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METHODOLOGICAL ASPECTS OF QUALITATIVE-QUANTITATIVE ANALYSIS OF DECISION-MAKING PROCESSES

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Abstract
The paper aims at recognizing the possibilities and perspectives of application of qualitative-quantitative research methodology in the field of economics, with a special focus on production engineering management processes. The main goal of the research is to define the methods that would extend the research apparatus of economists and managers by tools that allow the inclusion of qualitative determinants into quantitative analysis. Such approach is justified by qualitative character of many determinants of economic occurrences. At the same time quantitative approach seems to be predominant in production engineering management, although methods of transposition of qualitative decision criteria can be found in literature. Nevertheless, international economics and management could profit from a mixed methodology, incorporating both types of determinants into joint decision-making models. The research methodology consists of literature review and own analysis of applicability of mixed qualitative-quantitative methods for managerial decision-making. The expected outcome of the research is to find which methods should be applied to include qualitative-quantitative analysis into multicriteria decision-making models in the fields of economics, with a special regard to production engineering management.

Keywords
qualitative-quantitative analysis, hierarchical decision-making, neural-network models, management, manufacturing processes.

Introduction

Reducing decision-making processes in economic and technical environment to their quantitative dimensions only does not reflect their complex character. It is therefore necessary to apply methods that incorporate qualitative determinants into such analysis. Only a mixed approach that connects both types of decision-making determinants, can provide researchers with a fresh, developing perspective. Thus, when analyzing decision-making processes of both economic and technical nature (e.g. production engineering management) it is fully justified to search for mathematical instruments that transpose qualitative decision-making determinants into numbers.

The application of such apparatus for managerial multicriteria decision-making of economic and technical nature can bring an innovative contribution to the science of Economics and Management. This paper considers potential advantages and problems resulting from use of mixed methods in widely defined managerial processes.

Theoretical introduction to quantitative and qualitative methodology

In Economics the quantitative approach became the predominant research methodology. It is justified by the mass character of analyzed occurrences, the need for repetitiveness of scientific experiments or extracting an appropriately numerous research sample in order to assure representativeness. Burns and Groove [1] define quantitative research as "*a formal, objective, systematic process in which numerical data are used to obtain information about the World*". Same authors point at following applications of this type of research methods: (i) to describe variables; (ii) to examine relationships among variables; (iii) to determine cause-and-effect interactions between variables [1].

Qualitative methodology, however still not popular in economic decision-making, has recently gained some attention. The reasons are the following: (i) constantly growing complexity of economic phenomena; (ii) need for expanding the spectre of analysis by non-material determinants of socio-economic environment; (iii) necessity for more precise mapping of multicriteria decision-making processes; (iv) recognition of their driving forces. In technical sciences qualitative determinants have been considered in managerial processes for some time already. For example, in the field of production engineering Niemczewska-Wójcik, Mathia and Wójcik [2] state that "*the assessment of machined surface can be quantitative as well as qualitative. A quantitative assessment requires the determination of the parameters describing the measured surface [whereas] a quality [qualitative] assessment is based on the analysis of images which are obtained from surface measurements with the use of a variety of devices (measurement techniques)*".

Barkin [3] states, that "*the term qualitative evokes a narrative or analytical richness, a method that brings out more detail and nuance from a case than can be found by reducing it to quantitative measures*". But he also recalls Hoffmann's [4] opinion, that "*in practice the term is generally used simply to mean not quantitative*". Stemplewska-Żakowicz [5] thinks that qualitative methods are useful when the results of objective tests are not explaining enough, so they should be seen as methods that deepen the understanding of research lead with quantitative methods.

Accordingly to the same author, qualitative and quantitative approaches define the sense of research process differently. Whereas quantitative methodology aims at understanding and controlling the analysed phenomenon, qualitative one focuses on understanding it through the perspective of its participants. Therefore the knowledge resulting from qualitative research cannot be objective. Moreover, it is perceived as valuable only if it reflects adequately subjective senses and perspectives [5]. For some researchers this is the reason for depreciation of qualitative research as not relevant, due to low representativeness of the research sample. In fact, it is a common misunderstanding of the nature of this type of methods, as subjectivity provides the respondent with enough representativeness – exactly due to his/her individual perspective. It is important to underline though that drawing general conclusions on such a basis would be a methodological mistake.

