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Ethical Issues in Engineering Models

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Publication date:
2010

[Link to publication in Tilburg University Research Portal](#)

Citation for published version (APA):

Kleijnen, J. P. C. (2010). *Ethical Issues in Engineering Models: Personal Reflections*. (CentER Discussion Paper; Vol. 2010-09). Operations research.

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No. 2010–09

**ETHICAL ISSUES IN ENGINEERING MODELS: PERSONAL
REFLECTIONS**

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January 2010

ISSN 0924-7815

Ethical issues in engineering models: personal reflections¹

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14 January 2010

Abstract

I start this contribution with an overview of my personal involvement—as an Operations Research consultant—in several engineering case-studies that may raise ethical questions; these case studies employ simulation models. Next, I present an overview of the recent literature on ethical issues in modeling, focusing on the validation of the model's assumptions; the decisive role of these assumptions leads to the quest for robust models. Actually, models are meant to solve practical problems; these problems may have ethical implications for the various stakeholders; namely, modelers, clients, and the public at large. Finally, I briefly discuss whistle blowing.

Keywords: ethics, code of conduct, stakeholders, validity, risk analysis, simulation, operations research

JEL: Z00, Z13

¹ The first version of this paper was prepared for the symposium titled “Ethical Issues in Modelling and Simulation”, organized at the occasion of the retirement of professor Maurice Elzas in Wageningen (the Netherlands) on 2 July 1999. Next I updated the original version when Sjoerd Zwart (Delft University of Technology) invited me to speak at the “Workshop on Ethical Modeling” in Delft on 11-12 January 2010, at the occasion of the farewell of the Vice Chancellor (Rector Magnificus), Professor Jacob Fokkema; see <http://www.tbm.tudelft.nl/live/pagina.jsp?id=8fd53f3a-8c78-498e-ad09-b26ba9b2f486&lang=nl>). I acknowledge comments on preliminary versions from Rengga Kharisma (Institut Teknologi Bandung, Indonesia), Tuncer Ören (University of Ottawa, Canada), and Sjoerd Zwart (Delft).

1. Introduction

I like to start with a confession: I am neither an engineer nor a philosopher! But then the organizer hinted that most philosophers lack practical engineering experience. And though my personal education was in business and economics, I did work together with quite a few engineers, on a variety of specific practical problems that—on hindsight—did imply serious ethical questions. Despite the (French) expression “he who excuses himself, accuses himself”, I’d like to further explain my excuse.

Let me give an example of an *engineering model* in which I was involved personally—as a consultant. I dare claim that Figure 1 looks like an engineering model of a modern man-made artifact. Actually, this figure is a static model of the so-called *Waste Isolation Pilot Plant* (WIPP), built near the town of Carlsbad in New Mexico (NM), USA. The client (patron) is the Environmental Protection Agency (EPA) of the Department of Energy (DOE). The consultant is Sandia National Laboratories in Albuquerque (NM). The other stakeholders become clear when I point out that the WIPP stores *nuclear waste*. This waste might leak away from the WIPP to the surface (this “plant” resembles an underground coal or salt mine, as it includes a “waste shaft”—see the same words in Figure 1—that is dug into the earth). Such leakage may endanger the health of human beings, so *ethical* issues certainly play a role! More precisely, not only the people now living near Carlsbad are at risk: future generations are at risk too. Therefore the criterion is the chance of leakages in the next 10,000 years; this time horizon is required by the EPA. Note that the local population also enjoys the benefits of new employment and business opportunities!

Actually, the waste stored in this WIPP consists of garments worn by medical personnel while treating cancer patients. So besides the risks and benefits for the people living in Carlsbad and other places now and in the future, there are the benefits of these patients. The simulation model quantifies the chance of nuclear leakage, but does not balance the costs and benefits of all the different stakeholders! (I shall return to the role of stakeholders.)

Note that the WIPP model is much bigger than Figure 1 alone; i.e., the model includes many nonlinear differential equations plus some stochastic (random or chance) processes (namely, so-called Poisson processes). This model simulates the physical, chemical, and human processes that may occur when a WIPP is built according to the construction specifications in Figure 1. For more details I refer to Helton (2009) and also Kleijnen and Helton (1999).

