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SELECTED MODELS OF MULTI-CRITERIA EVALUATIONS IN THE SYSTEM SUPPORTING MANAGEMENT IN THE AREA OF KNOWLEDGE MANAGEMENT

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Multi-criteria evaluation of complex phenomena is an important part of decision problems. The multi-criteria evaluations are different types of difficulties, in particular, the multiplicity and diversity of the assessed phenomena, the multiplicity and the variety of diagnostic variables characterizing the evaluated phenomenon, the difficulty to transform the quality characteristics of quantitative traits, the difficulty of aggregating sub-criteria. This paper presents selected models of multi-criteria evaluation corresponding to different decision-making situations. These models will be applied in the system supporting management in the area of knowledge management in mechanical engineering industry enterprises.

Keywords: multi-criteria evaluation, information system supporting knowledge management

1. Introduction

An assessment is a value judgment expressing the positive or negative attitude to the subject of the assessment object (a person, a situation, an event). The idea of "value" is a primary term [6]. To make the proper assessment it is necessary to know assessment subjects and circumstances concerning the evaluation (Figure 1). Therefore, in the evaluation process, there are two main components:

– subjective component (evaluation in the strict sense), which determines the value of objects according to the entity evaluation system, which is designed for evaluation.
– objective component (assessment of objects), i.e. as the way of full information acquiring of the assessment objects and circumstances affecting the evaluation. Information is not always accessible by observation or measurement, it is necessary to obtain them by indirect methods, primarily through expert assessment, the prediction based on experiences and mental models of experts [10]. In expert estimating, statistical methods and artificial intelligence methods (among others expert systems, neural networks) may be helpful [15].

Assessment objects are generally complex phenomena [13], which are described by at least one qualitative feature or at least two quantitative or logical features. Examples of complex phenomena can be personnel's qualifications, the competitiveness of products, the attractiveness of contracts. The assessment of complex phenomena is the multi-criteria evaluation.

This paper presents the complexity of circumstances of a multi-criteria assessment process. To take into consideration these circumstances, it is necessary to apply a number of different models of multi-criteria evaluations. In chapter 4 there is the example solution supporting creating the ranking, which can be applied in the information system supporting knowledge management in mechanical engineering industry enterprises [6] working out in the framework of the R&D project, carried out at the Institute of Management and Administration in the Faculty of Organization and Management, Silesian University of Technology [1, 2, 3, 4, 5].

2. The assessment process and its circumstances

The general characteristics of the assessment process is presented in Fig. 1. In multi-criteria assessment it can be specified the following circumstances:

1. The cardinality of the assessment objects set . It is not always necessary to assess all subjects completely.
2. The variety of assessment objects. In some cases it is possible to divide all assessment subjects into subsets of similar objects.
3. The cardinality and the uniqueness of assessing criteria, variability in time, dependency on random factors.
4. The substantive aggregation circumstances of partial evaluations. There are two basic types of aggregation: balancing and dominated by one evaluation. The balancing aggregation applies when the unfavorable partial evaluation can

be compensated by the favorable state of the other partial assessment. The dominated by one evaluation aggregation refers to such cases when the resultant assessment depends on the worst (or the best) partial assessment. The dominated by one evaluation aggregation applies in particular to the classification evaluation. In some multi-criteria evaluations may be more complex types of aggregation, such as the deceptive aggregation (Table 1).

5. The ability to create patterns, which can be compared with the assessment objects. The source of patterns may be generally applicable standards, average and marginal values characterizing objects. The assessment involving comparing to the pattern object (real or abstract) is largely independent of the subjective evaluation system of the expert.
6. The complexity of the assessment objects and the associated multiplicity and the diversity of features characterizing these objects.
7. The measurement and observation availability of diagnostic features, the cost of acquiring the information of the specific diagnostic features.
8. The accuracy and the clarity of determining of diagnostic features. Sometimes the information cannot be immediately available and it should be acquired by the expert estimation. The qualitative characteristics is difficult to express in an unambiguous manner.
9. The purpose of the assessment process. In some situations, the thorough evaluation of all assessment objects (e.g. the periodic evaluation of employees) is needed, but in most cases, for example in decision-making problems, it is sufficient to choose only one or a few of the best assessment objects.
10. The form of final evaluations. Objects can be characterized by the verbal description, by a few partial evaluations or by one aggregated assessment. It is possible to create the ranking of the assessment objects (all objects or just the top ones) or the selected groups (classes).
11. Requirements of the assessment process - the accuracy and the rightness of assessments, the cost of the assessment process, the time of assessment, the unitary treatment of all assessment objects (e.g. material procurement procedures).
12. Other situational circumstances, such as the repeatability of the assessment process, the involvement of experts and others.