To sum up, quantitative approach can be understood as a search for common, repetitive, objective characteristics in a mass of people, whereas qualitative approach aims at finding unique and subjective features of individuals that co-create this entity. An exaggerated attachment to one group of research methods only brings risks and threats that have been presented further in this paper.

Pros and cons of quantitative and qualitative approaches

Goczek [6] points at several problems that result from concentrating on quantitative (statistical) analysis only, without taking into account qualitative (contextual) factors:

- concentration on the method of estimation – when the focus of a quantitative researcher on the compliance with statistical rules leads to the omission of qualitative aspects of analysed phenomenon; example: a simple quantitative estimate of the number of faulty machined products is just an ascertainment; only a qualitative analysis provides the researcher with knowledge about causes of these aberrations that can reduce (or eliminate) them in the future;
- partial rejection of quantitative variables for theoretical reasons – some research provides contextual (qualitative) ground for rejection of a part of variables, even though they are conform to the quantitative research criteria; example: replacing nominal values with real ones;
- lack of deepened knowledge on research object and its environment – characteristics of decision-making environment, sense and logic of decision-making process, definition of variables of decision-making model, etc. can strongly influence the quality of incoming quantitative data; example: faulty estimation of technological quality of products can be the reason for rejecting good products, that have been mistakenly assessed as wrong ones; Goczek [6] accurately observes: "*data are just numbers with some context and only this context provides them with significance*";

- sometimes the choice of a quantitative method precedes a solid study on the research object, which constitutes a dangerous malpractice – although obtained results will be conform to quantitative approach criteria, their credibility is doubtful; this is due to the fact that the main weight has been put on methodological correctness instead of focusing on scientifically valid image of reality; example: correlation analysis without former minutious analysis of character of compared variables; errors of this type are hard to discern, because the methodological perfection effectively masks shortcomings in theoretical and contextual bases of analysed decision-making model;
- omitting of endogenousness and identifiability of some model variables – i.e. introducing as continuous variables of a quantitative model determinants that reflect irregular, exponential or discontinuous phenomena (qualitative characteristic); they can badly influence calculations of statistical values, although they should be seen as random factors only; example 1: car industry crisis caused by a supply shock on the oil market, without noticeable reasons for changes in car demand; example 2: unexpected machine tool vibrations in some ranges of rotation speed;
- Type III error risk (right answer to wrong question) – when good answers lead to wrong conclusions; the researcher obtains a precise image of an occurrence, but not the one initially targeted by research; example: question: what is a device that performs various operations on objects, such as cutting, drilling, deformation or facing? Correct answer: a machining tool; wrong answer: a lathe; explanation: however a lathe indeed is a machining tool, not all machining tools are lathes.

Meanwhile, concentrating on qualitative methodology only generates some limitations, too. Barkin [3] enumerates them: (i) negative associations of this term in social sciences (qualitative research is perceived as simply non-quantitative, therefore not systematized, scientifically unsound); (ii) in the eyes of some colleagues, the application of qualitative methods disqualifies the research task as non-scientific, because it impedes an explicit assignment of research object to a specific branch of science; (iii) teaching qualitative methods brings counterproductive results – it gives the students a set of fuzzy criteria, instead of clear and precise methodological indications (which does not enhance the development of a sound scientific apparatus); (iv) as qualitative methods seem to be easier to apply than quantitative ones, they tempt to be overused, which is not always correct nor possible.

Goczek [6] points at other types of errors, that occur when the context (qualitative variables) become more important that mass phenomena (quantitative variables): (i) research populism – lack of confirmation of some popular theories in empirical data; (ii) gaps in researcher's mathematical and statistical apparatus – misunderstanding of data generating and gathering processes, amplified by use of wrong or outdated methods of statistical analysis; (iii) logical error – confusion between correlation and causality; (iv) methodological inadequacy of the researcher – omitting the stationarity of time series, properties of research instruments, autocorrelation and heteroscedastocity of random residuals; (v) hasty conclusions based on result estimates. Incidentally, most of these errors could be avoided by promoting ubiquitous cooperation of researchers and statisticians (e.g. a compulsory consultation of research plan, methodology and final text of the paper with a statistician, prior to publication).

Piech [7] warns from choosing research approaches prior to analysis of a wider research context (e.g. organization size): "*[in companies] it can be hard to perform qualitative analysis, because of "information noises", i.e. singular opinions of employees, which are not confirmed by other people from the company. [...] If the questionnaire covers a larger sample, some recurring opinions can be identified and treated as dominant – giving an image of the company in the eyes of most employees. [...] It is different in SME's. Here, every opinion can be true and refer to a specific field of the company (e.g. someone's worksite)*".

