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Technology Strategic Decision Making (SDM): an overview of decision theories, processes and methods

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Research Background

Technology Strategic Decision Making (SDM) requires a fair amount of information regarding the field in which the technology is to be selected for (Kalbande and Thampi, 2009) due to the nature of technological uncertainty (Grant, 2012). The literature argues that different methods can be applied to these SDM processes, with the most common being the qualitative scorecard approach (Cooper, 2007; Goffin and Mitchell, 2016; Mitchell et al., 2014, 2017). In addition, these SDM processes should have unique selection criteria, due to the risky and uncertain nature of early stage technology projects (Ajamian and Koen, 2002; Koen et al., 2002) and due to the different outcomes each decision gate leads to (Cooper, 2006). In this paper, we contribute to the growing literature on technology strategic decision making by producing a narrative literature review on strategic decision making processes, decision theory and strategic decision making methods.

Methodology

The paper aims to contribute to the growing literature on technology strategic decision making via a narrative literature review (Cronin et al., 2008). The articles on SDM decision theory, SDM processes and methods are identified from databases to find the most relevant published articles or in press articles, using a research strategy and a snowball effect, with relevant literature (Creswell, 2013).

We search within the tittle, abstract and key words for various terms such as "Decision making", "Decision theory", "Strategic decision makings", "Strategic decisions", "Decision making criteria", "Decision making factors". These are then narrowed to the field of technology and innovation management using the following terms: "technology development", "innovation", "innovation management", "technology", "stage gate", and limited to the areas of business aand management. The following sections provide the readers with a summary of the results.

Strategic Decision Making Process

A decision, usually taken at the gate of a stage gate process (Fig. 1), is a commitment to mobilise resources (Cooper, 2006; Edwards, 1954; Ullman, 2002). SDM is the process of steps of identifying and choosing strategic alternatives to reduce uncertainty, and arrive at rational decision (Ahmed et al., 2014; Dewey, 1911; Mintzberg et al., 1976; Simon, 1961, 1993).

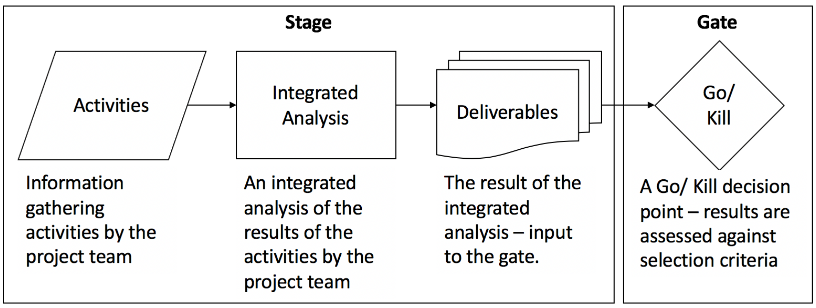
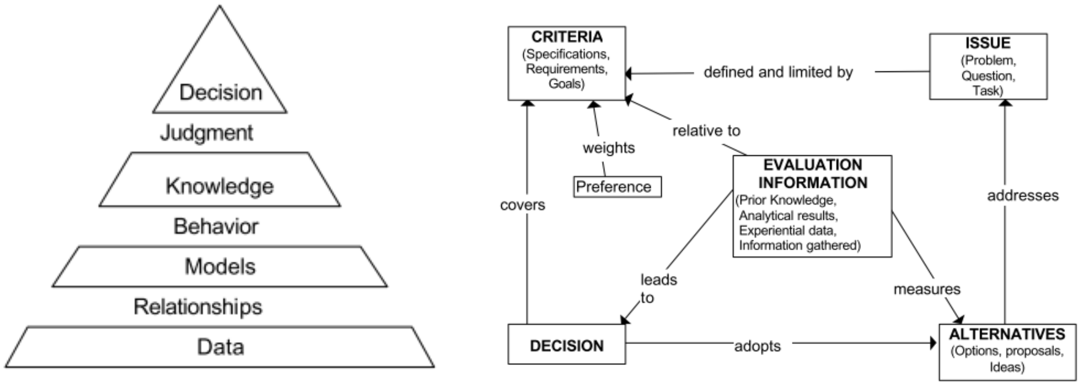


Fig. 1 Stage Gate Strategic Decision Making Process Commitment, source: Cooper (2007)

Following the vlaue of information pyramid, a decision is based on the judgement of knowledge gain, which has been composed by the behaviour of the models, which have analysed the relationship of data (Fig. 2a). Thus, for a given issue, a decision arises, when a number of criteria are used to specify the issue, and the information measuring alternatives is evaluated relative to these (Fig. 2b). Papadakis et al. (1998) argues that the importance of SDM is based on the characteristics and understanding of the long term nature of the effects of the decision and the bridge between deliberate and emerging strategy, and organizational learning, similar to Grant (2012); Mintzberg and Lampel (1999). There are several SDM process models in the literature that are summarised in Table 1, with Fig. 3 showing the basic features of these.