Taking into account the above-mentioned considerations enables the choice of the appropriate assessment models and the proper design of assessment process.

3. Models of assessment processes and procedures creating them

To overcome the difficulties of multi-criteria assessing, there are used different models and procedures for the whole evaluating process. In particular, the following solutions are applied:

– the gradual assessment refining. Because of the type of evaluation such assessments can be distinguished:
  - the evaluative assessment, in which the assessment object is assigned the numerical value
  - the classification assessment, by which the assessment object is included in one of the classes,
  - the descriptive assessment, consisting of the verbal description of the structure and the most characteristic features of the assessment object.

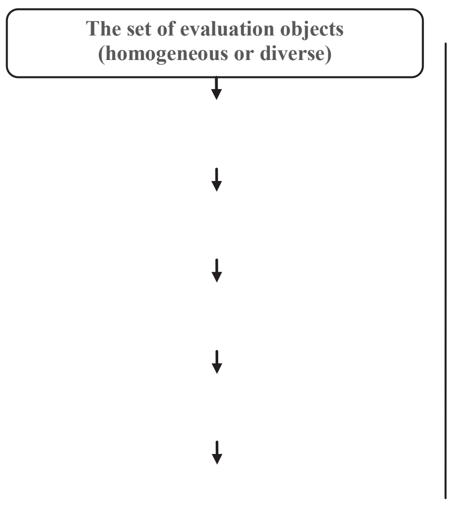
  In the case of events with a high complexity and diversity it is often begun with the descriptive assessment, then the classification assessment, and finally the value assessment.
– the selection of assessment objects which do not meet the certain circumstances. Special cases of selection are:
  - the rejection of assessment objects which do not meet the necessary conditions, it is generally easy to check.
  - the multi-stage selection involving the gradual rejection these of the assessment objects which do not meet the most important and the most easily verifiable criteria. The disqualification of the assessment object can also occur as a result of the preliminary simplified estimation. This concept is in a sense similar to the strategy A-star.
  - the rejection of dominated assessment objects, i.e. those which, under the terms of each of the sub-criteria are worse than other assessment objects (in the sense of Pareto optimization). The concept of Pareto optimality is very general, but it cannot be applied in the case of the deceptive aggregation of partial evaluations (Table 1).
– the taxonomic assessment methods. The characteristic feature of these methods is the assessment independence from the assessment system of the evaluator. The comparative references are diagnostic features of the entire set of assessment objects achieved by appropriate statistical. The example of such a method is proposed by Z. Hellwig Multi-criteria Comparative Analysis, in which one sub-criterion (or some aggregates) is assumed as the leading criterion and the other evaluation criteria are used to check the admissibility of the solution [11].
– the comparing of assessment objects with the patterns. Creating patterns is not always possible, especially when objects are characterized by a large variety of the structural evaluation.

– the ranking, i.e. the determination of the sequence of assessment objects by paired comparison method. The ranking may be the final result of the assessment process or the preliminary stage to make the value assessment.
– the assessment in terms of individual criteria and the aggregation of the partial evaluations. When evaluation criteria and the value of diagnostic features are known the multi-criteria evaluation procedure can be carried out in two stages:
  - making the partial evaluations, each of which includes only one criterion. Such an evaluation may vary depending on one or more of the diagnostic features.
  - the aggregation of partial evaluations. It` is one of the most widely used models of a multi-criteria assessment, particularly in the case of the algorithmic assessment process.