Let me briefly expand this example, beyond my personal experience. Currently, a different WIPP is being modeled; namely, a WIPP for the waste created by the production of *atomic bombs* (this WIPP may be built in the Yucca Mountains in Nevada). The design and production of such bombs raises different ethical questions (a personal experience was my visit to the exhibition on the first two atomic bombs, dropped in Japan; this exhibition is in Albuquerque, New Mexico; see <http://www.nuclearmuseum.org/>).

The rest of this article is organized as follows. Section 2 discusses some more case studies with ethical implications in which I was personally involved. Section 3 reviews codes of conduct in several engineering subdisciplines and in other sciences including Operations Research; it emphasizes that the validity of models (including simulation models) depends on the model assumptions. Section 4 reviews recent literature on ethics in modeling, and the related issues of model validation, risk analysis, and robust models. Section 5 examines ethical aspects of models used in war and peace; it also discusses computer games. Section 6 briefly discusses some cases of whistle blowing. Section 7 gives some conclusions. The article finishes with many references that facilitate further study of ethics and modeling.

2. More “personal” case studies

Besides the WIPP discussed in the Introduction, there are more engineering models in which I have been involved—and that may raise ethical questions. One case originated in Delft, where Lombaers (one of my former Ph.D. supervisors) requested my help in the scientific evaluation of a simulation model for the project planning of the *storm surge barrier* in the Dutch province called Zeeland (see <http://www.neeltjejans.nl/index.php/en/home>). At that time the construction of this novel type of dike had just started; many challenging engineering questions arose; e.g., should this barrier be built starting from the South to the North across the Easter Scheldt estuary, or starting from the North, or starting from both sides simultaneously? I do not remember whether at that time any ethical questions were raised; maybe the memory of nearly 2000 people who drowned in 1953 was too vivid? Nowadays, however, I would wonder how to balance the values of stakeholders such as fishermen, local inhabitants, and tourists.

Another “personal” engineering case-study is the search for *explosives* (mines) on the bottom of the sea, deploying sonar. The goal of this study is the quantitative evaluation of various tactical and operational strategies of the Dutch navy (the client), such as the tilt angle of the sonar and the ship’s

course—given the environment (the mine field, the water temperature and salinity, the type of sea bottom, the operator’s behavior). To answer these questions, a simulation model was developed by TNO/FEL, the largest Dutch research organization (see <http://www.tno.nl/index.cfm>). The technical problem that I examined is how to determine the validity of the model? For more details, I refer to Kleijnen (1995a).

Obviously, any *military* model raises ethical questions, because the goal of the military is to eliminate the “bad guys”, “terrorists”, or “aggressors” (but remember the definition of “aggressive weapons”: weapons in the hands of the opponent).

A recent urgent worldwide problem—that also involves engineers and has ethical implications—is *global warming* (the recent Copenhagen conference did not solve this problem). The Dutch “National Institute for Public Health and the Environment” (in Dutch: RIVM) developed a simulation model for this problem. Like in the WIPP example, the issue is the survival of future generations; that survival requires a *sustainable* world. My students and I helped RIVM with the validation of their model, and the selection of the really important factors (namely, 15) among the many (281) potential factors; see Bettonvil and Kleijnen (1996), and Kleijnen, van Ham, and Rotmans (1992).

A final personal example concerns *milk robots*; i.e., cows are milked by robots instead of farmers. Clearly, besides human welfare we should consider animal welfare. Dutch parliament does have a Party for the Animals (PvdD; see www.pvdd.nl/).

3. Ethical codes and models in engineering and other sciences

Given the case studies discussed in the preceding two sections, I agree with the following definition of engineering in Wikipedia (<http://en.wikipedia.org/wiki/Engineering>: “*Engineering* is the discipline, art and profession of acquiring and applying technical, scientific and mathematical knowledge to design and implement materials, structures, machines, devices, systems, and processes that safely realize a desired objective or inventions.”