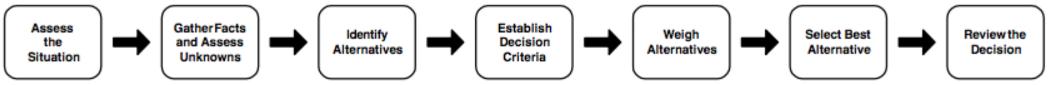


(a) The value of information (b) Decision making information

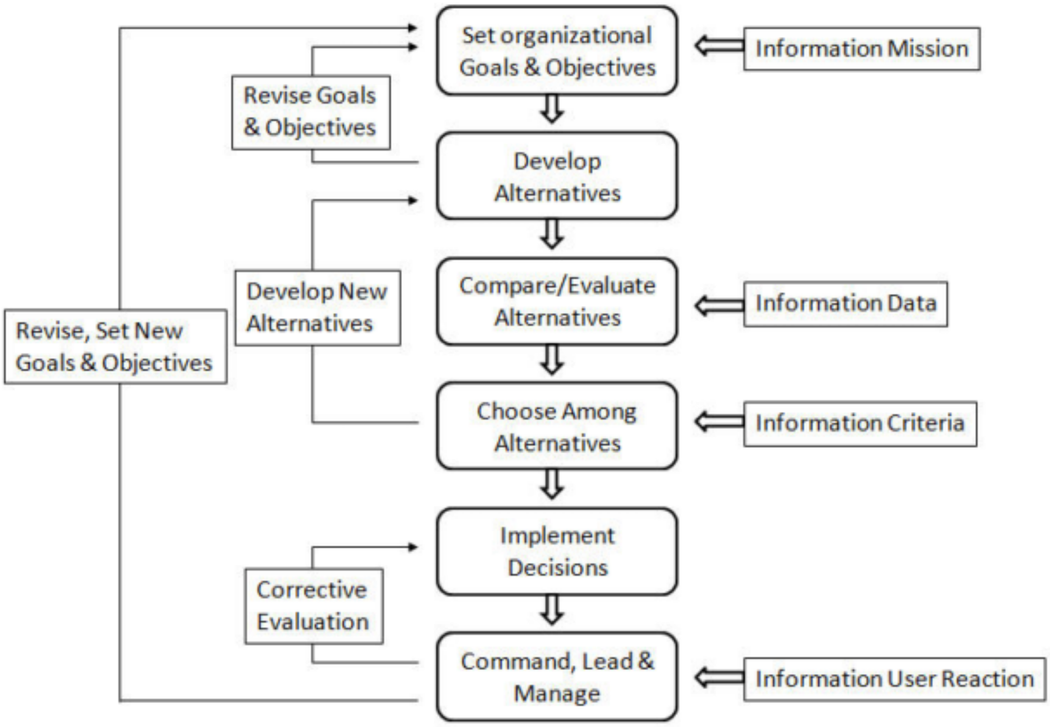
Fig. 2 Strategic decision making knowledge-information classes, and the value of information, source: Ullman (2002)

Table 1 Strategic decision making process models, based on Grant (2012); Nickols (2015)

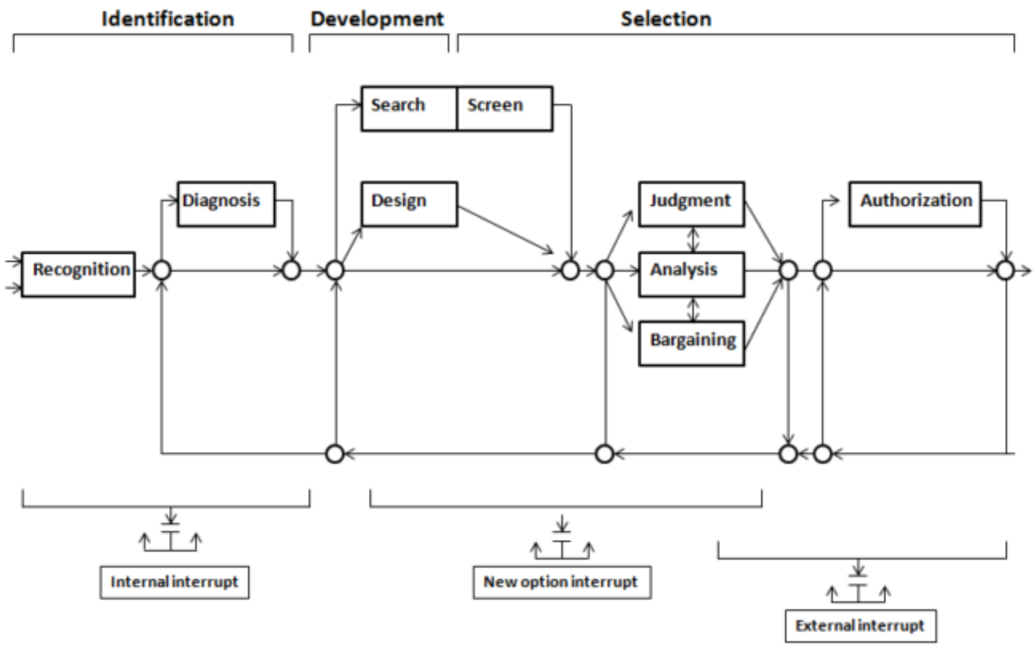
Model	Author	Summary
Classical decision making process	Dewey (1911)	Rational-Analytic approach. Sequential Model. The model assumes certainty conditions in the decision making process arising from intelligence, design and choice. The models assumes that the causal relationships are known and knowable.
Military model	Nickols (2015)	Goal setting objective approach. Sequential Model. The model is based on the classical decision making process and have the same limitations as above. Iterative decision making process using feedback loops.
Mintzberg's General Model	Mintzberg et al. (1976)	Three phase and seven routine approach. Non-sequential model. There are three phases the identification, development and selection phase, where the decision is defined as a commitment to a course of action. The model also highlights decision control implications but lacks the procedural guidance on how to used it.
Cynefin Framework	Kurtz and Snowden (2003); Snowden and Boone (2007)	Evolutionary perspective of complex systems approach. Non-sequential model. The model combines research from adaptive systems theory and cognitive science, and seeks to understand how people perceive situations in order to make decisions. The four quadrants of the model have to do with the decision making categories: complex, complicated, chaotic, simple.
MCDA	Montibeller and Franco (2010)	The model deals with a decision problem under conflicting criteria with large uncertainty. It follows as set of procedures in analyzing complex decisions to identify the most preferred option.



