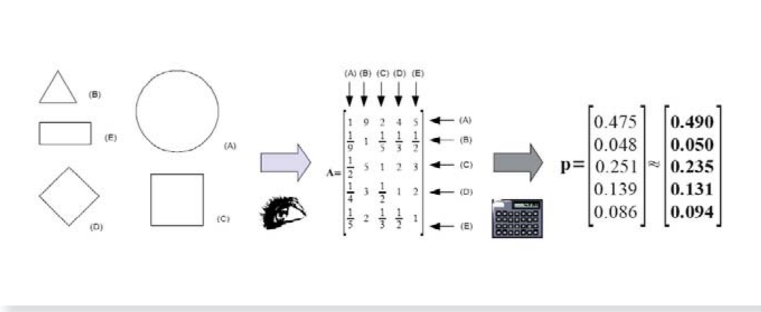


Fig. 4
Data and results for touch-based AHP application

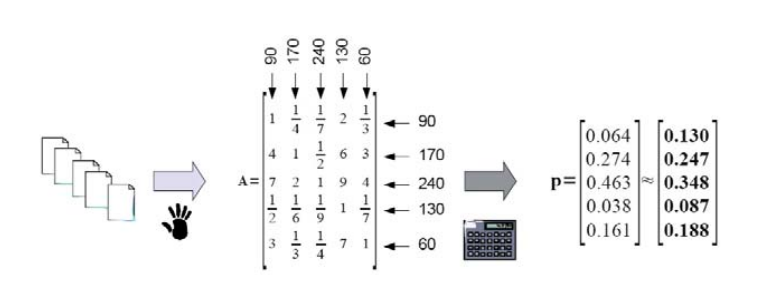


Fig. 5
Data and results for audition-based AHP application

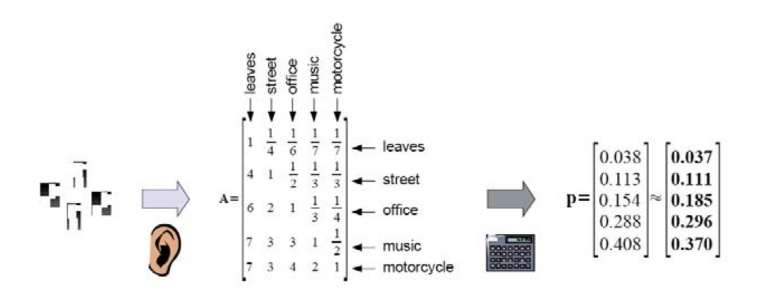
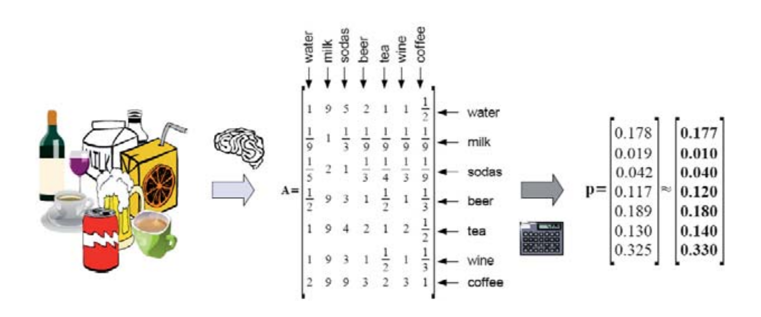


Fig. 6
Data and results for the drink consumption survey



ments pertaining to relations appearing between the items should be delivered. This set makes it possible to obtain a judgement matrix devoted to the group under consideration. There is a group of considered alternatives and there can be several groups of criteria. The group of alternatives occupies the bottommost level of a control hierarchy. The topmost level of criteria includes general criteria called control criteria. Each control criterion can own a group of subcrtieria. Each subcriterion can also own its group of subcriteria and etc. The importance of subcriteria depends on the importance of groups they belong to and relative importance of subcriteria inside a group. The importance of the whole group of criteria is equal to the importance of a criterion which owns a group.

The final ranking of alternatives (P) is obtained aggregating the final ranking of covering criteria and partial rankings of alternatives. The influence of each partial ranking on the overall ranking of alternatives is proportional to the importance of corresponding covering criterion. The rules of AHP application are illustrated in fig.7 (see page 36) using control hierarchy for a sample analysis. The analysis includes 5 control criteria (C1–C5). One control criterion (C5) owns a group of subcriteria (S1–S5). Five decision alternatives (A1–A5) are considered. A set of covering criteria consists of 4 control criteria without subcriteria (C1–C4) and 5 subcriteria of the fifth control criterion (S1–S5).