Wikipedia further discusses “engineering ethics” in detail in http://en.wikipedia.org/wiki/Engineering_ethics. This discussion includes *codes of ethics* of the American Society of Civil Engineers (ASCE), the National Society of Professional Engineers (NSPE), American Society of Mechanical Engineers (ASME), Institute of Electrical and Electronics Engineers (IEEE), and American Institute of Chemical Engineers (AIChE).

In the Netherlands, the Royal Institute of Engineers (KIVI NIRIA) also has a code of conduct (see <http://www.kiviniria.net/CM/PAG000002106/Gedragcode.html>).

Because I am not an engineer, I will not further discuss these ethical guidelines published by various engineering organizations. Instead, I will reflect on ethical issues in engineering models, from my personal perspective—as a human being and a scientist active in *Operations Research* (OR). Actually, OR is a rather fuzzy area of science (see <http://www.informs.org/>); some well-known OR methods are Linear Programming (LP), Markov models, and simulation. Several other contributors to this workshop (e.g., Le Ministrel and Van Wassenhove 2010) focus on ethics and OR models.

So, besides engineering models, there are other types of models. For example, personally I have been involved in simulation studies that model the logistics of modern *education* at a particular level of Dutch secondary schooling (in Dutch, this type is called “ROC”). Another project was the quantification of the costs and benefits of changing specific *social laws* (also see the next section)?

OR does not have its own code of ethics—but closely related disciplines do; namely, the American Statistical Association (ASA)—see <http://www.amstat.org/index.cfm>—the Association for Computing Machinery (ACM) —<http://www.acm.org/about/code-of-ethics>—the Society for Computer Simulation (SCS)—see <http://www.scs.org/ethics/> (which lists various organizations that have accepted the SCS code; e.g. NATO). ASA’s code emphasizes *model validation*. This emphasis is also found in some of my own publications; see Halachmi et al. (2001), Kleijnen (2000, 1999, 1995a, 1995b), Kleijnen, Cheng, and Bettonvil (2001). References to older publications on ethics and OR models are given in my previous article, Kleijnen (2001); my present contribution updates that older article. Gass (2009) also discusses several ethical codes, while focusing on OR. *Codes of conducts* in *non-engineering* disciplines—such as law, medicine, psychology, and social sciences—are discussed by Gustafsson, Hermerén, and Petersson (2005), Kleijnen (2001) and White (2009). (Currently the electronic patient file and its threat to privacy is the topic of political debate in the Netherlands.) Codes of ethics in many disciplines are surveyed on <http://www.scs.org/ethics/addlInfo.html#Codes> .

Obviously, a mathematical model itself has no morals; it is an abstract, mathematical entity that belongs to the immaterial world. Such a model reflects an existing or planned system in the real world; the goal of this modeling is to solve a problem in that world. That *goal* may have ethical implications; e.g., a model meant to increase the profits of a heroin dealer has moral aspects

Any model—be it mathematical or mental—is based on particular simplifying *assumptions*; e.g., it assumes linear equations with specific parameter values. Hence, the model’s results (output) are valid

if those assumptions hold. So the crucial question arises: What happens when these assumptions do not hold? Often the answer remains unknown, because the modelers do not investigate this question thoroughly; maybe their clients like the answers that the model gives. Yet, an old saying in computer science is “Garbage In, Garbage Out (GIGO)”! Currently, the role of assumptions is emphasized in the public debate around the problems of global warming, the damage caused by expansion of the Amsterdam airport, etc. I claim that the interest in the validation of model assumptions is more articulated in the public domain than in private business with its confidentiality issues; also see the panel discussion reported in Banks (2001). The validity of models in any science is also emphasized by Gustafsson et al. (2005, p. 36-37)..

Note that the preceding case studies in engineering and social sciences illustrate that mathematical *simulation* models are applied by *any* scientific discipline that studies dynamic systems, ranging from sociology to astronomy—certainly encompassing the various engineering (sub)disciplines. OR is applied in many of these areas; e.g., in inventory management and queuing systems (telecommunications, traffic).