It seems that a natural solution to above limitations of both approaches is the application of a mixed qualitative-quantitative approach. Although justified in multicriteria decision-making models, it shows some limitations as well. When discussing the statistical hierarchization in multidimensional models Kukuła [8] states that: "*there are various methods of standardization of quantitative attributes [...]. The problem becomes more complicated when both quantitative and qualitative attributes come into question. It reflects a situation when the research sample contains both quantitative and qualitative attributes at the same time*".

Stemplewska-Żakowicz [5] tries to anticipate that problem by proposing a set of criteria to provide the representativeness and reliability of qualitative research task (after Lincoln and Guba [9]). Table 1 presents such sets both for qualitative and quantitative approach.

Stemplewska-Żakowicz [5] discusses pros and cons of both approaches by stating: "*when compared* *to quantitative research, qualitative approach shows one serious weakness – it does not lead to certain and universal knowledge*". She explains that "*"Certain knowledge" does not mean always and everywhere truthful (no procedure in social sciences can provide us with such wisdom), but rather the kind of knowledge for which applicability requirements and error criteria are known*" [5]. She adds: "*qualitative approach can lead to such knowledge, but at a cost of serious limitations of its questions and reduction of meanings, that for many prove to be painful*" [5]. Finally, the author summarizes: "*on the other hand, only at such cost scientists are able to create a just and accurate research tool (in frames of this definition), that can be applied in praxis*" [5].

Table 1
Criteria of methodological evaluation of quality of research techniques and procedures.

Quantitative approach criteria	Qualitative approach criteria
Internal accuracy	Credibility
External accuracy	Transferability
Reliability	Dependability
Objectivity	Confirmability

Source: [5].

To sum up, it can be stated that in a complex environment multidimensional decision-making problems require a mixed qualitative-quantitative approach. Next chapter presents a choice of mixed methods that can be applied for multicriteria decision-making processes of economic and technical nature, such as production engineering management.

Multicriteria research methods in economics and management

Trzaskalik [10] divides multicriteria decision-making methods into 7 groups: (i) additive methods; (ii) methods of analytic hierarchization and related; (iii) verbal methods; (iv) ELECTRE methods; (v) PROMETHEE methods; (vi) use of reference points; (vii) interactive methods.

Between additive methods this author counts: SAW (Simple Additive Weighting Method), F-SAW (Fuzzy Simple Additive Weighting Method), SMART (Simple Multi-Attribute Ranking Technique) and SMARTER (Simple Multi-Attribute Ranking Technique Exploiting Ranks). The common denominator of this group of methods is the modelling of decision-making process through an additive linear function. The choice of decision alternative is based on the highest weighted sum of evaluations or the highest utility rank. The ranking is based on changing level of fulfilment of criteria from least to most desirable. Particular methods from this group mainly differ in the procedure of evaluation of decision alternatives, i.e. calculation of matrixes of normalized evaluations or sum of ranks.

Methods of analytic hierarchization are AHP (Analytic Hierarchy Process), REMBRANDT (Ratio Estimation in Magnitudes or deciBells to Rate Alternatives which are Non-DominaTed), F-AHP (Fuzzy Analytic Hierarchy Process), ANP (Analytic Network Process), F-ANP (Fuzzy Analytic Network Process) and MACBETH (Measuring Attractiveness by a Categorical Based Evaluation TecHnique). The base method in this group is AHP, characterized by the creation of a vector of scale through pairwise comparisons of decision-making criteria (each with each). The chosen decision alternative is the one that maximally meets all the criteria simultaneously. Other methods propose alternative ways of ranking of decision-making criteria. They have been elaborated as a response to criticism of AHP method.

As verbal methods concentrate on qualitative variables only (without taking into account any of quantitative variables), they are not interesting for research tasks discussed in this paper and as such will not be further discussed, but only enumerated. Trzaskalik [10] classifies ZAPROS (Rus.: ЗАмкнутые ПРоцедуры у Опорных Ситуаций) and its development ZAPROS III as verbal methods.