Evaluating the multi-criteria assessment is not possible without the participation of experts. There are two basic models of the participation of experts in the assessment process (Figure 2):

– the direct assessment is applied in particular when the relatively low number of objects is to be evaluate, but these objects are different and described by many diagnostic features, especially qualitative or in the case when it is difficult to formalize criteria. The disadvantage of this assessment method is its high subjectivity,
– the indirect assessment is based on the fact that experts make assessment procedures, and the direct evaluation of assessment objects is carried out algorithmically. Algorithmization for assessment is possible if the objects are described by the quantitative and logic diagnostic features. The advantage is the uniformity of assessment and the reduction of the expensive participation of experts, which is of particular importance when there are a large number of objects. The formalized, algorithmic evaluation, however, may be less accurate, especially when the assessment object has individual features that have not been taken into account within the assessment procedure.

Important instruments for algorithmic assessment are evaluative functions (Table 1) and the functions aggregating the partial evaluation. The most commonly used evaluative functions are functions of one variable, which for each diagnostic characteristics define the partial assessment. In a relatively simple assessment models are also used evaluative functions of several variables, such as linear functions, which determine the aggregate assessment. The functions aggregating the partial evaluation have the form similar to the function assessing many variables (Table 1).



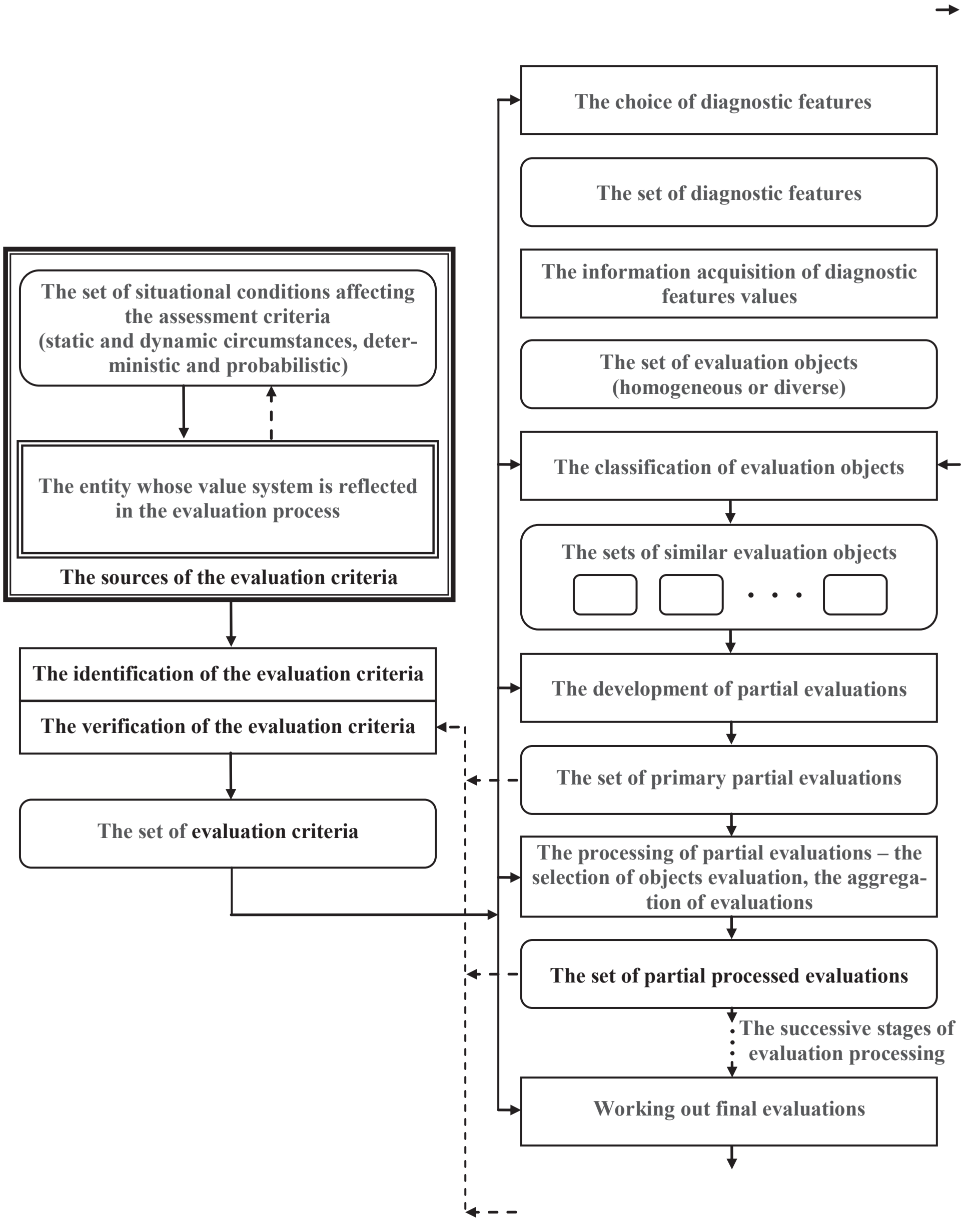
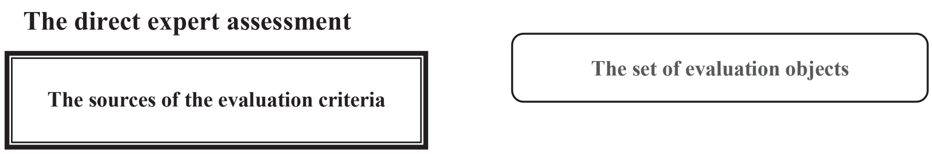