4. Recent literature on ethics, validation, risk, and robustness

Recently, the journal *Omega* published a special issue on ethics in OR. In that issue, Le Menestrel and Van Wassenhove (2009) provide a state-of-the-art in ethics and OR for researchers and practitioners, including a vast range of recent references. Cooper et al. (2009) discuss privacy problems (and other types of problems) in the “surveillance society”, illustrating these problems through a case study on the tracking of cellular phones (I add that “tracking and tracing” is a hot topic in logistics research and practice).

Models may be used in good or in bad ways, by modelers or clients—and the public may get hurt. These clients and the public may not understand the reasoning that modelers have built into their computer program, because they have not read the *instruction manual*. This model documentation should explain the model’s underlying reasoning, especially its performance measures (criteria, responses, outputs) and its assumptions with their validation. For example, I tried to explicitly state all assumptions in my critical analysis of IBM’s inventory management package called “IMPACT”; see Kleijnen and Rens (1978).

Model documentation is also necessary to enable other researchers to reproduce the outcomes of the model; reproduction—or its antithesis, *falsification*—is a basic principle of science; also see Walker (2009).

I add a technical note: When testing the validity of a model, *auxiliary assumptions* are introduced; e.g.; the responses are usually assumed to have normal (Gaussian) distributions. Actually, most modelers are brainwashed into assuming Gaussian distributions so they often forget distribution-free statistical tests and computer-driven statistical techniques such as bootstrapping. Another problem is that multiple tests increase the probability of falsely rejecting a valid model: so-called “type I error probability” or modeler’s risk. So the documentation should also cover the assumptions of statistical techniques used for testing the validity of the model.

It is a challenge to develop *on-line* computerized documentation on the model’s goals, assumptions, and validation. That documentation should be accessible through a help button. Many simulation models do provide part of their documentation through *animation*, which explains—in user terms—the simulated system through a kind of cartoon movie. Animation, however, can be a misleading validation technique, because it uses very short simulation runs; see Law (2007), the standard textbook on discrete event simulation.

These issues become even more important when the modelers do not know who the users will be, as is the case if there are many stakeholders. A model without documentation is like a (rental) car without an instruction booklet. If the model is used respecting the documentation, then the users are entitled to a “warranty”: the modelers should pay for wrong model conclusions. If, however, the clients use the model outside its validity range, then these clients are to be blamed. While “driving” the model, red warning lights may switch on when the users enter inputs into the model that violate its validity range; also see the “experimental frame” in Zeigler, Praehofer, and Kim (2000). Like a car that is periodically returned to the garage for maintenance; a model may be returned to its builders, for updating. For other software it is well-known that maintenance is a crucial and expensive part of the life cycle; updating is standard in software: new versions keep appearing, repairing “bugs” discovered during usage.

Another analogy is provided by the instructions that come with most *medicines*: these instructions warn against all kinds of undesirable side-effects. Likewise, the documentation of a model should warn against improper usage. And likewise, this documentation should be updated continually.

In the Netherlands there is now much discussion on *norms and values*. In the context of models, these values concern clients, modelers, and other stakeholders. An example (in which I was personally

involved as chairman of a steering committee) is the simulation model that computes the financial consequences of changes in certain social security laws—for both the national government (macro-economic view) and the individual employees (micro-economic view) in the Netherlands; see Bosch et al. (1994). A recent example is the increase of the age at which employees may retire according to the retirement law (in Dutch: AOW). Possibly conflicting values of one or more stakeholders are discussed by Wenstøp and Koppang (2009). (The views of the stakeholders might be compared with the views of the blind men touching the elephant.)

Simulation models do not optimize, whereas mathematical programming (e.g., LP) models do—if the latter models’ assumptions hold! Simulation typically gives multiple performance criteria, which should measure the values of all the stakeholders; i.e., simulation models assume that these values are quantifiable (a quantitative output may be converted into a qualitative one; e.g., if the quantitative output exceeds a threshold value, then the qualitative output is scored as “unacceptable” which may correspond with the binary variable with values 0 or 1). Note that there is also *qualitative simulation*—see Kuipers (2001)—but I do not know any practical applications, though Kuipers mentions “Ongoing research topics include ... modeling methods suited for particular application domains.”