The group of ELECTRE (Fr.: ELimination Et Choix Traduisant la REalité[1]) methods propose to ground the analysis of significance rankings of decision-making criteria on four preference levels: strong, weak, equal and incomparable. The incomparability of criteria provides an argument in favour of analytic hierarchization methods, where independence of criteria is a condition *sine qua non* for construction of a hierarchical model. One should also observe, that the lack of relation between decision-making criteria does not have to imply their incomparability. ELECTRE methods anticipate this problem by introducing equivalence thresholds and preferences of grouped (mutual) relations, as well as the rule of limited compensation. Subsequent versions of ELECTRE method (ELECTRE I, ELECTRE Iv, ELECTRE Is, ELECTRE III, ELECTRE TRI, ELECTRE I+SD, ELECTRE III+SD) differ

[1]Trzaskalik [10] wrongly decodes this acronym – instead of the French word "*realité*" (reality) the word "*realia*" has been used. In fact it describes the characteristic features of a given culture, written only in plural: "*les realia*".

mainly in the way of defining thresholds of evaluations of decision-making criteria and how to clarify the ambiguities (with or without participation of decision-maker/expert).

The next group are PROMETHEE (Preference Ranking Organisation METHod for Enrichment Evaluations) methods. For each decision criterion the preference function is derived from differences in evaluations of significance of decision alternatives. A serious difference means a strong preference for a given decision alternative. Particular methods from this group (PROMETHEE I, PROMETHEE II, EXPROM – EXtension of the PROMethee method, EXPROM II, PROMETHEE II+veto, EXPROM II+veto, PROMETHEE II+veto+SD, EXPROM II+veto+SD) differ mainly in the way of calculation of outranking flows (the extent to which one alternative outranks others in the eyes of decision-makers). Methods with a "veto" or "veto+SD" mark are combinations of base PROMETHEE methods with adequate ELECTRE methods.

The following methods are based on reference points: TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), F-TOPSIS (Fuzzy Technique for Order Preference by Similarity to Ideal Solution), VIKOR (VIsekrzterijumska Optimizacija i Kompromisno Resenje), BIPOLAR and its evolution – modified BIPOLAR. In this group, the essence of calculations is to determine the extremities – ideal and anti-ideal solutions. The next step is the measurement of distance of each decision alternative from both extremities. The alternative closest to ideal solution is acknowledged as the highest attainable optimum. Particular methods differ in the measurement of this distance. In praxis combinations of reference-point-based methods are applied, e.g. DEMATEL+ANP+VIKOR or BIPOLAR+SD. In this case each decision-making level is managed by a single method.

From the perspective of qualitative-quantitative methodology an interesting group are interactive methods, such as STEM-DPR (STEp Method for Discrete Decision-making Problems under Risk), INSDECM (INteractive Stochastic Decision-making) and ATO-DPR (Analysis of Trade-Offs for Discrete Decision-making Problems under Risk). They are based on individual evaluations of decision alternatives or their groups by the decision-maker. His/her preferences provide basis for calculations that arrange decision alternatives respectively to their distance from ideal solution. If needed, the process is repeated until a satisfactory approximate solution is reached (subjective assessment of the decision-maker). Particular methods vary in the moment of decision-maker's intervention and in approximation of satisfaction from fulfilling a given criterion or a group of criteria.

As shown, wide possibilities of linking qualitative criteria with quantitative data exist. Dixon and Reynolds [11] describe the methodology of building quantitative models based on qualitative data in sociology and political sciences, Zaborek [12] in management, a large number of publications can be also found in medical science. It is though justified to ask whether and which any of groups of methods presented above is particularly exploitable for applications in the field of production engineering management. In author's opinion most promising are analytic hierarchization methods, especially AHP & ANP, together with their fuzzy versions, F-AHP & F-ANP and Artificial Neural Networks (ANN). It is also possible, that at various stages of decision-making process combinations inside this group can bring better results.

After Dytczak and Wojtkiewicz [13], research methods appropriate for hierarchic decision-making problems are the following: MUZ (Pl.: Metoda Unitaryzacji Zerowanej), DEMATEL, Cluster Analysis (Pl.: taksonomia wrocławska), Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP). Góralski and Pietrzak [14] describe MUZ as "*one of methods that allow normalization of diagnostic variables through analysis of characteristic's range. It is a universal method that can be applied for normalization of various variables, independently of their type, sign, size, unit*". Similar approach has been formerly presented by Kukuła [15]. Yang et al. [16] describe DEMATEL as a tool for formation and analysis of causal links between evaluation criteria, whereas Lin and Tzeng [17] apply it to derive schemes of interdependencies between indexes (decision criteria). Ćwiąkała-Małys and Nowak [18] state that "*cluster analysis [...] is a method that can be successfully used for linking objects (variables) into homogenous groups in respect of n-characteristic (dimensions)*".