A number of considered alternatives bigger than 9 requires a division of a decision making problem into a number of partial problems, each pertaining to not more than 9 alternatives. To combine the results of partial problems into overall ranking of alternatives, the results for each problem should correspond to the results of a different problem. A common alternative is typically applied to join the results of two corresponding partial problems. Description of other advanced issues pertaining to AHP application can be found in various sources e.g. in (Dytczak and Ginda, 2006).

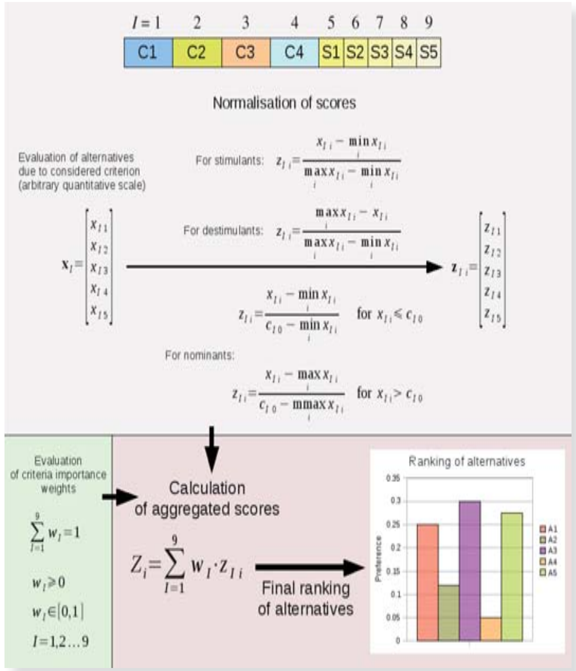
Other utilised MCDA approaches

Zero Unitarisation Method, ZUM (Kukuła, 2000) applies a concept of decision attribute value normalisation. The value of attribute pertains to the evaluation of alternatives with regard to the associated criterion. Arbitrary continuous interval evaluation scale can be applied. The domain of each attribute is mapped onto [0,1] interval. Diversified nature of attributes results in their division into three distinct classes:

1. stimulants (higher value of attribute is better);
2. destimulants (lower attribute value is better);
3. nominants (there exists the optimal value of attribute).

A different form of mapping formula is utilised for each kind of attribute. The attributes can also differ importance level. The importance level of attributes is expressed using weights of importance. The weights should be non-negative and sum up to one. They can be defined in any way. The overall score of an alternative is expressed by a weighted sum of partial outcomes obtained for distinct attributes. The score defines the position of alternative in the final ranking. Rules of ZUM application are presented in fig. 8. The same sample analysis as the one used to illustrate AHP application rules is utilised in case of ZUM.

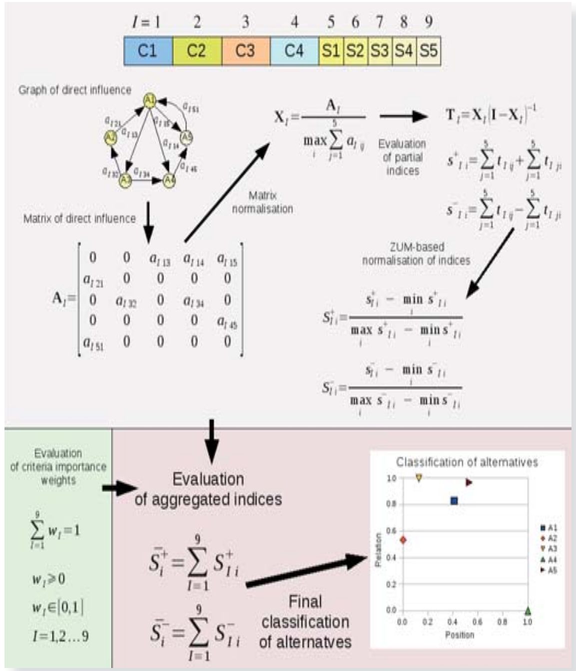
Fig. 8
Illustration of ZUM application rules



DEcision MAking Trial and Evaluation Laboratory, DEMATEL method has been developed to support solving of global and regional world's problems (Fontela and Gabus, 1976) and is described in detail in (Fontela and Gabus, 1976a). It is based on concept of a graph. The graph of a direct influence expresses directions and intensity of a straightforward cause-effect relation appearing between alternatives. A pairwise comparison of alternatives is utilised to estimate the intensity of relations. A discrete scale 0–N is applied for the estimation:

0—denotes a lack of influence,
1—means a slight influence of alternative,
…
N—expresses an extreme influence of alternative.

