Teaching Decision Making Analytical Skills to Engineeris: A New Paradigm

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Abstract- *Throughout their professional lives engineers are both decision agents and decision-makers. Decision making environments where engineers are active quite often involve multiple criteria, imprecise and incomplete data, multiple actors and pressure groups, etc. Although practically all engineering disciplines aim at helping engineers to develop good decision making capabilities a conscious effort based upon the state-of-the-art of the so-called decision sciences must be carried out if one wants to simultaneously maximize quality and productivity of engineering decision making. That effort, however, must not be mistaken for teaching traditional methods of operations research or statistical analyses. This paper describes the authors' experience with teaching decision making skills to both graduate and undergraduate engineering students. In essence such a course on how to be a good decision maker must encompass the following topics: (i) understanding the cultural environments of engineering and multidisciplinary decision making; (ii) identifying a decision making problem; (iii) designing a decision aiding analysis and choosing an applicable set of analytical methods; (iv) running the analysis and testing for robustness; (v) recommending a course of actions or selecting the best action for implementation; (vi) validation analysis (i.e. ex-post evaluation) of the decision aiding exercise; (vii) organizing information for future decision making. The paper closes with emphasizing where to embed teaching the new paradigm and related methods in engineering curricula.*

Introduction

Unlike scientists engineers are decision-makers or decision agents. Engineers are indeed either agents through which complex decision processes take place or decision makers themselves or both. The complexities inherent to most decision processes that are to rely on some engineering knowledge arise from the identification of conflicting, quantitative as well as qualitative criteria, imprecise and incomplete data, multiple actors and pressure groups, etc..

Although all engineering sciences and specializations aim at improving the quality and productivity of engineering decision making any engineer is likely to be a better professional if he or she has good decision making capabilities. Although this depends on psychological characteristics (e.g. being able to fastly understand a problem from a very broad perspective and to produce a good solution to that problem within limited resources) a practical, working knowledge of the so-called decision sciences can significantly contribute to improving these personal decision making capabilities. This, however, must not be mistaken for teaching traditional, decision making-oriented methods of operations research or statistical analyses (e.g. decision trees or hypothesis testing) to engineering students and to graduated engineers.

Explaining the general engineering decision making process, Krick [1] states the following:

> "Although the specifics vary from situation to situation, in almost every instance these four steps must be taken before na intelligent decision can be reached: (1) criteria must be selected and their relative weights determined; (2) the performance of alternative solutions must be predicted with respect to these criteria; (3) the alternatives must be compared on the basis of these predicted performances; and then (4) a choice must be made." (p. 148)

About the same time when the essence of good engineering decision making was stated so objectively and so clearly by Krick, new tools were merging that were to add substantially to the engineering decision making skills. At present, the decision makings skills that must be taught to engineers emerge not only from the body of knowledge of social psychology but also from the new paradigm of the decision sciences that is most often denoted by Multi-Criteria Decision Making [2]. This paper describes the authors' experience with teaching major elements of that paradigm to both graduate and undergraduate engineering students.

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Major elements of the paradigm are the following: (a) problem understanding and its clarification; (b) decision criteria – interdependencies, exhaustiveness, operationality; (c) weighting, concordance, discordance; (d) alternative solutions to the decision problem – dominated and non-dominated alternatives; (e) performances of alternatives for each criterion; (f) preparing recommendations for decision making; (g) group decision making, negotiation, mediation, and arbitration.

Based upon the understanding of the paradigm, a course on analytical skills for good engineering decision making must set the following learning goals: (i) understanding the cultural environments of engineering and multidisciplinary decision making; (ii) identifying a decision making problem; (iii) designing a decision aiding analysis and choosing an applicable set of analytical methods; (iv) running the analysis and testing for robustness; (v) recommending a course of actions or selecting the best action for implementation; (vi) validation analysis (i.e. *ex-*

post evaluation) of the decision aiding exercise; (vii) organizing information for future decision making.