Moreover, the simulation should give these multiple performance criteria for various scenarios. These *scenarios* represent different assumptions about the future environment and different decisions. The analysts should consider a population of scenarios, which includes a most likely scenario and a reasonable worst-case scenario. Such scenario analysis is also called *what if* analysis. The simulation analysts may present the users with a set of non-dominated or *Pareto optimal* solutions. Next, these users may decide on their preferred solution, depending on their values! In the private domain (e.g., the banking sector) managers are paid so well because they must make such decisions (e.g., concerning their portfolio of securities)—and live with the consequences! In the public domain, politicians make the final decision (e.g., concerning the infrastructure of the country). In the medical domain, the doctor—not the patient—often decides (about the treatment).

There are many publications on measuring various criteria (often called “multiple objectives”) and quantifying their tradeoffs; see the famous textbook by Keeney and Raiffa (1976) and the recent updates by Rosen, Harmonosky, and Traband (2008), and Wallenius et al. (2008).

Dynamic Programming teaches us that we should try to avoid *irreversible decisions*; e.g., we should not make decision on nuclear energy that burden many future generations with the consequences including contamination by nuclear waste.

Note that spreadsheets (based on popular software like Excel) can be a type of simulation. Unfortunately, most spreadsheet software complicates the validation of the underlying model, because that model is not explicitly formulated in terms of equations and inequalities; see Whittaker (1999).

Simulation models are often used in *uncertainty analysis* or *risk analysis*: they quantify the probability of a “disaster”, such as a terrorist attack, a nuclear accident, an ecological breakdown, or a financial collapse—now or in the (distant) future. These disasters are unique events, whereas (say) a model for airplanes’ fuel efficiency concerns repetitive events: the airplanes make many flights. Consequently, validation in risk analysis is very difficult; a better term may then be credibility. A detailed monograph is Helton (2009).

Actually, there are two types of uncertainty: (i) *epistemic* (subjective) uncertainty: the analysts lack the knowledge about the true values of the parameters and input variables (see the preceding discussion on uncertainty analysis); (ii) *aleatory* (objective) uncertainty: uncertainty inherent in the system (e.g., a traffic system). Engineering models without human components do not suffer from aleatory uncertainty, because the dynamic behavior is determined by the laws of nature (physics and chemistry). An example is the behavior of a robot in a Flexible Manufacturing System (no aleatory uncertainty) versus a human operator. Many Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) models have epistemic uncertainty only. Helton (2009), Kleijnen (2008, p. 124) and Walker (2009, p. 1056) further discuss these uncertainty types, and provide references.

The chance of using a model wrongly becomes much smaller if that model is *robust*; i.e., the model’s output is not very sensitive to the exact values of the model’s parameters and inputs. The Japanese engineer *Taguchi* has emphasized the importance of robustness, but he limited himself to the design of physical products such as Toyota cars. An example of a study on the robustness of a simulated system is inventory management based on the Economic Order Quantity (EOQ) by Dellino, Kleijnen, and Meloni (2009). The goal of the classic EOQ model is to minimize the total inventory costs, assuming that the fixed demand rate is known: no epistemic uncertainty. In practice, however, that rate always differs from the assumed value. Therefore Dellino et al. derive the order quantity that minimizes the expected cost while guaranteeing that the variability of the cost does not exceed a threshold provided by the users. Changing that threshold gives a set of Pareto-optimal solutions.

Note that we may spread various related risks (i.e., we should not put all our eggs in one basket); e.g.; we may select a portfolio of energy resources (coal, nuclear, wind, biomass, etc.).

5. Models with unethical goals?

Currently, there is a surge of models that aim at fighting terrorism; e.g., *homeland security* is a hot topic in OR. How many models have been developed at the request of terrorist organizations I have no idea at all! Neither do I know of models developed by criminal organizations like the mafia. Note that the RAND Corporation developed a gaming model to study the USA's drug problem; see Caulkins (1995). In practice, it is not always clear what is terrorism and crime: is a suicidal bomb a heroic act or terrorism; is abortion a crime, even in case of rape? It all depends on one's norms and values! Also see Howard (1999) and Wenstøp and Koppang (2009, p. 1118).