Fig. 9
Illustration of extended DEMATEL application rules



Nodes of the graph represent the considered alternatives and arcs denote the direction and intensity of relations. Mathematical expression of the graph called direct influence matrix is utilised to get classification of alternatives with regard to their influence on remaining alternatives. The application of appropriate formulae makes it possible to obtain two indices describing each alternative. The first index s^+ is called the position and expresses the overall (direct and indirect) meaning of an alternative. The second index s^- is called the relation and expresses the overall influence of an alternative on other alternatives. The relation delivers means for ranking alternatives. Joint application of indices delivers means for classification of alternatives.

DEMATEL can be extended to allow MCDA analysis (Dytczak and Ginda, 2008). To do so, the notion of influence relation should be replaced with the notion of importance relation. The final classification of alternatives is based on partial results obtained for exclusive influence of each considered criterion. Therefore, distinct forms of a graph of direct influence are required to include influence of different criteria. Partial analyses deliver normalised indices (S^+, S^-) for each alternative. ZUM formula for stimulants is applied to obtain the indices. The aggregation of these indices gives the final classification of alternatives. The influence of each partial analysis (stemming from the importance level of an associated attribute) is expressed using a normalised weight. A set of weight values for criteria can be obtained using an arbitrary approach. The weights should be non-negative and sum up to one. Rules for extended DEMATEL version application are given in fig.9. Presentation of the rules is based on the same sample problem like in cases of rules presentation for AHP and ZUM approaches.

Sample analysis

Needed calculations are made by means of own spreadseet-based application. A typical, discrete 9 point Saaty's judgement scale is applied while using AHP method. All AHP-based results conform to a required consistency level. The application of extended DEMATEL is based on a 0–8 discrete judgement scale. A stimulating nature of printing speed, accessories criterion and destimulating nature of other criteria is assumed in the case of ZUM application. Values of importance weights for the considered attributes in the case of DEMATEL and ZUM application are equal to those delivered by AHP application. At first, a ranking of choice criteria is obtained. The ranking is shown in fig.10.

Next partial rankings of alternatives are derived then. Preference levels corresponding to the influence of individual criteria are presented in figs.11.

Several shapes of the overall ranking of alternatives are obtained. Three different forms of ranking pertain to three distinct cases. The first case is related to including a full set of criteria (fig.12a) and it corresponds to the overall ranking of criteria presented above. These results are also presented in tab.2 together with their validation. The results obtained reveal the supremacy of two equipment models with a slight advantage of the SHARP model over the Canon machine. The Lexmark equipment is the third best, the Ricoh model comes immediately after and xerox equipment is a clear (although not cheap) loser.

The lack of the the price criterion results in minor changes in the obtained outcomes (fig.12b). Two formerly best alternatives retain their supremacy, although they swap ranks. The swap is obviously due to more favourable nature of the price criterion in the case of the SHARP model. Two next machines also exchange their ranks (the Ricoh equipment gains some advantage over the Lexmark model due to lower operational costs and supreme score in case of accessories criterion). Once again, xerox equipment occupies the last place.

The considered direct allowable price limit (PLN 40000) excludes the two most expensive models (fig.12c). Thus, a set of admissible alternatives consists of just three models now. Once again, a full set of choice criteria is taken into account.

The absence of the Canon model results in clear domination of the SHARP machine over the competitors left. The Lexmark equipment is the second best with a slight advantage over the Ricoh model.

