Manažment v teórii a praxi 2/2006
on-line odborný časopis o nových trendoch v manažmente

SELECTION OF THE INFORMATION SYSTEMS' DEVELOPMENT IN ENTERPRISES BY MULTI-CRITERIA DECISION-MAKING

Vesna Čančer

ABSTRACT

This article presents the methodology for the selection of information systems' development in enterprises. In order to consider the need to complete up with special insights of other experts and to support this complex decision-making problem, it is based on systems thinking and the methods that have been most preferred for multi-criteria decision-making in the last two decades. To determine the criteria's weights, the methods based on interval (SWING, SMART) and ratio (AHP) scales were found more suitable than SMARTER that is based on an ordinal scale. Direct input, pair-wise comparisons and value functions were used to measure local alternatives' values. The article offers an original explanation how to create piece-wise linear value functions. Experts in a Slovenian company that applied the above mentioned computer-supported methods evaluated them as excellent tools in requisitely holistic decision-making about further information systems' development.

KEYWORDS: complexity, decision-making, information system, multiple criteria, scale, value function

JEL classification: C44, C88, M13, 014

INTRODUCTION

Some scientists and practitioners dealing with complex problem solving [2, 10] agree that traditional quantitative methods, emphasizing mainly common-practice statistical methods or single criterion optimization methods, cannot satisfactorily support many complex decision-making processes.

From the arguments of rare "philosophers of mathematics" [9] thirty-five years ago that over-specialization makes true inter-disciplinary work difficult [9], the emergence of complexity science has paralleled the embrace of new theories of knowing and knowledge among mathematics education researchers [5]. In parallel, Operations Research practitioners in enterprises express the need to (re)shape it following the needs of different management fields and to move from a posture of passive consultant to one of active leadership by, e.g. [10] greater emphasis on visual analyses and interpretation, on communication skills, on interdisciplinary studies and problem formation, and further focusing decision theory on real decision-making in a business context, as well. Therefore, specialists in practice express the need to complete up with other special insights in order to attain the requisite holism [12]. Mulej [12] concluded that it was systems thinking which has always helped people fight oversight. Besides to several systems thinking approaches (to mention only system dynamics, management cybernetics, soft systems methodology, dialectical systems theory, cognitive mapping, and models, for example viable system model), the 20th and the 21st centuries have brought notable developments to a special set of decision analysis methods called *multi-criteria decision making* (MCDM) (for a critical overview of these methods, together with an evaluation of adequate computer programs, see [4]). Since many phenomena are of a non-linear nature, and criteria are often (more or less) conflicting or incommensurable, MCDM based on non-linear relationships [11] are coming into force in modern systems research.

In this article, we present the methodology for the selection of suitable approach to further information system (IS) development of multi-project business processes (MPBP) in enterprises. It includes the methods that have been most preferred for individual and group MCDM in the last two decades. Special attention is given to the methods for the criteria weights determination based mainly on interval (SMART, SWING), ordinal (SMARTER) and ratio scales (AHP), and to the measurement of alternatives' values with respect to each attribute by value functions, pair-wise comparisons and the direct method. Comparing computer aids for MCDM [4], we found easy-to-use software Web-HIPRE (the web-version of HIPRE 3+) [8] especially applicable for supporting the above mentioned methods. The methodology is presented and illustrated by using so-called 'step by step' approach with a practical case in a Slovenian enterprise. The article offers an original explanation how to create piece-wise linear (and non-linear) value functions.

SOME ASPECTS OF THE SELECTION OF APPROPRIATE MCDM METHODS

In MCDM, *ranging* has a principal role. An analyst has to find a relative importance of each criterion or a relative preference to each alternative. Scales can be defined as nominal, ordinal, interval and ratio [3]. Nominal scales are the least restrictive and - consequently - the least informative: numbers, symbols or descriptions are used for identification. Ordinal scales enable ordinal ranging, where specific differences between the criteria importance or preferences to alternatives are not known. On the contrary, interval and ratio scales enable adjudging exact numerical level of importance or preference. With interval scales it can be expressed for how much the criteria importance or preferences to alternatives differ from each other. With ratio scales it can be expressed how many times the criteria importance or preferences to alternatives differ from each other.

