Wiley Series in Operations Research and Management Science

HANDBOOK OF DECISION ANALYSIS

Second Edition

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Eric R. Johnson, Steven N. Tani, Eric Specking

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Handbook of Decision Analysis

Wiley Series in
OPERATIONS RESEARCH AND MANAGEMENT SCIENCE

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Handbook of Decision Analysis

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Foreword to the 1st Edition

This handbook represents a significant advance for decision professionals. Written for practitioners by practitioners who respect the theoretical foundations of decision analysis, it provides a useful map of the tools and capabilities of effective practitioners. I anticipate that this and future editions will become the primary repository of the body of knowledge for practicing decision professionals.

This Handbook Is Timely

The practice of decision analysis (DA) is at a major inflection point. That high-quality decisions can generate immense value is being demonstrated again and again. Leaders of organizations are increasingly aware of how opportunities are lost by making "satisficing" decisions – that is, decisions that are "good enough." The benefit-to-cost ratio of investing in better decisions is frequently a thousand to one. I know of no better opportunity for value creation anywhere. As Frank Koch,[1] president of the Society of Decision Professionals (SDP), has said, "Benefit to cost ratios ... are immense simply because the added cost of doing DA is negligible. We would still be paying the analysts and decision makers without DA; they would simply be talking about different things. The incremental cost of having a better, more relevant conversation is zero, so regardless of the benefit, the ratio is infinite! Even if I throw in the cost of training and learning some software, that's measured in thousands and the benefits are clearly measured in millions."

Why is this huge opportunity still a secret from most decision makers? It is because we humans are wired to believe that we are making good decisions even when we leave value on the table. We are wired to be satisfied with good enough. We shape our memories with hindsight and rationalization. The burgeoning set of literature from the behavioral decision sciences documents many of our biases and draws attention to the gap between true decision quality (DQ) (see Chapter 5) and our natural decision-making tendencies.

Our individual cognitive biases are amplified by social behavior, like groupthink. We assume that advocacy decision processes in use by most organizations produce good decisions, yet they are designed to suppress good alternatives. We assume that agreement is the same as DQ, yet we see a lot of agreement around nonsense. It is not uncommon to hear statements like, "I can't believe it – what were we thinking?"

1 Frank Koch in a written response to the question: What is the ROI of investing in DA based on your experience at Chevron? Frank Koch retired in 2010 after the Chevron team had been awarded the best practice award for *20 Years of DA at Chevron*.

If DQ can create immense additional value in specific decisions, can we develop DQ as an organizational competence? The answer is yes, and Chevron has shown the way. Over the period in which it has implemented a deep and broad adoption of DQ, Chevron has outperformed its peer group of major oil companies in creating shareholder value. While many organizations have pockets of organizational decision quality (ODQ), to my knowledge, Chevron has the broadest and deepest adoption to date. And by "adoption," I don't just mean better analytics. All the major oil companies have the analytics to address uncertainties and risk. The difference is that the whole Chevron organization seems to be in a passionate and collaborative pursuit of value creation based on quality decisions linked with effective execution. I believe that Chevron's success is the beginning of a big wave of broad adoption of organizational DQ.[2]

The immense value left behind by our satisficing behaviors represents the biggest opportunity for our business and societal institutions in the coming decades. If we begin to think of these opportunity losses as an available resource, we will want to mine this immense value potential. The courts – led by the Delaware Supreme Court – are raising the bar in their interpretation of a board director's duty of "good faith." In the coming years, board and top management's best defense is their documented practice of DQ.

Decision Professionals: The Practitioner Perspective

The SDP[3] states that the mission of decision professionals is to:

- Bring DQ to important and complex decisions.
- Provide quality insights and direction through the use of practical tools and robust methodologies.
- Promote high professional standards and integrity in all work done by decision professionals.
- Advance the profession to the benefit of mankind through helping decision makers.

The role of a decision professional as a practitioner of DA and facilitator of organizational alignment is gaining acceptance. Dozens of organizations have established internal groups of professionals, designed career ladders, and developed specific competency requirements. The recently formed SDP has created a certification process and career ladder that specifies increasing competency levels for practitioners.