Figure 1. The general characteristics of the assessment process



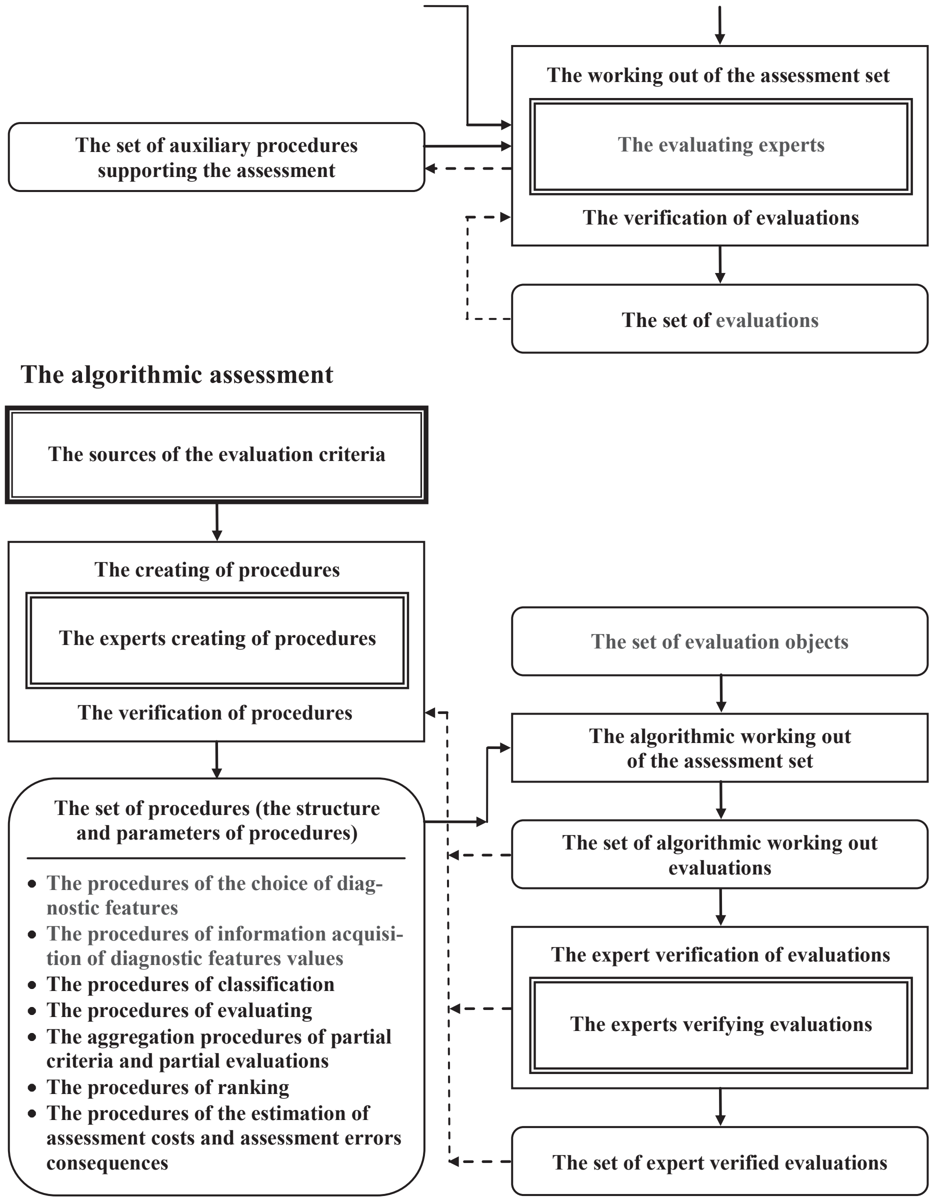


Figure 2. The role of experts in the evaluation process

Table 1. Examples of evaluating functions

No.	The evaluating function Q

1.	The maximizing function (Q increases with increasing x) $dQ(x)/dx > 0$
2.	The minimizing function (Q decreases with decreasing x) $dQ(x)/dx < 0$
3.	The optimizing function $dQ(x)/dx > 0 \quad x < x_{opt}$ $Q = Q_{max} \quad x = x_{opt}$ $dQ(x)/dx < 0 \quad x > x_{opt}$
4.	The linear function of the cut-off $Q = a\cdot(x - b) \quad x \geq b$ $Q = 0 \quad x < b$
5.	The linear function of many variables $Q = a_1\cdot(x_1 - b_1) + a_2\cdot(x_2 - b_2) + \ldots + a_n\cdot(x_{1n} - b_n)$
6.	The step function of one variable $Q = q_1 \quad x \in\langle a_0, a_1)$ $Q = q_2 \quad x \in\langle a_1, a_2)$ $\vdots$ $Q = q_n \quad x \geq a_n$
7.	The logistic function - the function of both sides fulfilling $Q = 1/(1 + \exp(-a\cdot(x - b))) \quad a > 0$
8.	The non-deceptive algebraic function of two variables $Q = x_1^2 + x_2^2 \quad x_1 = 0, x_2 = 0$ $\Delta x_1 > 0, \Delta x_2 = 0 \Rightarrow \Delta Q > 0$ $\Delta x_1 = 0, \Delta x_2 > 0 \Rightarrow \Delta Q > 0$ $\Delta x_1 > 0, \Delta x_2 > 0 \Rightarrow \Delta Q > 0$
9.	The deceptive algebraic function of two variables $Q = x_1^2 + x_2^2 - 2{,}1\cdot(x_1 + x_2) \quad x_1 = 0, x_2 = 0, \Delta x_1 \in (0, 1), \Delta x_2 \in (0, 1)$ $\Delta x_1 > 0, \Delta x_2 = 0 \Rightarrow \Delta Q > 0$ $\Delta x_1 = 0, \Delta x_2 > 0 \Rightarrow \Delta Q > 0$ $\Delta x_1 > 0, \Delta x_2 > 0 \Rightarrow \Delta Q < 0$