When defining the criteria weights, decision makers can use different techniques among which we emphasize, in this article, the ones based on ordinal, interval and ratio scales:

- In the SMART method, decision makers give 10 points to the least important attribute change from the worst criterion level to its best level. Then they give more than (or equal to) 10 points to reflect the importance of the attribute change from the worst criterion level to the best level with respect to the least important attribute change.
- In the SWING method, decision makers give 100 points to the most important attribute change from the worst criterion level to the best level. Then they give less than (or equal to) 100 points to reflect the importance of the attribute change from the worst criterion level to the best level with respect to the most important attribute change.
- In the SMARTER method, decision makers rank the attributes in the order of importance for the attribute changes from their worst level to the best level.
- In the AHP, decision makers compare by pairs each possible pair of attributes with respect to the criterion on the higher level. For each pair they judge which attribute is more important and how many times it is more important.

ISSN 1336-7137

Measuring the alternatives' values with respect to each attribute can be based on interval or ratio scales, as well; we can use the direct input and value functions (when preferring interval techniques), or pair-wise comparisons (when preferring ratio techniques). A value function can be defined as a mathematical representation of human judgements, because it translates the performances of the alternatives into a value score, which represents the degree to which a decision objective is matched [1]. Therefore, a value function maps the data of alternatives with respect to each attribute to the local value of alternatives. Using Web-HIPRE [8], decision makers can create linear, piece-wise linear or exponential value functions.

When applying these methods, the assumptions about decision makers' abilities and preferences are as follow:

- A decision maker is able to decide between two possibilities and to express his/her judgements about the criteria's importance and preferences to alternatives.
- Relations 'is more important than' and 'is preferred to' are transitive:
  $A\ P\ B \wedge B\ P\ C \Rightarrow A\ P\ C$ (1)
  Transitivity is a basis for measuring decision makers' inconsistency.
- Considering (1), the relation 'A is preferred to C' is stronger than the relation 'B is preferred to C'. This is true when researching the intensity of the criteria's importance, as well.
- Solvability. For example, when measuring the alternatives' values with respect to an attribute by using value functions, it is possible to assign scale values, e.g. 0.50, 0.25, 0.75 (see Figure 4).
- Finite upper and lower bounds of the alternatives' values.

Multi-criteria decision-making based on non-linear relationships (for a detailed description see [11]) are coming into force in modern systems research since they embrace synergies better than the linear ones do. Non-linear relationships can be considered, for example:

- Among the criteria (e.g. by using an interval number to evaluate the global scores [6]) or
- In criteria by non-linear objective functions or by non-linear value/utility functions when measuring local alternatives' values/utilities with respect to the criteria.

Almost a decade ago, Miettinen [11] concluded that taking into account the multiplicity of methods developed for solving non-linear multi-objective optimization problems, the number of widely tested and user-friendly computer programs that are generally available was small. However, when measuring the alternatives' values with respect to the criteria on the lowest level with the support of e.g. Web-HIPRE, we found the possibility to include non-linearity with exponential value functions.

THE METHODS' APPLICATION: A PRACTICAL CASE

Problem definition and model structuring

The methods based on interval and ratio scales were used in the selection of suitable approach to the IS development of multi-project business processes in a Slovenian enterprise. In the *problem definition*, the following software solutions which can support multi-project business processes were described as alternatives:

1. *Renovation – BIS*. Adaptation and further development of current information solutions to the business information system (BIS).
2. *Development – INTERNAL*. Development of new information solutions with current developmental tools in the enterprise.
3. *Development – EXTERNAL*. Development of new information solutions with the tools and on the platform, compatible to the current ones in the enterprise.
4. *Purchase – Add-On*. Purchase of the standardized solution of the program upgrade for the current IS to support MPBP.
5. *Purchase - STD*. Purchase of the standardized program solution to support MPBP on an independent platform.

The possibility to develop new information solutions of the program upgrade for the current IS to support MPBP in the enterprise (so-called Add-On) was eliminated as unacceptable: its implementation time would be too long.