Not all scientists are prepared to work for the *military* establishment (the origin of OR is the development of military models during World War II). Personally, I think that modeling for military defense is morally acceptable, in general (remember the case study in which I was personally involved, namely, sonar search for mines on the sea bottom; see Kleijnen, 1995a). I feel that exceptions are the development of unacceptable weaponry. Gass (2009) details how in 1971 the controversy around the antiballistic missile (ABM) system lead to a first set of guidelines for OR (which next became forgotten). Other examples of unethical weaponry are cluster bombs and land mines—according to many people. Since the 1940s, weaponry may include *nuclear* weapons—for many scientists a moral dilemma. Modern weaponry includes “unmanned aerial vehicles” or *drones* (such as the “predator” and the “reaper”), flying over Afghanistan while activated in the USA; this makes war look like a video game played with a joystick! I am aware of both engineering models to design these drones and OR models to decide on their tactical deployment.

So drones and their joysticks may be associated with a special type of simulation models, namely *computer games*; i.e., humans make decisions that are input to the simulated world, whereupon the computer calculates the consequences of these decisions. Besides computer games for entertainment, there are so-called serious games. *Serious* games are a good tool for studying human behavior, including ethical aspects; e.g., do the players go for “cut throat” competition or do they collude against the public? A recent survey focusing on war games is Samuelson (2009).

A more recent type of games is provided by *experimental economics*. The latter games are computationally much simpler, but the players get real money—depending on the decisions of all the players. These games are used to study altruistic versus egoistic behavior, rational versus emotional decision-making, etc. A recent online survey article is Smith (2010).

Instead of humans, we might use computerized robot players called *agents*; see Kleijnen (1980), Le Ministrel and Van Wassenhove (2009), Robbins and Wallace (2003), and Tan (2010), but these agents add another level of abstraction.

In summary, computer games are good tools for studying human behavior including ethical principles; these games have not yet become popular for the study of ethics in modeling.

6. Whistle blowers

In Kleijnen (2001), I summarized a few case studies on whistle blowers who lost their jobs (at the Dutch KEMA and RIVO organizations). Another case study dates back to 1999, when some Dutch parliament members raised questions about the permission to expand the Amsterdam airport (Schiphol), because an RIVM employee claimed that this permission was based on a wrong model instead of real-world measurements of the airplanes' noise and pollution. After 1999, that discussion was continued by Berkhout (Delft University of Technology) and Dutch parliament (First Chamber committee chaired by Eversdijk); unfortunately, I do not know the final outcome of that debate.

The disadvantages of real-world measurements are that they are expensive in time and money; moreover, they enable the testing of only a few scenarios; these tests may be dangerous because they may lead to accidents, etc. I do repeat the need for the validation of models, and the related issues of sensitivity and uncertainty analyses.

There is a practical problem that has both ethical and theoretical implications: "Don't bite the hand that feeds you" (Dutch analogue: "Whose bread one eats, whose word one speaks"). Note that in case of multiple stakeholders, financial costs and benefits may be allocated applying game theory to obtain an equitable solution (e.g., Nash equilibrium); see Shoham and Leyton-Brown (2009).

7. Conclusions

Ethical issues in modeling are essential issues, for all modelers: all modelers are human, and all humans must face moral problems!

Nevertheless, ethical issues are not part of the standard academic OR curriculum. An exception is the course by Howard at Stanford University (see <http://event.stanford.edu/events/212/21283/>). In engineering, however, ethics has become a required part of the curriculum in many countries (e.g., the

USA, the Netherlands); see Harris, (2008).

Occasionally these issues arise in the popular media (e.g., discussing whistle blowing), but these issues are then not discussed in a scientific manner. I must admit that I myself seldom stop to ponder these problems. Therefore it has been a challenge to force myself to reflect on this problem when invited to prepare this contribution.