(a) Classical decision making process



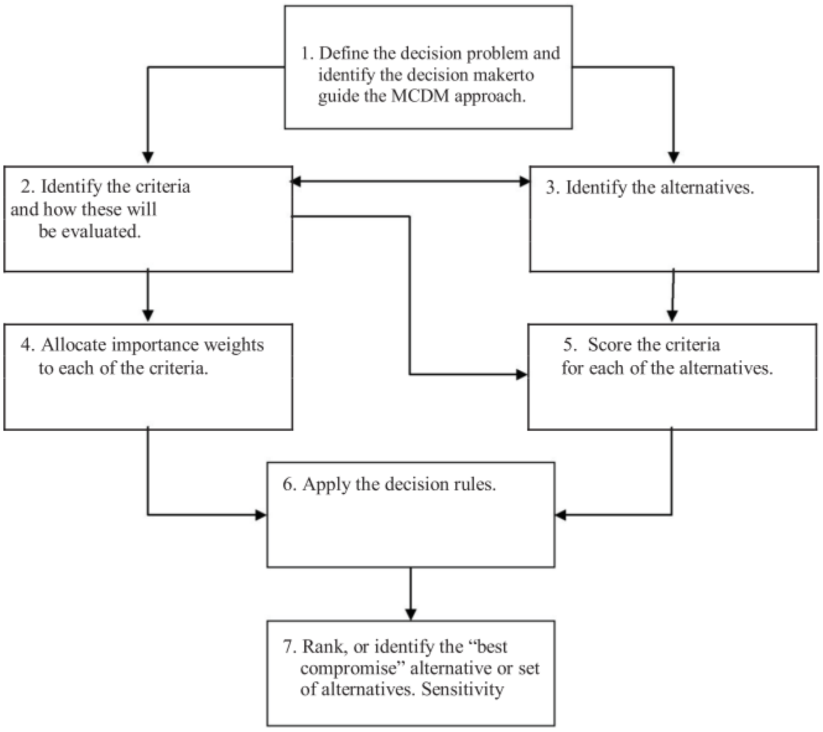
(b) Military decision making process



(c) Mintzberg's general process

Fig. 3 Strategic decision making process models, sources: Table 1

(d) Cynefin framework



(e) MCDA process

Fig. 3 *continued* Strategic decision making process models, sources: Table 1

Decision Theory

The theories linked to SDM are similar to the decision making theories. The majority of decision making theories are multidisciplinary and strategic in nature (Grant, 2012). Through out the years several authors have suggested several classifications of these theories, but there is no unonymous agreement on the classifications. Brown (2005) argues that the theories can be divided in single and group theories, based on the garbage-can theory (Cohen et al., 1998).

Many researchers argue that the theories can be divided between rational, non-rational and bounded rational (Edwards, 1954; Eisenhardt and Zbaracki, 1992; Oliveira, 2007; Stanovich and West, 2000). Rational theories assume a rational and completely informed decision making (Drummond, 2012), where as the bounded rational theories assume a process oriented view of satisfaction and decision making leading on optimal choice based on incomplete information (Turpin, 2004). This distinction can be further enhanced by the classification into normative and descriptive (behavioural) decision theories (Ahmed et al., 2014). The distinction is due to the fact that normative theories are concerned with how decision should be made and descriptive theories describe how decisions how are actually made (Williams, 2010). The main SDM theories in the literature are shown in Fig. 4 and the most important of them are described in Table 2.

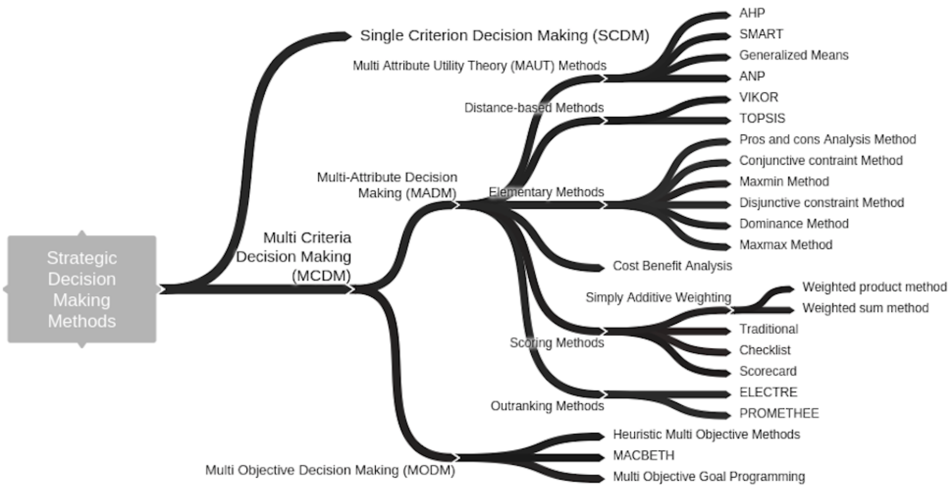
Fig. 4 Strategic decision making theories in the literature

Table 2 Strategic decision making theories in the literature

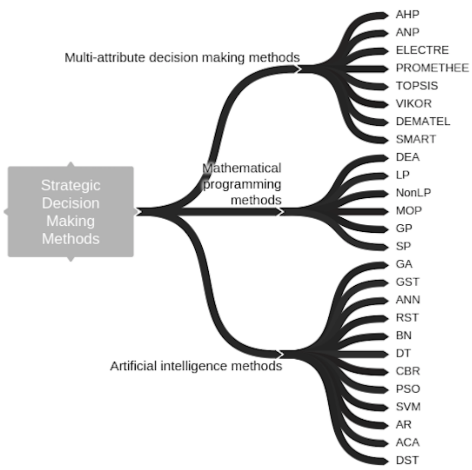
Theory	Authors	Summary
Attribute theory	Heider Fritz et al. (1958); Weiner (1972)	This theory originates from psychology and attempts to understand the causal behaviour of others by attributing internal and external factors. Internal factors are character, attitude, personality, where as external factors are the situation, environment. The theory has three stages: the observation, the deliberate behaviour and the attribution of causes.
Bayesian theory	Williams (2010)	It is a statistical theory that looks at the problem of pattern classification and considers the ideal situation. This situation is based on known probabilistic structures of the categories, and trade-off costs, which allow to determine the Bayes classification (optimal), predicting errors and generalization of novel constructs.
Game theory	Neumann and Morgenstern (1947)	It is an economic theory concerned with intelligent rational decision making. It argues that there is an equilibrium, which maximizes the gain for two actors independent of the information they have about the market or each other.
Multiple attribute utility theory	Keeney and Raiffa (1993)	This structured theory handles the trade-off between multiple attributes or objectives, comparing strengths and weaknesses of alternatives relative to the person taking the decision. It is the aggregation of single attribute utilities and this represents the difference between best and worst alternatives. The higher the multi-attribute utility measure, the more desirable is the alternative, which when ranked in order, shows the order of preference.
Prospect theory	Kahneman and Tversky (1979)	It is behavioural economic theory that describes how people make decisions between risky alternatives, when everything is known. It argues that people makes decisions based on the potential value of loss and gain. This is a descriptive theory and tries to evaluate real-life decision problems rather than come up with the optimal solution.
Satisfying theory	Simon (1946)	A bounded rationality theory, where the person taking a decision has limited information, and he uses this limited information with simplified knowledge to make a compromise (satisfying) decision, and not the optimal decision. The theory also argues that it is better off when a compromise solution is made rather than searching indefinite for the optimal solution.
Subjective expected utility theory	Kim et al. (2008); Savage (1954)	The theory argues that a decision is taken in the presence of risk between alternative strategies. The decision maker always seeks the best alternative and thus has a subjective weight of utility and estimation of likelihood. The theory makes the assumption that the person taking the decision is always rational.