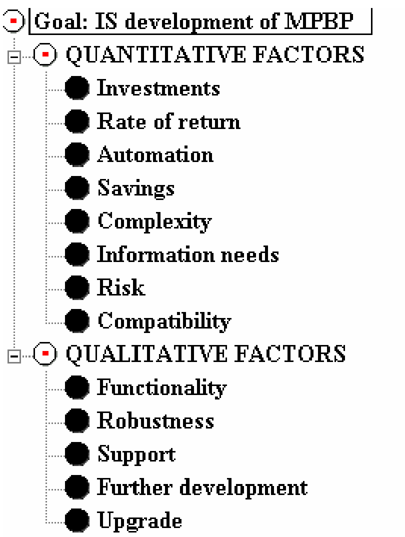

Figure 1 The criteria structure for the selection of IS supportive of MPBP

A requisitely holistic approach (as the opposite of a linear and piecemeal approach) was used in the *model structuring*. The criteria hierarchy presented in Figure 1 includes both the quantitative ('investments', 'rate of return', 'automation', 'savings', 'complexity', 'information needs', 'risk' and 'compatibility') and the qualitative factors ('functionality', 'robustness', 'support', 'further development', 'upgrade').

The included quantitative factors embrace mainly economical characteristics. The criterion 'investments' is expressed with the investments' net present value, in monetary units. 'Rate of return' is expressed with the rate on investments. 'Automation' presents the mode and the level of automation of the information support to MPBP on the operational, tactical and strategic management level; it is expressed in per-cent. The criterion 'savings' presents the influence of the information support to the expected annual savings due to more efficient and successful multi-project business; it is expressed in monetary units. 'Complexity' presents the level of the complexity of an information solution, from the point of view of application fields and users' levels; it is expressed in per-cent. The criterion 'information needs' explains the level of data and information availability, provided by an information solution. It includes different levels of the data aggregation, i.e. from operational to global information needs, and is expressed in per-cent. 'Risk' presents the probability that the system will not be built and implemented and that it will not meet the defined requirements, and is evaluated in per-cent. 'Compatibility' presents the level of the compatibility of the information solution supportive of MPBP with other information solution in the enterprise, as well as with external solutions; the enterprise's experts evaluated it and expressed it in per-cent.

The included qualitative factors embrace mainly technological characteristics. Decision makers evaluated them by assigning points (less than or equal to 100, where 100 points is given to the best possible solution with respect to the considered criterion). 'Functionality' presents an evaluation of expected functionality for the users at all levels. 'Robustness' presents the solution's reliability even in the case of interruption in information infrastructure. 'Support' includes suitable help for users in the phase of its implementation and use, as well; it has to provide additional training and advising, as well as current problem solving in the system. 'Further development' is described with the solution's perspective according to its long-term usefulness, adaptability and the possibility of improvements. 'Upgrade' contains the technological suitability of the solutions with respect to the used technological tools, and the construction of the information solution.

Expressing judgements about the criteria's importance

Quantitative factors were judged to be 1.5-times more important than the qualitative ones. Decision makers assessed the importance of quantitative criteria by using the SMART method. Figure 2 shows that 10 points were given to the change from the highest to the lowest 'investments', which is considered the least important attribute change. With respect to this change importance, 70 points were given to the change from the lowest to the highest 'rate of return', 60 to the change from the worst to the best 'automation' level, 90 to the change from the lowest to the highest 'savings', 100 to the change from the worst to the best meeting of 'information needs', 40 to the change from the highest to the lowest 'risk', 80 to the change from the lowest to the highest 'compatibility', and 85 points were given to the change from the lowest to the highest 'complexity'.