While there are important similarities between becoming a successful practitioner and becoming a tenured academic, there are also major differences. The decision professional is motivated by bringing clarity to complex decision situations and creating value potential in support of decision makers. He or she is less interested in the specialization required for peer-reviewed publication. Instead, the practitioner wants to acquire practical tools and relevant skills that include both analytical and facilitation skills (project management, conflict resolution, and other so-called "soft skills").

The ability to address both organizational and analytical complexity (see Figure F.1) are of great importance to the practitioner. As I like to say, "If you can only deal with the analytical complexity, you can get the right answer – but nobody cares. If you can only facilitate in the face of organizational complexity, you can resolve conflicts and gain agreement – but it can be agreement around

2 See the SDG white paper, *Chevron Overcomes the Biggest Bias of All* (Carl Spetzler, 2011). Available from SDG website, http://www.sdg.com.

3 See: http://www.decisionprofessionals.com.

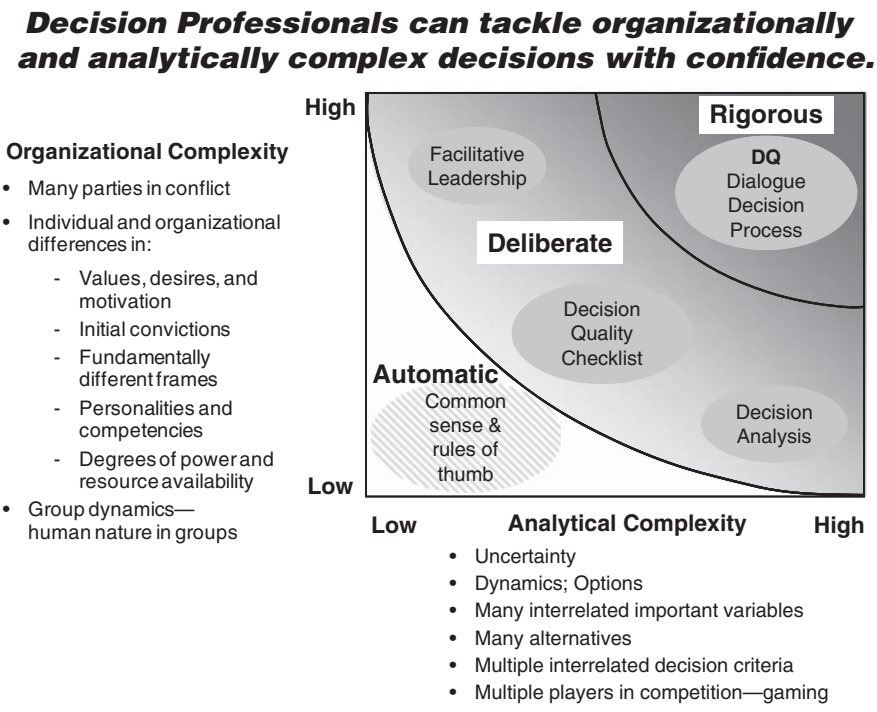

Figure F.1 Two Dimensions of Competence.

nonsense." To bring full value, we need to deliver the combination – agreement around the best answer, the answer that generates the greatest value potential.

Individual decision professionals can deliver this if they have the competency in both areas. However, many practitioners are significantly better in one or the other – either strong analytical capabilities or strong social/emotional intelligence and facilitation skills. Therefore, many practitioners find it best to team up with others to deliver the full value of DQ. To make such teaming effective, there must be mutual respect for the other competency and a recognition that value creation from the combination is the goal. It bears repeating: We need to gain alignment around the best answer – the answer that creates the greatest value potential.

As practitioners, we are always approximating and simplifying. We are practical decision engineers and decision facilitators who want robust solutions that are effective in creating a lot of potential value. We are organizational facilitators who are not satisfied unless the best decision is owned by the decision makers and implementers. Incisiveness with tools that produce insight and processes that foster effective engagement is more important to us than another refinement to the axioms of normative decision theory. In my experience, the academic debates at the edges of decision science over the last two decades have contributed surprisingly little to the practice. Seldom is the primary challenge in solving real decision problems a matter of advanced theory.