There are too few specialists in the field of ethics and (engineering) models; actually, I started by admitting that I am neither a philosopher nor an engineer. So this contribution collects selected personal reflections, based on my limited experience as an OR consultant. I hope that my expose is a worthwhile contribution to this field, and that it will stimulate further discussion on the issues of ethics in modeling!

References

Banks, J. (2001), editor, Panel session: education for simulation practice - five perspectives. *Proceedings of the 2001 Winter Simulation Conference*, edited by B.A. Peters, J.S. Smith, D.J. Medeiros and M.W. Rohrer, pp. 1571-1579

Bettonvil, B. and J.P.C. Kleijnen (1996), Searching for important factors in simulation models with many factors: sequential bifurcation. *European Journal of Operational Research*, 96, no. 1, pp. 180-194

Bosch, L., L. Smit, G. Elsendoorn, and P. Verhees (1994), *Loonelementen, daglonen en uitkeringslasten*. Sociale Verzekeringsraad, Zoetermeer, Netherlands

Caulkins, J.P. (1995), Dealing with the country's drug problem. *OR/MS Today*, 21, no. 1, pp. 32-40

Cooper, A.K., H.W. Ittmann, T. Stylianides, and P.M.U. Schmitz (2009), Ethical issues in tracking cellular telephones at an event. *Omega*, 37, no. 6, pp. 1063-1072

Dellino, G., J.P.C. Kleijnen, and C. Meloni (2009), Robust optimization in simulation: Taguchi and Response Surface Methodology. *International Journal of Production Economics* (accepted)

Gass S.I. (2009), Ethical guidelines and codes in operations research *Omega*, 37, no. 6, pp. 1044-1050

Gustafsson, B., G. Hermerén, and B. Petersson (2005), *Good research practice – What is it? Views, guidelines and examples*. Vetenskapsrådet (The Swedish Research Council), Stockholm, Sweden (This report can be ordered at www.vr.se)

Halachmi, I., A. Dzidic, J.H.M. Metz, L. Speelman, A.A. Dijkhuizen, and J.P.C. Kleijnen (2001), Validation of a simulation model for robotic milking barn design. *European Journal of Operational Research*, 134, no. 3, 677-688

Harris, C.E., M.S. Pritchard, and M.J. Rabins (2008), *Engineering ethics: concepts and cases. fourth edition*, Wadsworth, Belmont, California

Helton, J.C. (2009), Conceptual and computational basis for the quantification of margins and uncertainty. Sandia National Laboratories, Report SAND2009-3055

Howard, R.A. (1999), The ethical OR/MS professional. Working paper, Department of Engineering ± Economic Systems and Operations Research, School of Engineering, Stanford University

Keeney, R.L. and H. Raiffa (1976), *Decisions with multiple objectives: preferences and value tradeoffs*. Wiley, New York

Kleijnen, J.P.C. (2008), *Design and analysis of simulation experiments*, Springer

Kleijnen, J.P.C. (2001), Ethical issues in modeling: some reflections. *European Journal of Operational Research*, 130, no.1, pp. 223-230

Kleijnen, J.P.C. (2000), Strategic directions in verification, validation and accreditation research: a personal view. *Proceedings of the 2000 Winter Simulation Conference*, edited by J.A. Jones, R.R. Barton, K. Kang and P.A. Fishwick), pp. 909-916

Kleijnen, J.P.C. (1999), Validation of models: statistical techniques and data availability. *Proceedings of the 1999 Winter Simulation Conference*, edited by P.A. Farrington, H.B. Nembhard, D.T. Sturrock, and G.W. Evans, pp. 647-654

Kleijnen, J.P.C. (1995a), Case study: statistical validation of simulation models. *European Journal of Operational Research*, 87, no. 1, pp. 21-34

Kleijnen, J.P.C. (1995b), Verification and validation of simulation models. *European Journal of Operational Research*, 82, no. 1, pp. 145-162

Kleijnen, J.P.C. (1980), *Computers and profits: quantifying financial benefits of information*. Addison-Wesley, Reading (Massachusetts)