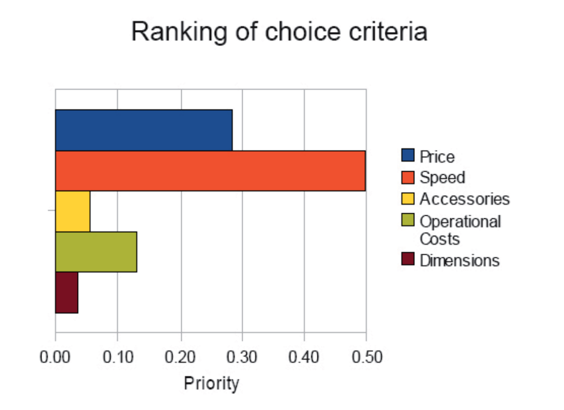


Fig. 10
Ranking of choice criteria

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Fig. 11
Partial rankings of alternatives

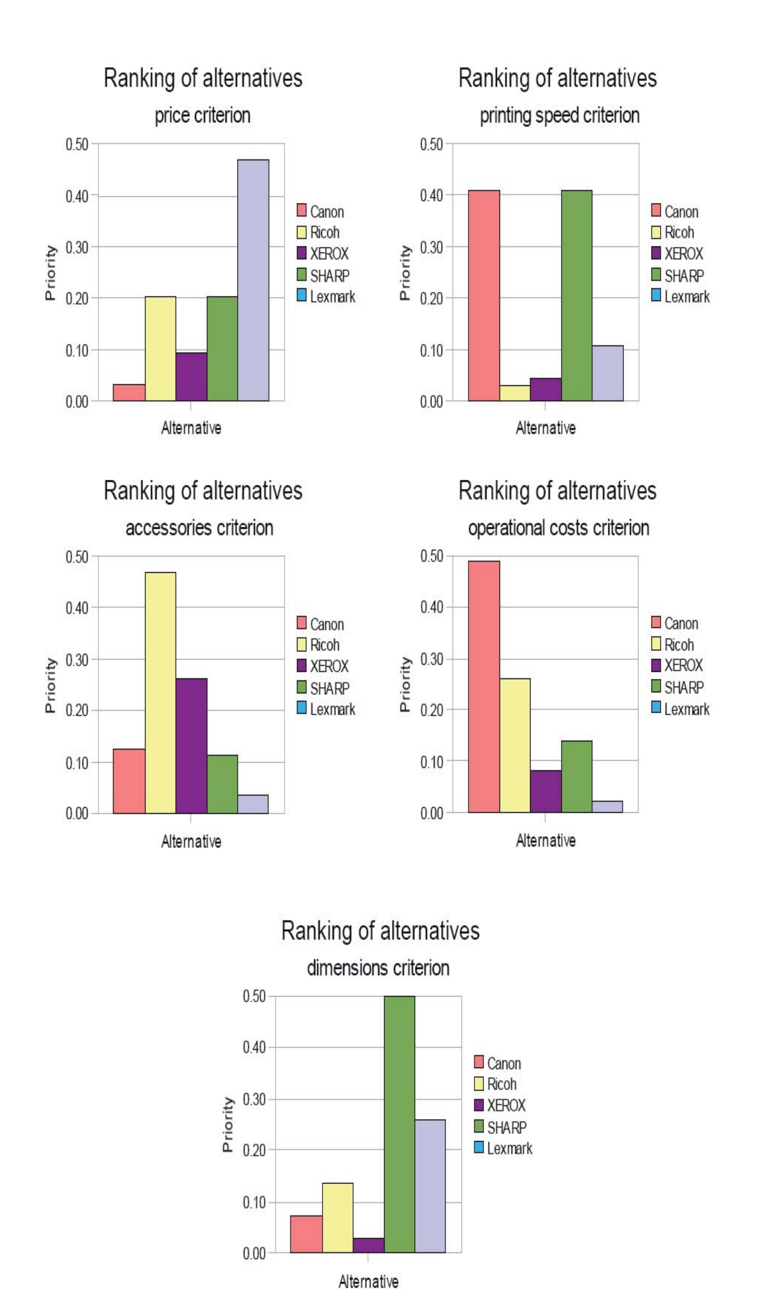
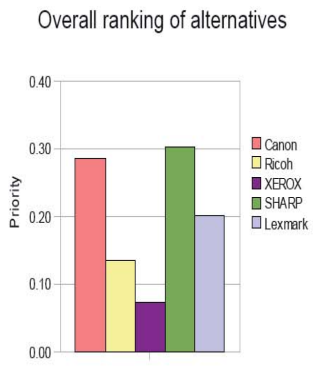
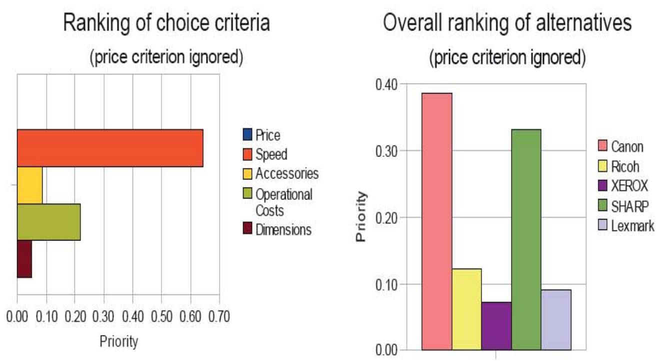