Strategic Decision Making Methods

Depending on the problem, there are different types of SDM methods, arising from the theories. These are divided in two types: single criterion and multi-criteria, as shown on Fig. 5a. Different authors have considered different classifications for these, based on characteristics and method logic (Verbano and Nosella, 2010), or criteria interaction (Golcuk and Baykasoglu, 2016) or information on criteria (Zavadskas and Turskis, 2011). With the rise of artificial intelligence recently, Chai et al. (2013) divides the SDM methods in three categories: multi-attribute decision making methods, mathematical programming methods and AI methods (Fig. 5b). Table 3 summarizes the most commonly used SDM methods in the literature.



(a) Traditional classification



(b) Radical recent classification, abbreviations and source: Chai et al. (2013)

Fig. 5 Strategic decision making methods in the literature

Table 3 Most commonly used Strategic decision making methods in the literature

Method	Summary	Strength/ Weakness	Studies
ANP, AHP	This method is based in the hierarchic identification of weights of importance for selection criteria and alternatives. Each element is assumed to be independent and known. In its simplest form, it can act as a balanced score-card.	Loss of information can occur due to potential compensation between good scores on some criteria and bad scores on other criteria. Complex and time-consuming computation is required.	Azis (1990); Dehe and Bamford (2015); Dodgson et al. (2009); Gade and Osuri (2014); Goffin and Mitchell (2016); Kabir et al. (2014); Kolios et al. (2016); Korhonen and Wallenius (1990); Mardani et al. (2015); Millet and Harker (1990); Saaty (1990a,b); Triantaphyllou and Shu (1998); Ullman (2002); Xu and Yang (2001); Zahedi (1990); Zavadskas et al. (2014)
DEMATEL	This methods identifies interdependencies between criteria through causal relationships, identifying the influential strength of these.	Simple to compute. Does not require the criteria to be independent. Identification of causal relationships. Many hybrid variations.	Bian and Deng (2017); Büyüközkan and Ifi (2012); Chai et al. (2013); Chang et al. (2011); Chao and Chen (2009); Golcuk and Baykasoglu (2016); Kahraman et al. (2015); Lin and Wu (2008); Liu et al. (2017); Mardani et al. (2015); Marttunen et al. (2017); Shieh et al. (2010); Tseng et al. (2007); Wu (2008); Wu and Lee (2007a,b); Zavadskas et al. (2014)
ELECTRE	This method is concerned with outranking pair wise relations between alternatives, establishing a partial ranking by a process of elimination.	Applicable even when there is missing information, and when there are incomparable alternatives and uncertainty. Time consuming.	Andriosopoulos et al. (2012); Behzadian et al. (2010); Dehe and Bamford (2015); Figueira et al. (2010, 2016); Fülöp (2001); Gade and Osuri (2014); Greco et al. (2001); Kabir et al. (2014); Kahraman et al. (2015); Kolios et al. (2016); Majumder (2015); Mardani et al. (2015); Roy (1991); Songa et al. (2010); Triantaphyllou and Shu (1998); Zavadskas and Turskis (2011); Zavadskas et al. (2014); Zopounidis and Doumpos (2002)

MACBETH	This interactive method allows the evaluation of alternatives by making qualitative comparisons based on differences and attractiveness.	Applicable even when there is missing information. Simple and easy to use. Problems arise when the group cannot agree on alternatives and weights.	Dodgson et al. (2009); Ferreira (2013); Kahraman et al. (2015); Zavadskas and Turskis (2011); Zavadskas et al. (2014)
PROMETHEE	This is an outranking method for a finite set of alternatives based on conflicting criteria. It compares alternatives and identifies the deviations of each alternative to the selection criterion.	Simple and efficient. No normalization is required. There are different versions, which can cause confusions. Time consuming. Complicated when the number of selection criteria is large.	Behzadian et al. (2010); Brans and Vincke (1985); Brans et al. (1984, 1986); Deshmukh (2013); Fülöp (2001); Gade and Osuri (2014); Kahraman et al. (2015); Macharis et al. (2015); Mardani et al. (2015); Mareschal (1988); Songa et al. (2010); Zavadskas and Turskis (2011); Zavadskas et al. (2014)
TOPSIS	This is a value-based compensatory method, which attempts to choose alternative solutions based on the shortest distance from the ideal solution. The ideal solution maximizes benefit and minimizes cost.	Does not require attributes to be independent. Cardinal ranking of alternatives. Easy to implement. Only applicable when exact and total information is collected. Vector normalization is required.	Behzadian et al. (2012); Dehe and Bamford (2015); Hwang et al. (1993); Kabir et al. (2014); Kalbande and Thampi (2009); Kolios et al. (2016); Lai et al. (1994); Mardani et al. (2015); Triantaphyllou and Shu (1998); Xu and Yang (2001); Yeh (2002); Zavadskas and Turskis (2011); Zavadskas et al. (2014)
VIKOR	This method maximizes group utility and minimizes regret, by identifying a solution closest to the ideal in the presence of conflicting criteria.	Non-preference model. No interactive participation of decision makers necessary. Linear normalisation needed.	Kabir et al. (2014); Kahraman et al. (2015); Mardani et al. (2015); Opricovic and Tzeng (2002, 2004, 2007); Zavadskas and Turskis (2011)