Quantitative factor	***Points***	*Rank*	*Weight*
Investments	**10**	**8**	**0.019**
Rate of return	**70**	**5**	**0.131**
Automation	**60**	**6**	**0.112**
Savings	**90**	**2**	**0.168**
Information needs	**100**	**1**	**0.187**
Risk	**40**	**7**	**0.075**
Compatibility	**80**	**4**	**0.150**
Complexity	**85**	**3**	**0.159**

Figure 2 Judgements about the quantitative criteria's importance by the SMART method

ISSN 1336-7137

Decision makers assessed the importance of qualitative factors by using the SWING method. Figure 3 shows that 100 points were given to the change from the worst to the best 'functionality', which is considered the most important attribute change. With respect to this change importance, 60 points were given to the change from the worst to the best 'robustness', 90 to the change from the worst to the best 'support' level, 70 to the change from the worst to the best 'further development', and 50 points were given to the change from the worst to the best 'upgrade' level.

Qualitative factor	***Points***	*Rank*	*Weight*
Functionality	**100**	**1**	**0.270**
Robustness	**60**	**4**	**0.162**
Support	**90**	**2**	**0.243**
Further development	**70**	**3**	**0.189**
Upgrade	**50**	**5**	**0.135**

Figure 3 Judgements about the qualitative criteria's importance by the SWING method

Measuring the alternatives' values

To evaluate alternatives with respect to the qualitative factor 'robustness', we compared preferences to alternatives by pairs, and to evaluate alternatives with respect to other attributes, i.e. qualitative factors at the lowest level in the model, we used the direct method. We evaluated the considered software solutions with respect to:

- 'Investments' by using the convex (decreasing) function;
- 'Compatibility' by using the increasing piece-wise linear function;
- 'Risk' by using the decreasing linear function; and
- 'Rate of return', 'automation', 'savings', 'complexity' and 'information needs' by the direct method.

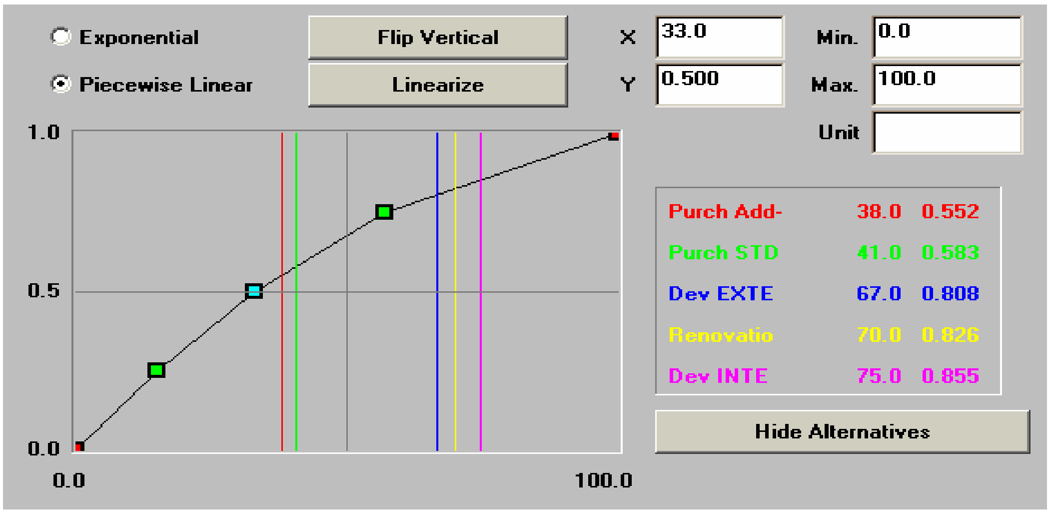

Figure 4 Piece-wise linear function for the measurement of the alternatives' values with respect to 'compatibility'

For example, Figure 4 shows the piece-wise linear function for measuring the alternatives' values with respect to 'compatibility'. To the enterprise's experts, the increase of the 'compatibility' from 0 to 33 per-cent is equally favorable as its increase from 33 to 100 per-cent. Therefore, the local value of 33 is 0.5. Further, the increase of the 'compatibility' from 0 to 15 per-cent is equally preferred as its increase from 15 to 33 per-cent; the local value of 15 is 0.25. Finally, the increase of the 'compatibility' from 33 to 57 per-cent is equally favorable as its increase from 57 to 100 per-cent; the local value of 57 is therefore 0.75.