10.	The non-deceptive logic function of two variables $Q = x_1 \vee x_2$ Q(FALSE, FALSE) = FALSE Q(FALSE, TRUE) = TRUE Q(TRUE, FALSE) = TRUE Q(TRUE, TRUE) = TRUE
11.	The deceptive logic function of two variables $Q = (x_1 \wedge \neg x_2) \vee (\neg x_1 \wedge x_2)$ Q(FALSE, FALSE) = FALSE Q(FALSE, TRUE) = TRUE Q(TRUE, FALSE) = TRUE Q(TRUE, TRUE) = FALSE

4. The assessment objects ranking by the intractive pairs comparing method

The direct assessment of numerous sets of information is difficult, and thus significant errors occur. It is believed that in the case of 40 - 50 objects it is impossible to make the accurate evaluating, what is connected with the error of inconstant criticism. For a single assessment it would be necessary to keep in mind all assessment objects, and this condition is difficult to meet. This difficulty can be significantly reduced if the ranking is done by pairs comparing. The standard paired comparison method, however, has the disadvantage of very labor intensive. It requires the comparison of all pairs. To order a set of n evaluation objects, it is necessary to undertake $(n^2 - n) / 2$ comparisons. The application of the below-mentioned method i.e. the interactive paired comparison method reduces the number of comparisons to below $n \cdot \log_2 n$. The method is based on the combination of a comparative assessment of two objects with the current sorting set. Thus it is not necessary to compare all pairs, but only some of them. The choice of pairs and the sequence of the comparison result from the sorting algorithm depending on the answers given by the users in the previous comparisons [16].