Our goal should be to make our concepts and methods as simple and accessible as possible. As I am writing this, I am participating in a 2-week program to teach incoming high school freshmen the basics of DQ and help them apply the concepts to significant school decision projects. I recommend that all decision professionals become engaged with spreading decision skills to youth[4] for the simple reason that it will make one a better decision professional. Senior executives and ninth

4 Check out the Decision Education Foundation at http://www.decisioneducation.org.

graders have about the same attention span (albeit for different reasons) and want to get to the essence simply and clearly. Even when we employ advanced tools, our results should always be made transparent.

Our Profession

What does it mean to be in a profession? A profession differs from a trade. In providing a professional service, we recognize that the customer cannot fully judge our service and must trust the integrity of the professional to act in the customer's best interest – even when the customer does not wish to hear it. Our customers are the decision makers – the leaders of organizations. We have the responsibility to speak "truth to power."

We also have the obligation to not "fake it." Decision professionals must be able to recognize which tools are normative (that is consistent with the norms of decision theory) and which are not but may be useful in practice. We also have to recognize destructive or limited practices. A true decision professional avoids making claims that can be proven to violate the basic norms of decision theory.

As with the medical field, we have to protect our profession from quackery. The profession is beginning to step up to this challenge, taking measures to assure quality and certify competence. This is, of course, a sensitive area in a field that incorporates science, art, and engineering. While I recognize the risks of trying to come to agreement on a definition of decision competence, I support this trend fully and applaud the start that the SDP has made.

The Biggest Challenge

In this nascent profession, our biggest challenge is to gain greater mindshare among decision makers. The fraction of important and complex decisions being made with the support of decision professionals is still very small. We can make faster progress if we unify our brand and naming conventions. I urge all practitioners to use a common language to make more headway with our audiences.

Here are my suggestions:

- Let's call ourselves "decision professionals" instead of decision analysts, decision consultants, decision advisors, decision facilitators, and so on.
- Let's use the term "decision quality" as the overall name that combines getting to the right answer via DA and gaining organizational alignment via process leadership, decision facilitation, and other soft skills.
- Let's refer to DA as the field that provides decision professionals with the analytical power to find the best alternative in situations of uncertainty, dynamics, complex preferences, and complex systems. The use of the term "DA" also means we will be consistent with the norms of decision theory – usually with a single decision-making body – whose preferences are aligned.
- Multiparty decisions – negotiation, collaboration, competition (game theory) – need to become a part of the decision professional's domain of expertise, whether or not these areas are considered a subset of or adjacent to DA.
- Decision professionals frequently act as mediators and facilitators with "soft skills" to lead decision processes to reach sound conclusions and to gain alignment and commitment for action.

While these skills are not usually considered a part of DA, they are as crucial as model building to the decision professional.

On behalf of the profession, I would like to express my gratitude to Greg Parnell, Steve Tani, Eric Johnson, and Terry Bresnick for creating this handbook. This handbook represents a valuable contribution to the practitioner community. I expect that it will be the first edition of many to come.

Carl Spetzler

Foreword to the 2nd Edition

William J. Perry, former Secretary of Defense, holds a bachelor's, master's, and Ph.D., all in mathematics, but does not wear these credentials on his sleeve. At a university gathering after his retirement from the Pentagon, he was asked whether he had created mathematical models on the spot to aid in defense decisions on emergent issues. "No," he replied, "there was never the time or the data to do that, but because of my training, I think differently about these issues." Amen. Perhaps the greatest benefit of Decision Analysis (DA) is in terms of changing the way we think.

The first edition of this book was published in 2013 with an excellent foreword by Carl Spetzler, so what has changed since then? Plenty, as it turns out, in the form of technology, which makes DA more important than it was yesterday, and less important than it will be tomorrow. In this regard, I will consider the impact on DA of Ubiquitous Computer Power, Big Data on the Internet, and Artificial Intelligence. From the perspective of someone who has been exposed to DA for seven decades, each of these has changed how I think about the subject.