However all these methods show applicability for modelling of multicriteria decision-making problems (at least in initial stages of decision-making process), Trzaskalik [10] sees AHP as the appropriate basis for a complete representation of hierarchical decision-making structures. Saaty [19] defines AHP as a tool supporting decision-making in highly uncertain environment. Kłos and Trebuna [20] say (after Saaty [21]) that "*by reducing complex decisions to a series of pairwise comparisons, and then synthesizing the results, the AHP method helps to capture both subjective and objective aspects of a decision*".

AHP application is mostly justified when the manager confronts a decision-making problem of high complexity. It can be applied when the problem can be presented in a hierarchical structure and when higher hierarchy elements do not interact, nor interfere with lower ones. AHP should be considered when the optimal solution is being chosen from many variants based on subjective criteria. Saaty [21] divides AHP process into:

- main goal level – desired effect of decision-making;
- criteria and sub-criteria level (with their determinants) – to evaluate the significance of particular determinants of the process;
- decision alternatives level – choices, that offer the decision-maker a possibly optimal decision that brings him/her closer (or further) to attainment of the main goal.

If the elaboration of a hierarchy of equivalent criteria is difficult, ANP should be considered. It is not subject to so many limitations as AHP and should be seen as its complement for fuzzy decision-making problems. Saaty [19] differentiates AHP & ANP in their ability of analysis of interdependencies between criteria: whereas AHP is limited to pairwise comparisons only, ANP allows simultaneous peer analyses of mutual influences of decision criteria. This in turn is the essence of decision-making networks, where final decision is influenced both by decision criteria and their interdependencies. ANP is based on the following construct: inside each network or sub-network decision elements are being grouped into sets defined for each control criterion of the subsystem. Afterwards, expert evaluations in form of pairwise comparisons of all combinations of decision elements and their groups are being performed (similarly to AHP). Then, inside each control subsystem, a BCOR (Benefits, Costs, Opportunities and Risk) synthesis of results follows. Zoffer et al. [22] complement the method by linking evaluations of all control subsystems through additive or multiplier (marginal) synthesis.

Tadeusiewicz [23] sees mathematical bases of AHP & ANP as similar (fundamental scale, pairwise comparison matrix(es), consistency test, control hierarchies or networks). ANP though requires to complement the procedure by evaluations of mutual influence of h_1 level criteria on elements of other h_n levels. Through pairwise comparisons, priority vectors $W = (w_1, w_2, \ldots, w_n)$ are being elaborated and put into columns of decision network supermatrix with $C_h : h = \{1, 2, \ldots, n\}$ levels. Each level contains n_h elements and forms the $E = \{e_{h1}, e_{h2}, \ldots, e_{hh}\}$ set. When an element does not interact with another one, its priority is attributed a "0". Saaty's [19] example of a decision supermatrix follows:

$$W = \begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \ldots & C_n \end{array} \\ \begin{bmatrix} W_{11} & W_{12} & \ldots & W_{1n} \\ W_{21} & W_{22} & \ldots & W_{2n} \\ \vdots & \vdots & \ldots & \vdots \\ W_{n1} & W_{n2} & \ldots & W_{nn} \end{bmatrix} \end{array}.$$

The control hierarchy (AHP) or control network (ANP) can be defined individually. Managerial decision-making problems will usually apply control networks built on already mentioned B, C, O, R subsystems [19]. Same logic can be applied for production engineering management, with a special regard to the specifics of machined surfaces and applied machining tools. A complete ANP analysis consists of 12 consecutive steps extensively presented in scientific literature (e.g. [19]). Reassuming, ANP can be perceived as a linkage between modelling of decision-making problems with a visible hierarchy of criteria, and those with a fuzzy structure. The convergence results from common mathematic and logical bases of AHP & ANP and another group of methods, i.e. Artificial Neural Networks (ANN).