There are a lot of sorting methods. In typical information applications, the effectiveness of the algorithm is determined mainly by the number of operations, such as moving data and control [14]. However, in the expert comparing pairs method, the primary criterion of optimization is the number of comparisons. The method minimizes the number of comparisons is the merging with inserting method described by L. Ford and S. Johnson [12]. In the Ford - Johnson method the sort of a set of n objects required in the pessimistic case $F(n)$ comparisons, where

$$F(n) = \sum \lceil lg(\tfrac{3}{4}k) \rceil \qquad k = 1, 2, \ldots, n \qquad lg(\,)\ \text{means}\ log_2(\,) \tag{1}$$

The closed form of the sum can be expressed by the formula

$$F(n) = n \lceil lg(\tfrac{3}{4}n) \rceil - \lfloor 2^{\lfloor lg(6n) \rfloor} / 3 \rfloor + \lfloor \tfrac{1}{2}\, lg(6n) \rfloor \tag{2}$$

In comparison with the standard, the pairs comparing method resulting in the considerable reduction in the number of comparisons. For example, to sort the set of 100 assessment objects just less than 534 comparisons is needed instead of 4950.

The number of comparisons can be even lower in the following cases:

- the collection of assessment objects are pre-ordered. This situation occurs when the ranking is carried out successively be a few experts,
- in the set there are a couple or a group of assessment objects, which are evaluated equally because of the criterion of sorting.

The developed interactive pairs comparing system IPCS is the Ford - Johnson method modified to enable in above-mentioned cases to reduce the average number of comparisons, without increasing the number of pessimistic comparisons. The user can select different options to modify the sorting method.

In large research projects in order to further reduce the number of comparisons, it should be considered the application of artificial intelligence methods for managing sorting algorithms.

The conception of the current sorting of the set and the comparing of assessment objects in the order determined by the sorting algorithm is also useful in solving two derived problems:

1. The determination of a number of initial objects of the sorted set. In many cases it is not necessary to order the whole set, but only the determination of the number k of the initial objects, for instance the most important components. As a result the number of comparisons is much less. This task can be accomplished using the first k phases of the tree insertion sort method [12]. This method for the ordering a full set requires more comparisons than the Ford – Johnson method, but the difference is not large. For example, for n = 1 000, $F(n)$ = 8 641, and the upper limit of the pessimistic number of comparisons by the tree insertion sort method is 8 977 (estimated based on Kislicyn's formula). It derives from the same theorem that the first 100 out of 1 000 assessment objects may be determined by making no more than 1 890 comparisons.

2. The merging of ordered subsets. The sorting of large sets can be carried out in three phases:

- splitting the set into subsets,
- subsets sorting,
- subsets merging,

The splitting of the set into subsets can be justified by the selection of objects for the substantive assessment due to the competence of evaluating experts. Another reason for the splitting into subsets may be shortening expertise time due to the parallel comparisons of subsets. In this case, the splitting should be done in such a way that the size of the merged subsets was approximately the same. The result is the reduction of the number of comparisons in merging process.

The choice of the method of merging two major sets depends on the number of objects respectively m and n. When the value is $2/3 < m / n < 3/2$ then the optimal method is the two-input merging method [12]. When $m \ll n$ then the optimal method is the merging with the binary search method [12]. The indirect method, similar to the optimal, joining the two-input merging method and the merging with the binary search method is the Hwang and Lin method [12].

The interactive pairs comparing method was applied to assess factors influencing the activity risk of a chosen average production enterprise [17]. To ranking 118 objects 358 comparisons were done. In case of the standard pairs comparing method 6903 comparisons would be necessary.

5. Conclusions

The multi-criteria assessment of complex phenomena is the important part of decision problems. The proper design of the assessment process, ensuring efficient and high quality assessment requires the consideration of a number of conditions and the selection of appropriate of assessment models. The conceptions presented in this article are used in the information system supporting knowledge management in mechanical engineering industry companies [7, 8, 9].