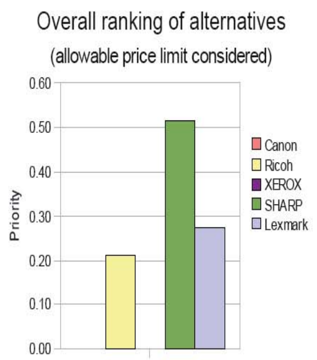
Fig. 12
Final rankings for alternatives



a. the price criterion included (without a limit of allowable price)

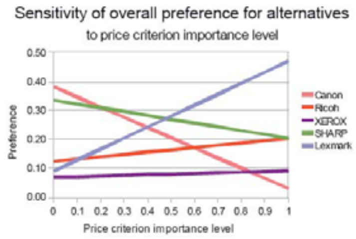


b. the price criterion ignored

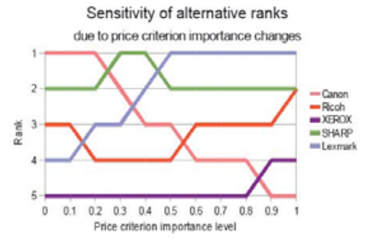


c. the price criterion included and a limit of allowable price (PLN 40000) considered

Fig. 13
Sensitivity of overall results to the price criterion importance level



a. sensitivity of overall preference



b. sensitivity of rank

A price constitutes a very important criterion while making business decisions. The considered equipment alternatives differ a lot with regard to a price level. Therefore, it can be advantageous to know more about the influence of price relative importance on scores and order of machines. To reveal this influence a kind of sensitivity analysis is conducted using AHP. To do so, different levels of the price criterion importance (relative to importance of a full set of criteria) are included ranging from 0 (total lack of the price criterion influence) to 1 (exclusive influence of the criterion). Intermediate importance levels correspond to a changing influence level of the criterion.

Results of sensitivity analysis are presented in fig.13a (continuous changes in choice preference level) and fig.13b (changes in ranks of alternatives). They reveal that the SHARP model comprises the most stable choice alternative for a full range of relative importance of price criterion. The most expensive Canon machine is the best choice in case of the price criterion absence or marginally small importance of the criterion (rare practical case). The Lexmark device becomes an especially preferable alternative in case of severe dependence on price criterion. As for intermediate levels of the price value relative importance, the SHARP and the Lexmark models are very close to each other.

A conclusion can be finally drawn that the results obtained clearly support the SHARP equipment as the best and the most stable choice recommendation.

The application of ZUM and extended DEMATEL methods gives different numerical results. But qualitative outcomes of these methods are in a good agreement with AHP-based analysis. Therefore, they confirm the overall form of final AHP-based ranking of alternatives (fig.14, tab.2).

The obtained ranks differ a lot from the proposal included in a journal (differences are denoted using bold face characters). Both rankings are consistent only in the case of the second best (namely the Canon) alternative. The order of other models is totally reverted despite identical general assumptions for both MCDA analysis and assessments made by experts employed by a journal publisher. Fundamental differences in both rankings confirm a suspicious nature of material included in a journal. It seems that possible manipulations could serve to attain specific (marketing?) objectives of a journal issue sponsors (device manufacturers).

The above conclusion reveals another possible advantage of the applied approach. It can be also utilised for the effective validation of external information and its sources. This use is also crucial as it deals with possible effects of business activities.

Fig. 14
Validation of overall results

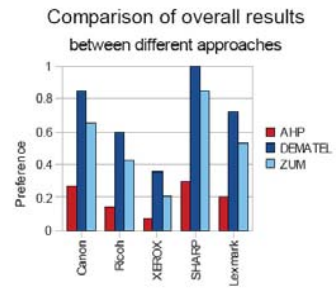


Figure 14. Validation of overall results

MCDA-based analysis					Rank presented in a journal
Overall rank	Alternative	AHP	ZUM	Ext. DEMATEL	
1	SHARP	0.30	0.85	1.00	5
2	Cannon	0.27	0.65	0.85	2
3	Lexmark	0.20	0.53	0.72	4
4	Ricoh	0.14	0.43	0.60	3
5	xerox	0.07	0.21	0.36	1

Table 2
Comparison of overall results

Conclusions

The application of the presented approach brings several distinct advantages:

1. structuring and addressing complex decision problems,
2. attaining objective decisions despite subjective assessments,
3. effective coping with intangibility of considered issues,
4. adaptation to future changes in conditions influencing the effects of decisions made,
5. open and easily applicable nature.