I got into DA on the ground floor in 1952, when my father, Leonard Jimmie Savage, referenced in Chapter 3 of this book, attempted to explain his axioms of decision theory in terms that a seven-year-old (me) would understand. I can't recall how many discussions at the dinner table in the ensuing years involved uncertainty, statistics, and decisions, but I aced my undergraduate courses in probability and statistics. This was despite a very spotty academic record overall, which I shared with my father. I took a single DA course in graduate school, and then in the mid-1990s, as an adjunct professor at Stanford, had the great fortune to sit in on Ron Howard's course on DA. Like others I know who took this course, it was a turning point in our lives. Ron had the ability to state simple obvious truths that, oddly, I had never thought about before but would never forget thereafter. I continue to be involved in decision-making in the face of uncertainty, through teaching, consulting, and the development of standards and software in this area.

Ubiquitous Computer Power

I will start with a quote from my father's 1954 book, *The Foundations of Statistics*. He describes a theory of rational decision-making based on the principle that *people will correctly assess uncertainties* and *make rational decisions to maximize their expected gain*. But then he says that from a practical point of view:

> … the task implied in making such a decision is not even remotely resembled by human possibility. It is even utterly beyond our power to plan a picnic or to play a game of chess in accordance with the principle …

This may be jarring to today's DA practitioner, but at the time he wrote this there were on the order of 100 computers in the United States, each in its own large building. Had he lived to see a computer declared the world chess champion in 1997, no doubt based on the principles of DA, I am sure he would have modified this statement. In fact, in 1970 he recognized that the cost of computation would become a factor in future systems of statistical thought. In the decade after his death in 1971, computational statistics extending Julian Simon's approach to resampled data, and Brad Efron's Bootstrap became cornerstones of this approach. Not coincidentally, DA has been moving away from decision trees and toward Monte Carlo Simulation, although I believe both are important and should be integrated when possible. As further evidence of ubiquitous computer power, today, native Excel, with its roughly one billion users, can perform tens of thousands of Monte Carlo trials before the user's finger leaves the enter key. Chapter 11 of this book takes advantage of these developments to bring interactive simulation to students of DA in a form they can easily take with them to the workplace to help their organizations *make rational decisions to maximize their expected gain*.

Big Data on the Internet

Big data on the Internet has had a profound effect on helping *people to correctly assess uncertainties*.

1) Prediction Markets
   My father's book took the position that probabilities were subjective and could ultimately be elicited by gambles that people were willing to make around uncertain events. Such wagers on sporting outcomes may date back to the dawn of civilization. Today, prediction markets on the Internet extend this concept beyond the realm of sports to events in areas as diverse as politics, economics, medicine, science, and corporate decision-making. They bring the wisdom of crowds to assessing uncertainties in a way that my father would have applauded but could not have dreamt of.
2) Smartphones
   Smartphones have revolutionized the way we gather and consume information. For example, cities used to spend many thousands of dollars hiring people to drive over their street network and report potholes. Today, we may harness the gravitometers in phones in thousands of cars, which when coupled to their GPS coordinates can accomplish in hours what used to take days. And as to planning picnics? I just discovered a phone app called Next Picnic, which helps you discover picnic and barbecue spots in nature, complete with real-time weather updates to plan your activities accordingly. It also allows users to rate and review locations, enhancing the planning experience. This app along with online weather information could certainly inform a decision analytic picnic decision.
3) Communicating Uncertainty with Stochastic Data
   Borrowing from techniques developed in the 1980s in the financial engineering and insurance industries, data containing the results of Monte Carlo simulations may be stored on the web and shared between simulations to aggregate results in portfolio decisions as discussed in Chapter 12. Furthermore, recent mathematical techniques have resulted in a massive compression of such data, greatly increasing its flexibility and applicability.