Tadeusiewicz [23] states that "*neural networks are a sophisticated modelling technique that is able to map functions of high complexity. Especially, neural networks show a non-linear character, which strongly enriches their applicability*". The author points at human brain as a prototype of this tool. The essence of the method comes from interrelations between neurons and synapses, where "*the neuron bears usually an arborescent structure of a multitude of data inputs (dendrites), a signal-merging body (perikaryon) and an output data carrier in form of a single fiber (axon); the axon multiplies the self-transmitted result of neuron's operation and sends it further to multiple receptor neurons through an arborescent output structure (telodendrite)*". Axons communicate between cells through synapses filled with neurotransmitter. Besides transmitting, they also modify transmitted signals and store data. In ANN the role of synapses is brought to multiplication of input signals by evaluations of their significance (weight), which are determined in the process of self-learning of the network. It is the self-learning ability that constitutes huge potential of neural networks for analysing multicriteria decision-making problems. Other important features are: the possibility of signal sending from one synapsis to many neurons simultaneously and the option for setting activation threshold values for particular neurons.

First characteristic reflects the multitude of simultaneous linkages and feedbacks inside one network, the second prevents the network from incorporating non-relevant decision criteria into decision-making process.

In ANN "*the level of neuron's innervation is just a linear function of input values. The so-determined cumulated innervation value is processed with a sigmoidal (S-shaped) function in order to determine the neuron's answer*" [23]. Network's response, called the sigmoidal hill, forms the plane of results from the first layer of the multilayer perceptron. It is formed through collation of mentioned multidimensional linear function and one-dimensional sigmoidal function. Self-learning of further layers of multilayer perceptron occurs through changes of sigmoidal hill orientation parameters, i.e. its position and inclination angle in the coordinate system. These changes happen because of modifications of weights and input values of threshold parameters, whereas sigmoidal hill's inclination angle reflects weights of particular decision criteria (the higher inclination angle, the higher significance of corresponding criterion). This procedure, characteristic for one neuron (decision criterion) is being multiplied for other neurons (criteria), which results in a multilayer network, i.e. a multicriteria decision-making model. Its graphical representation is a freely shaped plane, built of lower and higher terraces, bending towards each other at various angles and linked by miscellaneously angled slopes.

As mentioned before, the most important characteristic of ANN-based decision-making models is their self-learning ability. The learning process becomes possible only after determination of the learning task and environment, which happens by defining desirable and undesirable threshold conditions. Tadeusiewicz [23] questions: which state of the network (arrangement of terraces and slopes between them) is ideal and which is unacceptable from the perspective of the decision-maker? The network self-learning process starts by testing natural network preferences (random neuron weight parameter values are picked). Then the proper self-learning process starts. The network environment is constantly changed by random choice of values of particular neuron weight parameters. After each n-th change the network reacts accordingly to its actual state of knowledge (acquired in the $n-1$ round). The process happens repeatedly until a predefined number of repetitions has been reached (usually from a few dozens to several hundreds), after which the examining of the network takes place. The model has to provide evaluation values for all learned combinations. In most cases it takes form of a graphical monochromatic map of results, on which threshold values are pictured by black and white colours and intermediate values by shades of grey. However logical assumptions of ANN-based decision-making are clear, further examination of their applicability for analysis of managerial problems in the field of production engineering seems justified.

Choice of qualitative-quantitative methods for multicriteria decision-making

Goczek [6] observes: "*in Poland a too sharp division [...] between "quantitative" and "qualitative" methods understood separately can be observed, even though both groups are indispensable for each other, especially in practical applications in social sciences*". At the same time, in Economics generally, but also in Management, the application of analytic hierarchization and ANN methods occurs quite seldom. Meanwhile, as already mentioned, limiting the description of managerial environment to its quantitative determinants only does not reflect its complexity.

Multicriteria character of production engineering management brings a need for application of methods that enable the quantification of qualitative criteria. Therefore it seems just to concentrate on analytic hierarchization methods, enlarging decision-maker's toolbox by their fuzzy versions and artificial neural networks. A justification follows.

First argument in favour of the above statement is the diverse character of decision criteria, both qualitative and quantitative. Second is their number in multicriteria models – the decision-maker has to anticipate an important amount of determinants of decision-making process simultaneously. Third argument pro is the large number of successful AHP & ANP applications for analysis of interdependencies between input and output variables of decision-making models in other fields of science, e.g. in technical sciences and medicine. The usually asked question is what hierarchy of input data assures the obtaining of expected output results? Similar argument can be used for ANN methods, with a special regard to their success in the fields of technology, medicine, biotechnology and physics.

Next argument in favour is the non-linear character of economic occurrences, which bears a serious impact on management (e.g. supply and demand shocks). This argument acts rather in favour of fuzzy versions of discussed methods: F-AHP, FANP & ANN. ANN application should be considered especially, because the level of complexity of ANP highly exceeds the one of AHP. Therefore it is always just to check whether for a given decision problem it is rational to expand the model by the supermatrix and sub-criteria networks, when an alternative in form of ANN exists.