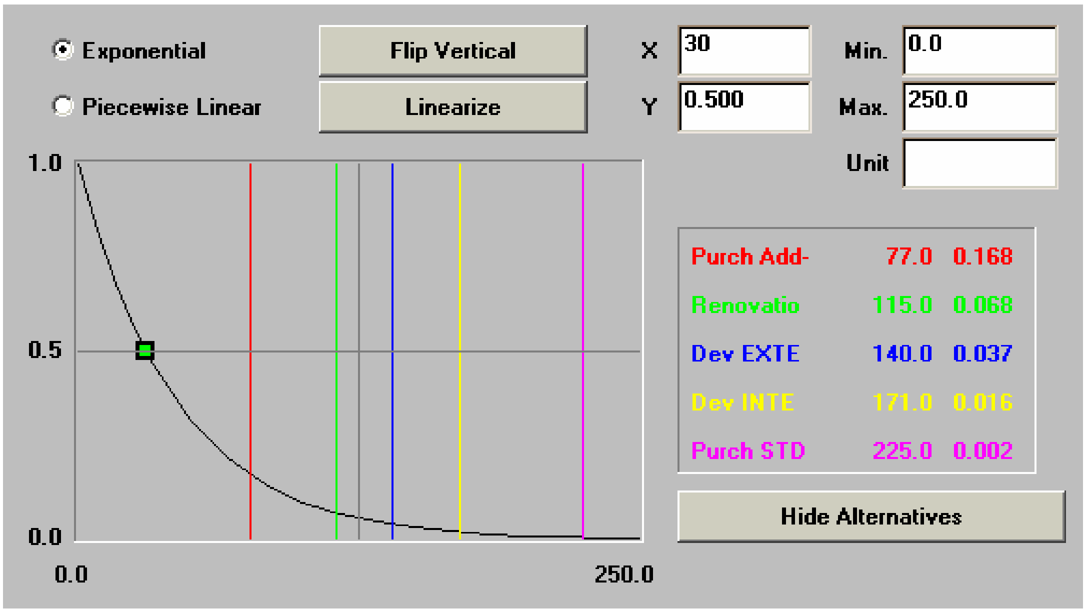

Figure 5 Decreasing convex function for the measurement of the alternatives' values with respect to 'investments'

Figure 5 shows that the increase of 'investments' from 0 to 30 monetary units is equally unfavorable to the experts as its increase from 30 to 250 monetary units. The local value of 30 is therefore 0.5. The decreasing convex function expresses that the increase of 'investments' e.g. from 1 to 15 monetary units is less preferred to experts (decreases the alternatives' values much more) than the increase of 'investments' e.g. from 235 to 249 monetary units.

Synthesis and sensitivity analysis

Table 1 Synthesis results

Software solution	Final value	Rank
Renovation – BIS	0.655	3
Development – INTERNAL	0.733	2
Development – EXTERNAL	0.818	1
Purchase – Add-On	0.571	5
Purchase – STD	0.650	4

ISSN 1336-7137

Considering the final values presented in Table 1 it can be concluded that Development – EXTERNAL is the most convenient software solution. By analyzing the sensitivity of its suitability to changes in the criteria weights we can confirm its selection.

CONCLUSIONS

The enterprise's experts that were choosing between approaches to further information system development evaluated MCDM and appropriate software as excellent tools in solving complex problems. Namely, the methods for determination of criteria weights which base on interval (SWING, SMART) and ratio (AHP) scales, as well as the ways of measuring local alternatives' values (direct input, use of value functions and pair-wise comparisons) were successfully used in this real-life problem. Because of sufficient information basis, the methods based on interval scales SMART and SWING were assessed as more convenient than the method based on an ordinal scale SMARTER in this application. In this practical case, the AHP method based on a ratio scale was found applicable when expressing judgements about the criteria's importance, mainly on the basis of their experience. Pair-wise comparisons enabled decision makers better understanding of the criteria's meaning and importance; they gave decision makers the opportunity to confront other participants' judgements.