Artificial Intelligence

This represents the future of DA, to which the contents of this book nonetheless apply. The only prediction we can make about AI in 2025 is that its evolution will be unpredictable. However, I believe that AI is already providing important opportunities for DA. I have listed a few that come to mind.

1) Extracting Probabilities from AI
   a) General statistical knowledge
      We are already at the stage where you can ask a Chatbot to provide parameters of probability distributions on subjects as diverse as how many bottles of wine to purchase for a party, to the distribution of remaining years of life for a person of specified age and gender. In some cases, the AI may even run a Monte Carlo simulation without being asked, to generate a probability distribution. How accurate is it? Who knows, but it is getting smarter at an alarming rate, and DA professionals must learn to master and validate this new source of probabilities.
   b) The Residual Errors of Machine Learning
      Machine learning dates back to the famous mathematician Gauss, who used least squares regression to make predictions about astronomical data. And like the machine learning of today, it involved creating a predictive model with residual errors, which estimate the accuracy of the model itself. DA professionals need not become experts in machine learning themselves. However, they should view it as a potentially rich source of probabilities.
2) The Value of AI
   An extremely important concept in DA is the value of information. That is, what would it be worth economically to learn today whether or not event E will occur tomorrow. If one learns definitively this is known as the value of perfect information. But if, like a weather forecast, it is sometimes wrong, it is known as imperfect information. Now think of AI as a generalization of a weather forecast. It will be important for the DA professional to learn to use AI and to evaluate the accuracy of its predictions in a rapidly evolving environment.
3) Autonomous Systems – Meta Decision Analysis
   We are well into the era of autonomous systems. That is, we are making design decisions about systems that will make their own decisions! I will call this Meta Decision Analysis until someone comes up with a better term. Here are some examples.
   a) Autonomous Cars
      Autonomous cars must make decisions such as, "Do I run over the three kids waiting for the school bus or do I slam my own driver into a tree to avoid hitting the kids?" I hope decision analysts are consulted in the design of such systems.
   b) Autonomous Military Systems
      Autonomous military systems such as swarms of drones will inevitably not always be under the direct control of a human. In fact, one can imagine a ratio of autonomous systems to humans of 10 to 1 or perhaps even 100 to 1. Good decision analysis will be vital to designing the autonomous decision capability of such systems.

Far from making DA obsolete, current technological advances are making it mandatory. And the material in this book is as relevant to the future of DA as it was to the past.

Preface

Our Decision Analysis Handbook 2nd Edition is written for the decision professional. Decision analysts work in many industries and government agencies; many work in oil and gas firms, pharmaceutical firms, and military/intelligence agencies. The target audience is the decision analysis practitioner who wants to increase the breadth and depth of his or her technical (concepts and mathematics) and soft skills (personal and interpersonal) required for success in our field. We assume the reader has a technical (engineering, science, mathematics, or operations research) or a business degree; a course in probability and statistics (Appendix A provide a probability review); and, perhaps, some introduction to single or multiple objective decision analysis in a college course or a professional short course. The book is not designed to introduce new decision analysis mathematics but rather to make the most common mathematics and best practices available to the practitioner.

The handbook is designed as a text for an undergraduate or graduate course in decision analysis, as a supplemental reading for professional decision analysis training courses, or as a reference for beginning and experienced practitioners. The 2nd edition now has a New Product Development NPV case study and a Data Center location case study including screen shots of Excel and Excel Addin Software solutions. The book should be useful to both domestic and international practitioners.

Another new feature of the 2nd Edition is the emphasis on the use of big data, analytics and artificial intelligence in decision analysis and the use of decision framing tools in data analytic decision problems.

Our handbook describes the philosophy, technical concepts, mathematics, and art of decision analysis for the decision professional. The handbook includes chapters on the following topics: decision making challenges; mathematical foundations of decision analysis; decision analysis soft skills, selecting the decision making process for interacting with decision makers and stakeholders; framing the decision; crafting decision objectives; designing creative alternatives to create value; performing deterministic modeling and analysis of alternatives; assessing uncertainty; performing probabilistic modeling and analysis; portfolio decision analysis; communicating with senior decision makers; and implementing decisions.