Conclusion

Technology Strategic Decision Making (SDM) requires a fair amount of information regarding the field in which the technology is to be selected for (Kalbande and Thampi, 2009) due to the nature of technological uncertainty (Grant, 2012). One such technology strategic decision is a commitment to mobilise resources (Cooper, 2006; Edwards, 1954; Ullman, 2002). SDM is the process of steps of identifying and choosing strategic alternatives to reduce uncertainty, and arrive at rational decision (Ahmed et al., 2014; Dewey, 1911; Mintzberg et al., 1976; Simon, 1961, 1993). In this short paper, we contribute to the growing literature on technology strategic decision making by producing a narrative literature review on strategic decision making processes, decision theory and strategic decision making methods. We hope researchers and practitioners will find this paper a useful overview of strategic decision making.

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References

Ahmed, A. H., Bwisa, H., Otieno, R., and Karanja, K. (2014). Strategic Decision Making: Process, Models, and Theories. *Business Management and Strategy*, 5(1):78–104.

Ajamian, G. M. and Koen, P. A. (2002). Technology Stage-Gate: a structured process for managing high-risk new technology projects. In *The PDMA toolbook for new product development*, pages 267–295. John Wiley & Sons, New York.

Andriosopoulos, D., Gaganis, C., Pasiouras, F., and Zopounidis, C. (2012). An application of multicriteria decision aid models in the prediction of open market share repurchases. *Omega*, 40(6):882–890.

Azis, I. J. (1990). Analytic Hierarchy Process in the benefit-cost framework: A post-evaluation of the Trans-Sumatra highway project. *European Journal of Operational Research*, 48(1):38–48.

Balachandra, R. and Friar, J. (1997). Factors for success in R&D projects and new product innovation: a contextual framework. *IEEE Transactions on Engineering Management*, 44(3):276–287.

Behzadian, M., Kazemzadeh, R. B., Albadvi, A., and Aghdasi, M. (2010). PROMETHEE: A comprehensive literature review on methodologies and applications. *European Journal of Operational Research*, 200(1):198–215.

Behzadian, M., Khanmohammadi Otaghsara, S., Yazdani, M., and Ignatius, J. (2012). A state-of the-art survey of TOPSIS applications. *Expert Systems with Applications*, 39(17):13051–13069.

Bian, T. and Deng, Y. (2017). A new evidential methodology of identifying influential nodes in complex networks. *Chaos, Solitons and Fractals*, 103:101–110.

Brans, J. and Vincke, P. (1985). A preference ranking organization method: the PROMETHEE method for MCDM. *Management Science*, 31(6):647–656.

Brans, J. P., Mareschal, B., and Vincke, P. (1984). PROMETHEE: A New Family of Outranking Methods in Multicriteria Analysis. In *Operational Research*, pages 477–490.

Brans, J. P., Vincke, P., and Mareschal, B. (1986). How to select and how to rank projects: The Promethee method. *European Journal of Operational Research*, 24(2):228–238.

Brown, W. A. (2005). Exploring the Association Between Board and Organizational Performance in Nonprofit Organizations. *Nonprofit Management & Leadership*, 15(3):317–339.

Büyüközkan, G. and Ifi, G. (2012). A novel hybrid MCDM approach based on fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS to evaluate green suppliers. *Expert Systems with Applications*, 39(3):3000–3011.

Chai, J., Liu, J. N., and Ngai, E. W. (2013). Application of decision-making techniques in supplier selection: A systematic review of literature. *Expert Systems with Applications*, 40(10):3872–3885.

Chang, B., Chang, C. W., and Wu, C. H. (2011). Fuzzy DEMATEL method for developing supplier selection criteria. *Expert Systems with Applications*, 38(3):1850–1858.

Chao, R. J. and Chen, Y. H. (2009). Evaluation of the criteria and effectiveness of distance e-learning with consistent fuzzy preference relations. *Expert Systems with Applications*, 36(7):10657–10662.

Christiansen, J. K. and Gasparin, M. (2016). Managing Controversies in the Fuzzy Front End. *Creativity and Innovation Management*.

Cohen, L. Y., Kamienski, P. W., and Espino, R. L. (1998). Gate system focuses industrial basic research. *Research-Technology Management*, 41(4):34–37.

Collins, M. and Williams, L. (2014). A three-stage filter for effective technology selection. *Research Technology Management*.

Cooper, B. (2009a). Conversations on the Cutting Edge. *Journal of Product Development*, (April 2007):1–5.

Cooper, R. G. (2006). Managing technology development projects. *Research Technology Management*, 49(6):23–31.

Cooper, R. G. (2007). Managing technology development projects. *IEEE engineering management review*, 35(1):67–77.

Cooper, R. G. (2008). Perspective: The Stage-Gate. pages 213–232.

Cooper, R. G. (2009b). Effective Gating - Make product innovation more productive by using gates with teeth. *Marketing Management*, 18(2):12.

Cooper, R. G. (2009c). How companies are reinventing their idea-to-launch methodologies. *Research Technology Management*, 52(2):47–57.

Cooper, R. G. (2010). Scorecards For Project Selection : Gates 1 & 3 The Seven Forces Profiling Model. *Institute for the sutdy of business markets*, pages 1–6.

Cooper, R. G. (2013). Where Are All the Breakthrough New Products?: Using Portfolio Management to Boost Innovation. *Research-Technology Management*, 56(5):25–33.

Cooper, R. G. (2014). What's Next?: After Stage-Gate. *Research-Technology Management*, 57(1):20–31.

Cooper, R. G. and Edgett, S. J. (2010a). Developing a product innovation and technology strategy for your business. *Research Technology Management.*, 53(3):33–40.

Cooper, R. G. and Edgett, S. J. (2010b). Process : What Best Practice Companies are Doing - Part Two Optimizing the Stage-Gate Process. *Technology Management*, 45(5):256–271.