Kleijnen, J.P.C., R.C.H. Cheng and B. Bettonvil (2001), Validation of trace-driven simulation models: bootstrapped tests. *Management Science*, 47, no. 11, pp.1533-1538

Kleijnen, J.P.C. and J. Helton (1999), Statistical analyses of scatter plots to identify important factors in large-scale simulations,1: review and comparison of techniques. *Reliability Engineering and Systems Safety*, 65, no. 2, pp. 147-185 (also published as Sandia Report SAND98-2202, April 1999)

Kleijnen, J.P.C. and P.J. Rens (1978), IMPACT revisited: a critical analysis of IBM's inventory package "IMPACT". *Production and Inventory Management, Journal of the American Production and Inventory Control Society*, 19, no. 1, pp. 71-90

Kleijnen, J.P.C., G. van Ham and J. Rotmans (1992), Techniques for sensitivity analysis of simulation models: a case study of the CO2 greenhouse effect. *Simulation*, 58, no.6, pp. 410-417

Kuipers, B. (2001), Qualitative simulation. *Encyclopedia of Physical Science and Technology, Third Edition*, edited by R.A. Meyers, Academic Press, pp. 287–300

Law, A.M. (2007), *Simulation modeling and analysis; fourth edition*. McGraw-Hill, Boston

Le Menestrel M. and L.N. van Wassenhove, editors (2009), Ethics in Operations Research and Management Sciences: A never-ending effort to combine rigor and passion, *Omega*, 37, no. 6, pp. 1039-1043

Le Ministrel, M. and L.N. van Wassenhove (2010), Ethical values beyond the objective function: a theory and a methodology. (This conference)

Robbins, R.W. and W.A. Wallace (2003), Modeling the social dynamics of individual ethical behavior: a hybrid multi-agent architecture. *Promoting Ethics in OR*, INSEAD, Fontainebleau, pp. 31-36 (http://www.prometheus.vub.ac.be/ETHICS_AND_OR/Insead/Ethics%20and%20OR%20Workshop%20Final%20Program2.pdf)

Rosen, S.C., C.M. Harmonosky, and M.T. Traband (2008), Optimization of systems with multiple performance measures via simulation: survey and recommendations. *Computers & Industrial Engineering*, 54, no. 2, pp. 327-339

Samuelson, D.A. (2009), Playing for high stakes. *OR/MS Today*, 36, no. 5, pp. 28-33

Shoham, Y. and K. Leyton-Brown (2009), *Multiagent systems: algorithmic, game-theoretic, and logical foundations*, Cambridge University Press, New York

Smith, V.L. (2010), Experimental economics. *The New Palgrave Dictionary of Economics* Online http://www.dictionaryofeconomics.com/article?id=pde2008_E000277 (doi:10.1057/9780230226203.0527)

Tan, Y-H. (2010), Self-regulation in international trade. (This conference)

Walker, W.E. (2009), Does the best practice of rational-style model-based policy analysis already include ethical considerations? *Omega*, 37, no. 6, pp. 1051-1062

Wallenius, J. et al. (2008), Multiple criteria decision making, multiattribute utility theory: recent accomplishments and what lies ahead. *Management Science*, 54, no. 7, pp. 1336-1349

Wenstøp, F. and H. Koppang (2009), On operations research and value conflicts. *Omega*, 37, no. 6, pp. 1109-1120

White, L. (2009), Challenge of research ethics committees to the nature of operations research. *Omega*, 37, no. 6, pp. 1083-1088

Whittaker, D. (1999), Spreadsheet errors and techniques for finding them. *Management Accounting*, 77, no. 9, pp. 505-551

Zeigler, B.P., H. Praehofer, and T.G. Kim (2000), *Theory of modeling and simulation; second edition*. Academic Press

TRI-6346-59-28.ai Figure 1:

An engineering example: the WIPP in Carlsbad, New Mexico (WIPP: Waste Isolation Pilot Plant)

Reprinted with permission from WIPP PA (Performance Assessment) Division. Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991. SAND91-0893/1-4. Albuquerque, NM: Sandia National Laboratories 1991-1992 (Fig. 1-9, Vol. 1)