The advantages of the approach make it an ideal choice for facilitating the process of complex problems solving in companies. Therefore, the approach should be more exploited for recommending the decisions to be made in a fast changing environment in contemporary complex business world.

The presented approach is applied for the solution of a strictly defined decision making problem in the paper. However, it has rather a general nature and it can be successfully applied to prepare recommendations for other kinds of decision problems appearing in a printing enterprise. The problems can include not only managerial issues (selection of employees, location of enterprise, a choice of advertisement technique etc.). They can also address issues pertaining to design. For example, Dytczak and Kołodziejuk use similar ideas for obtaining an optimal layout of a book (Dytczak and Kołodziejuk 2008).

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Editor's note: This article will be complemeted by a second paper in the next issue of this journal.

Bibliography

1. Dong Y., Xu Y., Li H., Dai M. (2008), A comparative study of the numerical scales and the prioritization methods in AHP. European Journal of Operational Research, 186(1):229–242.
2. Dytczak M., Ginda G. (2006), Benefits and costs in selecting fuel for municipality heating systems with the Analytic Hierarchy Process. Journal of Systems Science and Systems Engineering 15(2):165–177.
3. Dytczak M., Ginda G. (2008), Classification of building repair policy choice criteria. [In:] Sakalauskas L., Weber G.W., Zavadskas E.K. (Eds.) The 20th International Conference. Euro Mini Conference "Continous optimization and knowledge-based technologies" EurOPT-2008. May 20-23, Neringa, Lithuania. Selected papers. Vilnius "Technika" 2008, s.353–363.
4. Dytczak M., Kołodziejuk E. (2008), Multicriterial methods of making decisions in editorial processes while designing book's layout. [In:] 40th Conference of the International Circle,
7–11 October 2008, Warsaw. Conference Abstracts, pp. 38–39.
5. Figueira J., Greco S., Ehgott M. (Eds.) (2005), Multiple Criteria Decision Analysis. State of the Art Surveys. Springer Science+Business Media, LLC 2005.
6. Fontela E., Gabus A.: Current perceptions of the world problematique. – Churchman C.W., Mason R.O. (red.): World Modelling: a Dialogue, ss. 81–87. North Holland/Elsevier, Amsterdam, New York, 1976.
7. Fontela E., Gabus A.: The DEMATEL Observer. DEMATEL 1976 Report. Batelle Geneva Research Center, Genewa, Switzerland, 1976.
8. Kukuła K. (2000), Metoda unitaryzacji zerowanej. PWN, Warszawa.
9. Miller G.A. (1956), The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information. The Psychological Review, 63:81–97.
10. Saaty T.L. (1980), The Analytic Hierarchy Process, Planning, Piority Setting, Resource Allocation. McGraw-Hill, New York.
11. Saaty T.L. (1996), Decision Making with Dependence and Feedback The Analytic Network Process. RWS Publ., Pittsburgh.
12. Saaty T.L. (2003), Decision-making with the AHP: Why is the principal eigenvector necessary. European Journal of Operational Research, 145(1):85–91.
13. Saaty T.L., Vargas L., Dellmann K. (2003), The allocation of intangible resources: the analytic hierarchy process and linear programming. Socio-Economic Planning Sciences, 37(3):169–184.
14. Saaty T.L. (2005), The Analytic Hierarchy and Analytic Network Processes for the Measurement of Intangible Criteria and for Decision-Making. [In:] Figueira J., Greco S., Ehgott M. Multiple Criteria Decision Analysis. State of the Art Surveys. Springer Science+Business Media, LLC 2005, pp. 345–408.
15. Srdjevic B. (2005), Combining different prioritization methods in AHP synthesis. Computers & Operations Research, 25:1897–1919.
16. Vaidya O.S., Kumar S. (2006), Analytic hierarchy process: An overview of applications. European Journal of Operational Research, 169(1):1–29.
16. OR50 Conference Handbook (2008), 9–11 September 2008, The University of York. The OR Society, York.

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