Cooper, R. G. and Edgett, S. J. (2010c). Process : What Best Practice Companies are Doing - Part Two Optimizing the Stage-Gate Process. *Technology Management*, 45(5):256–271.

Cooper, R. G. and Edgett, S. J. (2014a). Benchmarking Best Practices Performance Results and the Role of Senior Management.

Cooper, R. G. and Edgett, S. J. (2014b). Portfolio Management for New Products : Picking The Winners Portfolio Management for New Products Picking The Winners.

Cooper, R. G., Edgett, S. J., and Kleinschmidt, E. J. (2001). Portfolio management for new product development : Results of an industry practices study portfolio management for new product development : results of an industry practices study. *R&D Management (Industrial Research Institute, Inc.)*, 13(4):1–39.

Creswell, J. W. (2013). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. 4th editio edition.

Cronin, P., Ryan, F., and Coughlan, M. (2008). Undertaking a literature review : a step-by-step approach. 17(1):38–43.

de Oliveira, M. G., Rozenfeld, H., Phaal, R., and Probert, D. (2015). Decision making at the front end of innovation: The hidden influence of knowledge and decision criteria. *R and D Management*, 45(2):161–180.

Dehe, B. and Bamford, D. (2015). Development, test and comparison of two Multiple Criteria Decision Analysis (MCDA) models: A case of healthcare infrastructure location. *Expert Systems with Applications*, 42(19):6717–6727.

Deshmukh, S. C. (2013). Preference Ranking Organization Method Of Enrichment Evaluation (Promethee). *International Journal of Engineering Science Invention*, 2(11):28–34.

Dewey, J. (1911). *How we think*, volume 6.

Dodgson, J. S., Spackman, M., Pearman, A., and Phillips, L. D. (2009). *Multi-criteria analysis : a manual*, volume 11.

Dornberger, U. and Suvelza, A. (2012). *Managing the Fuzzy Front-End of Innovation*.

Drummond, H. (2012). Guide to decision making: getting it more right than wrong.

Edget, S. J. (2014). Innovation : A Critical Capability. *European Busines Review*, January-Fe:10–12.

Edgett, S. J. (2015). Idea-to-Launch (Stage - Gate ®) Model : An Overview. *Stage-Gate International*, pages 1–5.

Edgett, S. J. and Jones, M. (2013). Ten Tips for Successfully Implementing a Stage-Gate ® Product Innovation Process. *Working paper*, pages 1–11.

Edwards, W. (1954). The theory of decision making. *Psychological Bulletin*, 51(4):380–417.

Eisenhardt, K. M. and Zbaracki, M. J. (1992). Strategic Decision Making.

Energy, U. D. o. (2007). Stage-Gate Innovation Management Guidelines: Managing risk through sturctured project decision-making. Technical Report February.

Ernst, H. (2002). Success factors of new product development: A review of the empirical literature. *International Journal of Management Reviews*, 4(1):1–40.

Ernst, H. (2003). Patent information for strategic technology management. *World Patent Information*, 25(3):233–242.

Ferreira, F. A. F. (2013). Measuring trade-offs among criteria in a balanced scorecard framework: possible contributions from the multiple criteria decision analysis research field. *Journal of Business Economics and Management*, 14(3):433–447.

Figueira, J. R., Greco, S., Roy, B., and Slowinski, R. (2010). ELECTRE Methods: Main Features and Recent Developments. *Handbook of Multicriteria Analysis*, 103:51–89.

Figueira, J. R., Mousseau, V., and Roy, B. (2016). ELECTRE methods. *International Series in Operations Research and Management Science*, 233:155–185.

Fülöp, J. (2001). Introduction to Decision Making Methods. *Operations Research*, pages 1–15.

Gade, P. K. and Osuri, M. (2014). *Evaluation of Multi Criteria Decision Making Methods for Potential Use in Application Security*. PhD thesis, Blekinge Institute of Technology.

Gardiner, C. (2010). Evaluation and selection of coagulometers. *International Journal of Laboratory Hematology*, 32(November):1–85.

Gaubinger, K. and Rabl, M. (2013). Structuring the front end of innovation. *Management of the Fuzzy Front End of Innovation*.

Goffin, K. and Mitchell, R. (2016). *Innovation Management: Effective Strategy and Implementation*. Palgrave Macmillan.

Golcuk, I. and Baykasoglu, A. (2016). An analysis of DEMATEL approaches for criteria interaction handling within ANP. *Expert Systems with Applications*, 46:346–366.

Grant, E., Van den Hof, M., and Gold, E. R. (2014). Patent landscape analysis: A methodology in need of harmonized standards of disclosure. *World Patent Information*, 39:3–10.

Grant, R. M. (2012). *Contemporary Strategy Analysis: Text & Cases*, volume 8.

Greco, S., Matarazzo, B., and Slowinski, R. (2001). Rough sets theory for multicriteria decision analysis. *European Journal of Operational Research*, 129(1):1–47.

Heider Fritz, Folkes, V., Koletsky, S., Graham, J., Sherman, S. J., Presson, C. C., Chassin, L., Corty, E., Olshavsky, R., Lau, G., Lee, S., Kelley, H. H., Michela, J. L., Kotsos, B., Weiner, B., Curren, M., Steckel, J., Van der Pligt, J., and Oliver, R. (1958). The Psychology of Interpersonal Relations. *The Journal of Marketing*, 56:322.

Hidalgo, A. and Albors, J. (2008). Innovation management techniques and tools: a review from theory and practice. *R&D Management*, 38(2):113–127.

Högman, U. (2011). *Processes and platforms aligned with technology development - The perspective of a supplier in the aerospace industry.*

Högman, U. and Johannesson, H. (2010). Technology development and normative process models. *11th International Design Conference, DESIGN 2010*, pages 265–274.

Högman, U. and Johannesson, H. (2013). Applying stage-gate processes to technology development - Experience from six hardware-oriented companies. *Journal of Engineering and Technology Management - JET-M*, 30(3):264–287.

Hultgren, A. and Tantawi, A. (2014). Front-End Idea Screening of Potential Radical Innovation in Large Firms. page 112.