Figure P.1 provides the organizational structure to the book. Chapter 1 provides an introduction to decision analysis. Chapters 2–4 provide the foundational knowledge required for decision analysis success. Chapters 5–14 provide the decision analysis best practices to create value as sequential, iterative steps. However, the order of the steps should be tailored to the application and some steps may not apply. For example, if the decision is a choice of the best alternative, the portfolio decision analysis chapter would not apply. Also, some steps can be combined. For example, the decision

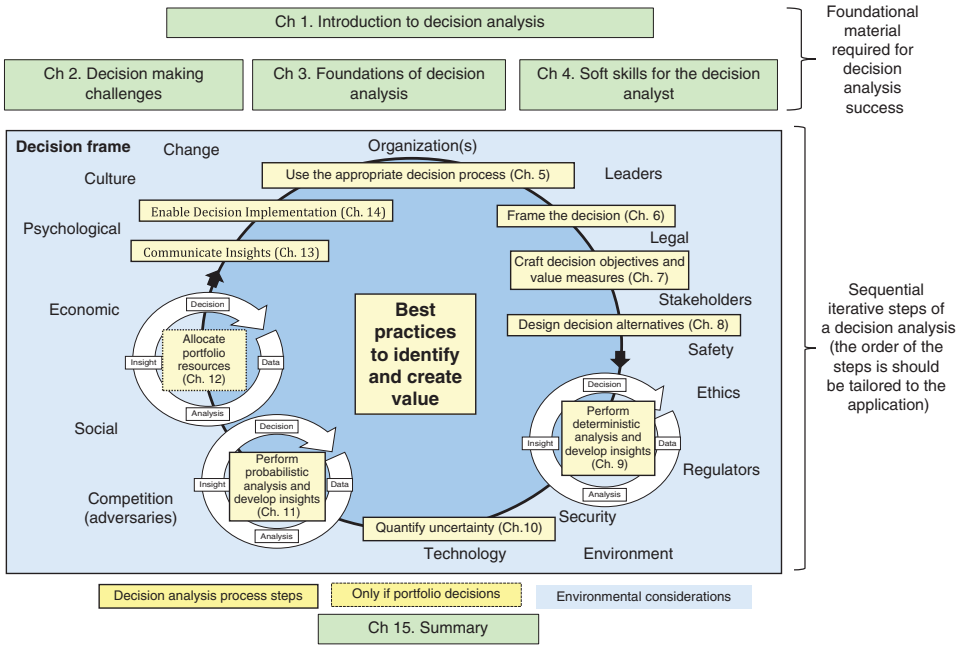

Figure P.1 Chapter organization of the *Decision Analysis Handbook*.

framing and crafting of the decision objectives may be done at the same time. Chapter 15 provides a summary of the major themes of the book.

The book also includes key insights from decision analysis applications and behavioral decision analysis research. The handbook references decision analysis textbooks, technical books, and research papers for detailed mathematical proofs, advanced topics, and further professional reading.

The handbook has five unique features.

1) The book provides a balanced presentation of technical skills (decision analysis concepts, mathematics, and modeling) and of soft skills (strategic thinking. leading teams, managing teams, researching, interviewing individuals, facilitating groups, and communicating).
2) The book integrates the techniques of single and multiple objective decision analysis instead of presenting them in separate sections of the book. Chapter 3 provides our framework.
3) The book uses four substantive illustrative examples (TechnoMagic New Product Development, Data Center Location, Geneption Personalized Medicine, and Roughneck North American Strategy (in Appendix D)) to illustrate the key decision analysis concepts and techniques; show the diversity of applications, and demonstrate how the techniques are tailored to different decision problems.
4) The book presents multiple qualitative and quantitative techniques for each key decision analysis task as opposed to presenting one technique for all problems. After describing the techniques, we discuss their advantages and disadvantages.
5) Wiley provides a website (www.wiley.com/go/Decision_Analysis_2e) for the handbook. This website will updated information on the book, Power Point slides for instructors, and the Excel files used in the textbook for instructors and students.