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REFERENCES

[1] Dohn K., Gumiński A., Zoleński W., (2012) „*Uwarunkowania decyzji o realizacji kontraktu w przedsiębiorstwie budowy maszyn*". Zeszyty Naukowe Uniwersytetu Szczecińskiego Nr 702. Ekonomiczne Problemy usług nr 87, str. 642-651, Szczecin.

[2] Dohn K., Gumiński A., Zoleński W. (2011) *"Assumptions for the creation of a system supporting knowledge management in an enterprise of mechanical engineering industry"*. Information systems in management XIII. Business intelligence and knowledge, pp. 19-27, WULS Press Warsaw.

[3] Dohn K., Gumiński A., Zoleński W. (2012) *„Uwarunkowania przygotowania do implementacji systemu informatycznego wspomagającego zarządzanie wiedzą w przedsiębiorstwie produkcyjnym"*. Wiadomości Górnicze nr 5/2012, str. 288-292.

[4] Dohn K., M. Matusek (2012) *„Identyfikacja obszarów wiedzy w procesie realizacji zamówienia"* Logistyka 1/2012.

[5] Dohn K., Matusek M., (2011) „*Zakres wsparcia systemami IT poszczególnych obszarów działalności przedsiębiorstw budowy maszyn. [w:] Nowoczesność przemysłu i usług. Koncepcje, metody i narzędzia współczesnego zarządzania"*. Praca zbiorowa pod red. J. Pyki, Katowice, s. 58-72.

[6] Grzegorczyk A. (2003) *"Psychiczna osobliwość człowieka"*. Wydawnictwo Naukowe Scholar, Warszawa.

[7] Gumiński A. (2012) *„System informatyczny wspomagający zarządzanie wiedzą jako istotny element poprawy efektywności zarządzania zasobami ludzkimi w realizacji kontraktów w przedsiębiorstwie przemysłu budowy maszyn"*. Zeszyty Naukowe Uniwersytetu Szczecińskiego Nr 702. Ekonomiczne Problemy usług nr 87, str. 93-100, Szczecin.

[8] Gumiński A., Zoleński W. (2011) *"Expected changes in the functionality of IT solutions in the area of knowledge management in selected enterprises of mechanical engineering industry"*. Information systems in management XIV. Security and Effectiveness of ICT Systems, pp. 34-44, WULS Press Warsaw.

[9] Gumiński A., Zoleński W. (2011) *„Wykorzystanie narzędzi informatycznych w zarządzaniu przedsiębiorstwami przemysłu maszynowego”*. str. 291-300, [w:] „Makroekonomiczne aspekty zarządzania w warunkach kryzysu”. Prace i materiały Wydziału Zarządzania Uniwersytetu Gdańskiego, Sopot.

[10] Hawkins J., Blakeslee S. (2006) *“Istota inteligencji”*. Wydawnictwo Helion, Gliwice.

[11] Hellwig Z. (1990) *“Taksonometria ekonomiczna i jej osiągnięcia, zadania i cele”*. Akademia Ekonomiczna, Kraków.

[12] Knuth D. E. (2002) *“Sztuka programowania. Sortowanie i wyszukiwanie”*. WNT, Warszawa.

[13] Kukuła K. (2000) *“Metoda unitaryzacji zerowanej”*. Wydawnictwo Naukowe PWN, Warszawa.

[14] Wirth N. (2004) *“Algorytmy + struktury danych = programy”*. WNT, Warszawa.

[15] Zieliński J. (2000) *“Inteligentne systemy w zarządzaniu”*, Wydawnictwo Naukowe PWN, Warszawa.

[16] Zoleński W. (2012) *“Wybrane modele interaktywnych systemów wspomagania decyzji”*. Zeszyty Naukowe Uniwersytetu Szczecińskiego Nr 702. Ekonomiczne Problemy usług nr 87, str. 787-795, Szczecin.

[17] Zoleński W. (2007) *“Metoda budowy informatycznego systemu wczesnego ostrzegania w zarządzaniu w przedsiębiorstwie”*, Politechnika Śląska, Gliwice.