Hwang, C.-L., Lai, Y.-J., and Liu, T.-Y. (1993). A new approach for multiple objective decision making. *Computers & Operations Research*, 20(8):889–899.

Ilevbare, I. (2013). *An investigation into the treatment of uncertainty and risk in roadmapping: A framework and a practical process*. PhD thesis, University of Cambridge.

Jugend, D., da Silva, S. L., Oprime, P. C., and Pimenta, M. L. (2015). Organizational issues for integration of high-technology in new product development: Framework proposal and case studies in Brazilian companies. *Innovation: Management, Policy and Practice*, 17(2):217–231.

Kabir, G., Sadiq, R., and Tesfamariam, S. (2014). A review of multi-criteria decision-making methods for infrastructure management.

Kahneman, D. and Tversky, A. (1979). Prospect Theory: An Analysis of Decision under Risk. *Econometrica*, 47(2):263–292.

Kahraman, C., Onar, S. C., and Oztaysi, B. (2015). Fuzzy Multicriteria Decision-Making: A Literature Review. *International Journal of Computational Intelligence Systems*, 8(4):637–666.

Kalbande, D. and Thampi, G. (2009). Multi-attribute and Multi-criteria Decision Making Model for technology selection using fuzzy logic. *Technia-International Journal of . . .*, 2(1):377–383.

Keeney, R. and Raiffa, H. (1993). *Decisions with multiple objectives–preferences and value tradeoffs*, volume 39.

Kerr, C. I., Mortara, L., Phaal, R., and Probert, D. R. (2006). A conceptual model for technology intelligence. *International Journal of Technology Intelligence and Planning*, 2(1):73–93.

Kim, Y. G., Suh, J. H., and Park, S. C. (2008). Visualization of patent analysis for emerging technology. *Expert Systems with Applications*, 34(3):1804–1812.

Koen, P. A., Ajamian, G. M., Boyce, S., Clamen, A., Fisher, E., Fountoulakis, S., Johnson, A., Puri, P., and Seibert, R. (2002). Fuzzy Front End: Effective Methods, Tools, and Techniques. In *The PDMA toolbook for new product development*, chapter 1, pages 2–35. John Wiley & Sons, New York.

Koen, P. A., Bertels, H. M. J., and Kleinschmidt, E. J. (2014). Managing the Front End of Innovation — Part I. *Research Technology Management*, 57(3):34–43.

Kohli, R., Fishman, J., Field, M., and Hyatt, M. (2010). Decision Gate Process for Assessment of a Technology Development Portfolio. *The Aeropsace Corporation, Civil and Commercial Operations Houston Programs*, pages 1–22.

Kolios, A., Mytilinou, V., Lozano-Minguez, E., and Salonitis, K. (2016). A comparative study of multiple-criteria decision-making methods under stochastic inputs. *Energies*, 9(7):1–21.

Korhonen, P. and Wallenius, J. (1990). Using qualitative data in multiple objective linear programming. 48:81–87.

Kurtz, C. F. and Snowden, D. J. (2003). The New Dynamics of Strategy: Sense-making in a Complex-Complicated World. *IBM Systems Journal*, 42(3):462–483.

Lai, Y. J., Liu, T. Y., and Hwang, C. L. (1994). TOPSIS for MODM. *European Journal of Operational Research*, 76(3):486–500.

Lakemond, N., Johansson, G., Magnusson, T., and Safsten, K. (2007). Interfaces between technology development, product development and production: critical factors and a conceptual model. *International Journal of Technology Intelligence and Planning*, 3(3):317.

Lercher, H. (2016). Big Picture Innovation Model Handbook. Technical report.

Lin, C. J. and Wu, W. W. (2008). A causal analytical method for group decision-making under fuzzy environment. *Expert Systems with Applications*, 34(1):205–213.

Liu, Y., Chen, Y., and Tzeng, G. H. (2017). Identification of key factors in consumers' adoption behavior of intelligent medical terminals based on a hybrid modified MADM model for product improvement. *International Journal of Medical Informatics*, 105(November 2016):68–82.

Macharis, C., Mareschal, B., Waaub, J.-p., and Milan, L. (2015). PROMETHEE-GDSS revisited : applications so far and new developments. *International Journal of Multicriteria Decision Making*, 5(1/2):129–151.

Majumder, M. (2015). Impact of Urbanization on Water Shortage in Face of Climatic Aberrations. pages 35–48.

Mardani, A., Jusoh, A., Zavadskas, E. K., Khalifah, Z., and Nor, K. M. (2015). Application of multiple-criteria decision-making techniques and approaches to evaluating of service quality: a systematic review of the literature. *Journal of Business Economics and Management*, 16(5):1034–1068.

Mareschal, B. (1988). Weight stability intervals in multicriteria decision aid. *European Journal of Operational Research*, 33(1):54–64.

Martinsuo, M. and Poskela, J. (2011). Use of evaluation criteria and innovation performance in the front end of innovation. *Journal of Product Innovation Management*, 28(6):896–914.

Marttunen, M., Lienert, J., and Belton, V. (2017). Structuring problems for Multi-Criteria Decision Analysis in practice: A literature review of method combinations. *European Journal of Operational Research*, 263(1):1–17.

Millet, I. and Harker, P. T. (1990). Globally effective questioning in the Analytic Hierarchy Process. *European Journal of Operational Research*, 48(1):88–97.

Mintzberg, H. and Lampel, J. (1999). Reflecting on the strategy process. *Sloan Management Review*, 40(3):21–30.

Mintzberg, H., Raisinghani, D., and Theoret, A. (1976). The structure of 'unstructured' decision processes.

Mitchell, R., Phaal, R., and Athanassopoulou, N. (2014). Scoring methods for prioritizing and selecting innovation projects. *PICMET 2014 - Portland International Center for Management of Engineering and Technology, Proceedings: Infrastructure and Service Integration*, (2001):907–920.

Mitchell, R., Phaal, R., and Athanassopoulou, N. (2017). Scoring methods for prioritising and selecting innovation projects.

Montibeller, G. and Franco, A. (2010). Handbook of Multicriteria Analysis. *Handbook of Multicriteria Analysis*, 103(May 2016):25–44.