The description of such a course should therefore include the following topics:

(1) Behavioural aspects of engineering decision making.
(2) Discrete and continuous decision problems.
(3) Preference modeling and utility functions.
(4) The AHP, outranking, and ordinal multicriteria methods.
(5) Negotiation and group decision-making.
(6) Multicriteria optimization.
(7) Informatics and multicriteria decisions.
(8) Application examples.

Typical readings for such a course are the following (in alphabetic order):

Belton, V. and Vickers, S. (1990): "Use of a Simple Multiattribute Value Function Incorporating Visual Interactive Sensitivity Analysis for Multiple Criteria Decision Making", in Readings in Multiple Criteria Decision Making, Bana e Costa, ed., Springer, pp. 319-334.

Dyer, R.F. and Forman, E.H. (1992): "Group Decision Making with the Analytic Hierarchy Process", *Decision Support Systems*, vol. 8, pp. 99-124.

Keeney, R.L., McDaniels,T.L. (1992): "Value-focused Thinking about Strategic Decisions at BC Hydro", *Interfaces*, vol. 22, no. 6, pp. 94-109.

Roy, B. (1990): "Decision-aid and decision-making" , *European Journal of Operational Research*, vol. 45, pp. 324-331.

Roy, B. (1990) "The outranking approach and the foundations of ELECTRE methods", in Readings in Multiple Criteria Decision Making, Bana e Costa, ed., Springer, pp. 155-183.

Saaty, T.L. (1995): *Decision Making for Leaders: The Analytic Hierarchy Process for Decisions in a Complex World*, Third edition, RWS Publications, Pittsburgh.

Siskos, J. and Assimakopoulos, N. (1989): "Multicriteria Highway Pl *Mathematical Computer Modelling*, vol. 12, no. 10-11, pp. 1401-1410.

Zeleny, M. (1994): "Six Concepts of Optimality", mimeo.

Besides having access to the required readings as well as to other equally important texts, students are given class notes prepared and updated every semester by the instructor.

Applications examples normally come from fields such as quality management, technology evaluation, water resources as well as transportation systems analysis, etc.. Students are suggested to go to the library, look for papers on real-world applications, and then make oral presentations of those papers in the classroom. Besides lectures and classroom discussion of papers, students are expected to prepare a term paper on some other, either real or idealized, application of at least one multicriteria methods. Although students are encouraged to use MCDM software that are made available by the instructor the most valued aspects of a term paper are the following: (i) being able to formulate a complex engineering decision problem with the help of the MCDM paradigm; (ii) construction of a coherent family of decision criteria; (iii) evaluation of the relative importance of criteria as well as the performance measures for every criterion; (iv) applying at least one MCDM method correctly and running a sensitivity analysis of the results; (v) producing a suggested course of action for decision making.

Fitting the Engineering Decision Making Course into a Curriculum

Although the prerequisite for such a course can be first-year Calculus only some exposition of students to either engineering design courses or to some engineering practice such as internships is highly desirable. Therefore a course on engineering decision making should be offered as a fourth year course or as a graduate course.

When offered as a graduate course, registered students are supposed to have some engineering background plus at least a first course on subjects as feasibility analysis of engineering projects and operations research. Those two subjects usually require engineering economy and probability & statistics as pre-requisites, which is quite desirable. Although the emphasis of the course lies on the discrete MCDM methods, applications of multiobjective linear programming and goal programming are also looked at during the course.

Closure

The author has been teaching introductory courses on engineering decision making from a Multiple Criteria Decision Making perspective in Central and South America, besides his own country (Brazil) for the last twenty years or so. It is his firm conviction that all engineering students should have a similar course in their curriculum.

The key idea behind teaching engineering decision making from a Multiple Criteria Decision Making should be that engineers are not simply cost minimizers but they must rely on the whole spectrum of technical analyses of MCDM in order to effectively add value to their decision making processes.

References

[1] Krick, E.V. (1969): *An Introduction to Engineering and Engineering Design*, second edition, John Wiley & Sons, Inc., New York.

[2] Steuer, R.E., Gardiner, L.R., and Gray, J. (1996): "A Bibliographic Survey of the Activities and International nature of Multiple Criteria Decision Making" , *Journal of Multi-Criteria Decision Analysis*, vol. 5, Issue 3, pp. 195-217.