Multi-criteria decision-making problems are characterized with internal and external complexity and the lack of information; experts from different professional fields should take part in the evaluation of the alternative's data. To measure alternatives with respect to factors by value functions, experts should know the characteristics of each factor. Value functions enable decision makers to understand the problem (as a whole and in details) better and provide insight into the structure of values for the decision. However, the enterprise's experts emphasized that the quality of the decisions made on the basis of their results depends on the responsibility in establishing priorities about the criteria's importance and preferences to alternatives.

Several groups (see e.g. [7, 8]) are actively developing computer aids for MCDM. They include the possibilities of the latest developments in Operations Research/Management Science, and information technology (such as multimedia and Internet), as well. Their worldwide-web availability strengthens their use in enterprises.

REFERENCES

1. BEINAT, E.: *Value Functions for Environmental Management*, Dordrecht, Boston, London: Kluwer Academic Publishers, 1997. ISBN 0-7923-4662-9
2. BELTON, V., STEWART, T. J.*: Multiple Criteria Decision Analysis: An Integrated Approach*. Boston, Dordrecht, London: Kluwer Academic Publishers, 2002. ISBN 0-79-237505-X
3. ČANČER, V.: *Analiza odločanja (Decision-making analysis. In Slovene).* Maribor: University of Maribor, Faculty of Economics and Business, 2003. ISBN 961-6354-29-9
4. ČANČER, V.: Multi-criteria decision-making methods for complex management problems: a case of benchmarking. *Manažment v teórii a praxi,* vol. 1, 2005, no. 1, pp. 12-24. http://casopisy.euke.sk/mtp/clanky/1-2005/cancer.pdf, consulted May 2006. ISSN 1336-7137

5. DAVIS, B., SIMMT, E.: Understanding Learning Systems: Mathematics Education and Complexity Science, *Journal for Research in Mathematics Education*, Vol. 34, No. 2, 2003, pp. 137-167. ISSN 0021-8251
6. DONG, J., HOU, W., LAI, K. K., WANG, S.: Multicriteria Decision for Portfolio selection Using Interval Number. In: *The First International Conference on Optimization Methods and Software, The Accepted Abstracts*. Hangzhou, 2002. http://www.zju.edu.cn/~oms/abstractreceived.php, consulted January 2006.
7. FORMAN, E. H., GASS, S. I.: The Analytic Hierarchy Process – An Exposition. *Operations Research*, Vol. 49, 2001, No. 4, pp. 469-486. ISSN 0030-364X
8. Helsinki University of Technology: *Web-HIPRE help.* http://www.hipre.hut.fi, consulted May 2006.
9. KUYK, W.: Wiskunde en maatschappelijke tendensen (Mathematics and societal trends). *Geloof en Wetenschap (Faith and Knowledge)*, Vol. 68, 1970, pp. 145-165.
10. McDONALD, G. C.: *Shaping Statistics for Success in the 21st Century: The Needs of Industry*. www.misd.net/Mathematics/projects/shapingstats.htm, consulted June 2005.
11. MIETTINEN, K.: *Nonlinear Multiobjective Optimization*. Boston, London, Dordrecht: Kluwer Academic Publishers, 1999. ISBN 0-7923-8278-1
12. MULEJ, M.: New Roles of Systems Science in a Knowledge Society: Introductory Provocation. In: Gu, J., Chroust, G. (eds.), *Proceedings of the first world congress The new roles of systems science for a knowledge-based society.* Kobe: International Federation for Systems Research, 2005. ISBN 4-903092-02-X

ABOUT THE AUTHOR

Doc. Vesna ČANČER, Ph.D. in Economic and Business Sciences
Department of Quantitative Economic Analysis at the University of Maribor's Faculty of Economics and Business, Slovenia
Research fields: decision analysis, business process optimization, systems thinking and several areas of managing complex problems
Please address all correspondence to: Vesna Čančer, University of Maribor, Faculty of Economics and Business Maribor, Razlagova 14, 2000 Maribor, SI-Slovenia. [Phone: ++ 386 2 2290 314, fax: ++ 386 2 251 04 61, e-mail: vesna.cancer@uni-mb.si]