The feature that predestines ANN methods for modelling of decision-making processes is the nonlinearity of environmental occurrences. Economists that apply mathematical apparatus for their research use usually linear modelling, which is not inherently wrong. Many economic trends show linear characteristics, which in turn makes prognostics easier and allows to base them on past trends. Linear models can be optimized gracefully as well, which allows a relatively simple analysis of influence of input data on output parameters. Meanwhile, the linear description requires a significant simplification of reality. But today's global economy shows a complex character, with shortening of economic cycles and an acceleration of sequence of events happening in parallel. As the result input data sets for linear models condensate, which lowers the probability of an accurate prognosis. Moreover, it will cover a shorter time period in the future. Tadeusiewicz [23] reacts: "*when solving these difficult and troublesome questions, referring to ANN models (that can easily map non-linear dependencies) can be the fastest and most convenient solution to the problem*".

Next argument in favour of ANN application for economic and managerial research is the ease of application. It can be assumed that mapping of nonlinear dependencies happens with a relatively low involvement of the researcher. The network learns the mechanism of analysed relation itself through processing of data accordingly to programmed input variables and type of network. It comes from the character of discussed method, which brings explorer's attention more to the nature of relations between input and output data, than to the processing mechanism itself. On one hand this is highly convenient for the decision-maker and shortens the entire process as well. On the other hand it is the most fragile conceptual moment that requires enough knowledge and attention from the researcher, as picking wrong type of network will seriously obscure obtained results.

Last, but not least, ANN-based decision-making models can be relatively easily optimized with regards to a predefined criterion or potential problem areas through mathematical optimization methods. One of examples can be the *metaheuristic Tabu search* by Glover [24].

Conclusions

To sum up it can be stated that the analysis of economic multicriteria decision-making problems, such as production engineering management, require the application of mixed qualitative-quantitative methods. For decision problems with a hierarchical structure Analytic Hierarchy Process seems to be the best choice. For problems with a fuzzy hierarchy of priorities Analytic Network Process should be considered. In cases, where multicriteriality is not perceived as the only key feature of the decision-making system, Artificial Neural Networks should be chosen. Their value lies in the possibility of network programming, their ability of self-learning and the multitude of simultaneous linkages and feedbacks between particular decision criteria.

It has to be said that the necessary, but not always sufficient condition for successful application of mixed qualitative-quantitative methods is an accurate preliminary observation of the decision-making problem or environment and a minutious characterization of decision-making goal, criteria and alternatives. Key success factors are: (i) a proper choice of set of input variables; (ii) choice of research method adequately to the nature of analyzed phenomenon (e.g. proper defining of neural network type); (iii) application of chosen method accordingly to its rules and limitations. Only after fulfilling the above criteria one can fully assess the applicability of qualitative-quantitative methods for economic or managerial research.

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References

[1] Burns N., Grove S.K., *The practice of nursing research: conduct, critique, and utilization*, 5th Ed. St. Louis, MO: Saunders, 2005.

[2] Niemczewska-Wójcik M., Mathia T., Wójcik A., *Measurement techniques used for analysis of the*

geometric structure of machined surfaces, Management and Production Engineering Review, 5, 2, 27–32, 2014, DOI: 10.2478/mper-2014-0014.

[3] Barkin S., *Qualitative methods?*, Qualitative methods in International Relations – a pluralist guide, A. Klotz and D. Prakash, Eds. London: Palgrave Macmillan, pp. 211–220, 2009.

[4] Hoffmann M.J., *Agent-based modeling*, in Qualitative methods in International Relations – a pluralist guide, A. Klotz and D. Prakash [Eds.], London: Palgrave Macmillan, pp. 187–210, 2009.

[5] Stemplewska-Żakowicz K., *Metody jakościowe, metody ilościowe: hamletowski dylemat czy różnorodność do wyboru?*, Roczniki Psychologiczne, XIII, 1, 87–96, 2010.

[6] Goczek Ł., *Problemy metod ilościowych w naukach ekonomicznych i społecznych*, Rola informatyki w naukach ekonomicznych i społecznych, Z. Zieliński [Ed.], Kielce: Wydawnictwo Wyższej Szkoły Handlowej, pp. 204–209, 2010.