Montoya-Weiss, M. M. and Calantone, R. (1994). Determinants of New Product Performance: A Review and Meta-Analysis. *Journal of Product Innovation Management*, 11(5):397–417.

Neumann, J. and Morgenstern, O. (1947). *Theory of games and economic behavior*.

Nickols, F. W. (2015). Strategic Decision Making: Commitment to Strategic Action.

Oliveira, A. (2007). A Discussion of Rational and Psychological Decision-Making Theories and Models : The Search for a Cultural-Ethical Decision-Making Model. *Journal of Business Ethics*, 12(2):1478–82.

Opricovic, S. and Tzeng, G. H. (2002). Multicriteria planning of post-earthquake sustainable reconstruction. *Computer-Aided Civil and Infrastructure Engineering*, 17(3):211–220.

Opricovic, S. and Tzeng, G. H. (2004). Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. *European Journal of Operational Research*, 156(2):445–455.

Opricovic, S. and Tzeng, G. H. (2007). Extended VIKOR method in comparison with outranking methods. *European Journal of Operational Research*, 178(2):514–529.

Papadakis, V. M., Lioukas, S., and Chambers, D. (1998). Strategic decision-making processes: The role of management and context. *Strategic Management Journal*, 19(2):115–147.

Phaal, R. (2015). Roadmapping for strategy and innovation. *Centre for Technology Management*, 47(March):1–7.

Phaal, R., Routley, M., Athanassopoulou, N., and Probert, D. (2012). Charting Exploitation Strategies for Emerging Technology. *Research-Technology Management*, 55(2):34–42.

Project Management Institute (2013). *A guide to the project management body of knowledge (PMBOK ® guide)*.

Robson, C. (2011). Real world research. *Edition. Blackwell Publishing. Malden*, pages 1–608.

Roy, B. (1991). The outranking approach and the foundations of electre methods. *Theory and Decision*, 31(1):49–73.

Saaty, T. L. (1990a). How to make a decision: The analytic hierarchy process. *European Journal of Operational Research*, 48(1):9–26.

Saaty, T. L. (1990b). Physics as a decision theory. *European Journal of Operational Research*, 48(1):98–104.

Savage, L. J. (1954). *The Foundations of Statistics*. New York, Wiley.

Shieh, J.-I., Wu, H.-H., and Huang, K.-K. (2010). A DEMATEL method in identifying key success factors of hospital service quality. *Knowledge-Based Systems*, 23(3):277–282.

Simon, H. A. (1946). *Administrative Behavior. A Study of Decison- Making Processes in Administrative Organizations*.

Simon, H. A. (1961). The New Science of Management Decision.

Simon, H. a. (1993). Decision Making: Rational, Nonrational, and Irrational. *Educational Administration Quarterly*, 29(3):392–411.

Snowden, D. J. and Boone, M. E. (2007). A leader's framework for decision making.

Soenksen, L. R. and Yazdi, Y. (2016). Stage-gate process for life sciences and medical innovation investment. *Technovation*, 62-63(August 2016):14–21.

Songa, S., Renb, Y., and Sampsonb, P. (2010). Probability Scoring and Uncertainty Modeling in Multi-Criteria Decision Analysis. *Stat.Washington.Edu*, (620):1–17.

Stanovich, K. E. and West, R. F. (2000). Individual differences in reasoning: implications for the rationality debate? *The Behavioral and brain sciences*, 23(5):645–665.

Triantaphyllou, E. and Shu, B. (1998). Multi-criteria decision making: an operations research approach. *Encyclopedia of Electrical and Electronics Engineering*, 15:175–186.

Tseng, Y. H., Lin, C. J., and Lin, Y. I. (2007). Text mining techniques for patent analysis. *Information Processing and Management*, 43:1216–1247.

Turpin, S. M. (2004). Decision-making : Theory and practice. 20(2):143–160.

Ullman, D. (2002). The Ideal Engineering Decision Support System. *Retrieved March*, 10:2009.

Verbano, C. and Nosella, a. (2010). Addressing R&D investment decisions: A cross analysis of R&D project selection methods. *European Journal of Innovation Management*, 13(3):355–379.

Weiner, B. (1972). Attribution Theory, Achievement Motivation, and the Educational Process. *Review of Educational Research*, 42(2):203–215.

Williams, C. (2010). Decision Theory. *October*, (October):1–94.

Wu, W. W. (2008). Choosing knowledge management strategies by using a combined ANP and DEMATEL approach. *Expert Systems with Applications*, 35(3):828–835.

Wu, W. W. and Lee, Y. T. (2007a). Developing global managers' competencies using the fuzzy DEMATEL method. *Expert Systems with Applications*, 32(2):499–507.

Wu, W. W. and Lee, Y. T. (2007b). Developing global managers' competencies using the fuzzy DEMATEL method. *Expert Systems with Applications*, 32(2):499–507.

Xu, L. and Yang, J.-b. (2001). Introduction to multi-criteria decision making and the evidential reasoning approach. *Isbn*, (0106):1–21.

Yeh, C.-H. (2002). A Problem-based Selection of Multi-attribute Decision-making Methods. *International Transactions in Operational Research*, 9:169–181.

Zahedi, F. (1990). A method for quantitative evaluation of expert systems. *European Journal of Operational Research*, 48(1):136–147.

Zavadskas, E. K. and Turskis, Z. (2011). Multiple criteria decision making (MCDM) methods in economics: an overview. *Technological and Economic Development of Economy*, 17(2):397–427.

Zavadskas, E. K., Turskis, Z., and Kildienė, S. (2014). State of art surveys of overviews on MCDM/MADM methods. *Technological and Economic Development of Economy*, 20(1):165–179.

Zemlickienė, V., Mačiulis, A., and Tvaronavičienė, M. (2017). Factors impacting the commercial potential of technologies: expert approach. *Technological and Economic Development of Economy*, 23(2):410–427.

Zopounidis, C. and Doumpos, M. (2002). Multicriteria classification and sorting methods: A literature review. *European Journal of Operational Research*, 138(2):229–246.