[7] Piech K., *Wybrane metody ilościowe w badaniu socjologicznych aspektów przedsiębiorstwa – case study*, Nowoczesne przedsiębiorstwo – strategie działania, rozwoju i konkurencji, Warszawa: Kolegium Zarządzania i Finansów, Szkoła Główna Handlowa, pp. 78–90, 2000.

[8] Kukuła K., *Propozycja budowy rankingu obiektów z wykorzystaniem cech ilościowych oraz jakościowych*, Metody ilościowe w badaniach ekonomicznych, vol. XIII, no. 1, B. Borkowski and K. Kukuła, [Eds.], Warszawa: Wydawnictwo Szkoły Głównej Gospodarstwa Wiejskiego, pp. 5–16, 2012.

[9] Lincoln Y.S., Guba E.G., *Naturalistic inquiry*, Beverly Hills, CA: Sage Publications, 1985.

[10] Trzaskalik T., *Wielokryterialne wspomaganie decyzji, przegląd metod i zastosowań*, Zeszyty Naukowe Politechniki Śląskiej, seria: Organizacja i Zarządzanie, 74, 1921, 239–263, 2014.

[11] Dixon D.S., Reynolds W.N. [online], *Quantitative models from qualitative data: Case studies in agent-based socio-political modeling*, Proceedings of the First International Workshop on Complexity and Policy Analysis, Cork, Ireland, Retrieved online on September 23rd 2015 from: <http://www.leastsquares.com/papers/cork 2005.pdf>, 2005.

[12] Zaborek P., *Qualitative and quantitative research methods in Management Science*, Selected methodological issues for doctoral students, M. Strzyżewska [Ed.], Warszawa: Warsaw School of Economics Publishing, pp. 41–50, 2009.

[13] Dytczak M., Wojtkiewicz T.J., *Metody wielokryterialnego wyboru systemów monitorowania*, Komputerowo zintegrowane zarządzanie, vol. I, R. Knosala [Ed.], Opole: Oficyna Wydawnicza Polskiego Towarzystwa Zarządzania Produkcją, pp. 397–405, 2010.

[14] Góralski P., Pietrzak S., *Ocena ryzyka kontynuacji działalności gospodarczej spółek ANR w aspekcie ich strategiczności oraz specyficznej funkcji rynkowej*, Zeszyty Naukowe Uniwersytetu Szczecińskiego: finanse, rynki finansowe, ubezpieczenia, 47, 686, 59–69, 2011.

[15] Kukuła K., *Metoda unitaryzacji zerowanej*, Warszawa: PWN, 2000.

[16] Yang Y.P., Shieh H.M., Leu J.D., Tzeng G.H., *A novel hybrid MCDM model combined with DEMATEL and ANP with applications*, International Journal of Operational Research, 5, 3, 160–168, 2008.

[17] Lin C.L., Tzeng G.H., *A value-created system of science (technology) park by using DEMATEL*, Expert Systems with Applications, 36, 9683–9697, 2009.

[18] Ćwiąkała-Małys A., Nowak W., *Zarys metodologiczny analizy finansowej*, Wrocław: Wydawnictwo Uniwersytetu Wrocławskiego, 2005.

[19] Saaty T.L., *Decision-making for leaders: the Analytic Hierarchy Process for decisions in a complex World*, 3rd Ed. Pittsburgh, PA: RWS Publications, 2000.

[20] Kłos S., Trebuna P., *Using the AHP method to select an ERP system for an SME manufacturing company*, Management and Production Engineering Review, 5, 3, 14–22, 2014, DOI: 10.2478/mper-2014-0023.

[21] Saaty T.L., *The Analytic Hierarchy Process*, New York, NY: McGraw-Hill, 1980.

[22] Zoffer J., Bahurmoz A., Hamid M.K., Minutolo M., Saaty T.L., *Synthesis of complex criteria decision-making: a case towards a consensus agreement for a Middle East conflict resolution*, Group Decision and Negotiation, 17, 5, 363–385, 2008.

[23] Tadeusiewicz R., *Wstęp do sieci neuronowych*, Biocybernetyka i inżynieria biomedyczna 2000, M. Nałęcz [Ed.], vol. 6: Sieci Neuronowe, W. Duch, J. Korbicz, L. Rutkowski, and R. Tadeusiewicz [Eds.], Warszawa: Akademicka Oficyna Wydawnicza Exit, pp. 3–28, 2000.

[24] Glover F., *Artificial intelligence, heuristic frameworks and tabu search*, Managerial & Decision Economics, 11, 365–378, 1990.