Decision Engineering

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Decision Models in Engineering and Management

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Decision Models in Engineering and Management

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To my husband José Carlos and my daughter Julia, who was born with this book, bringing much joy to our lives.

Foreword

This book has been edited by Patricia Guarnieri, a renowned scientist in the field. The book includes 16 distinct chapters in 8 parts written by 27 recognized and respected experts. Each chapter stands on its own, and the whole book is an overall composition on the topic of "Decision Analysis Models in Engineering and Management," which focuses on research and perspectives. It presents conceptual aspects of decision support applications in various areas including finance, vendor selection, construction, process management, water management and energy, agribusiness, production scheduling, and control and waste management.

The first three chapters of this book are an introduction to the rest of the book. "Introduction" presents a brief introduction on decision making in organizations, including a rough outline of the book. "Stochastic Cash Flow Management Models: A Literature Review Since the 1980s"–"Decision Models in Credit Risk Management" introduce terminology and concepts for readers who are not familiar with decision models in financial management. "Stochastic Cash Flow Management Models: A Literature Review Since the 1980s," is mainly about stochastic cash flow management models. "Multi-attribute Utility Model Based on the Maximum Entropy Principle Applied in the Evaluation of the Financial Performance of Brazilian Banks" is about the multi-attribute utility model based on maximum entropy. "Decision Models in Credit Risk Management" covers decision models in credit risk management.

"A Review on the Dynamic Decision Models for Manufacturing and Supply Chain"–"A Multicriteria Decision Model for Classifying Management Processes" provide an overview of decision models in production and processes management. These chapters cover a review on dynamic decision models for manufacturing and supply chains. Not only are models for manufacturing and supply chains mentioned, but also the multicriteria decision model for classifying management processes. Following the discussion on decision models in production and processes management, the experts present decision models in supplier selection and partnership management in "A Multi-criteria Decision Support System for Supplier Selection"–"Decision Making Regarding Information Sharing in Partnerships with

Suppliers." A multi-criteria decision support system for supplier selection, management of the negotiation process in interorganizational partnerships from the trust perspective and decision making regarding information sharing in partnerships with suppliers are described.

In "Multicriteria Decision Models in Industrial Energy Management Systems" and "Multicriteria Decision Analysis Applied to Water Supply Network," the network perspective on decision models in energy and the water industry is described, particularly multicriteria decision models. Topics related to decision models in public policies are presented in "Decision Model on Basic Sanitation Management Using Environmental Kuznets Curve (EKC)" and "A Proposal Based on Hard and Soft Systems for Public Policies Supporting Family Farms." In these chapters, experts mention important model decisions on basic sanitation management using the Environmental Kuznet Curve, and a proposal based on hard and soft systems for public policies supporting family farms.

The last three chapters introduce the Decision model in civil engineering. "PROMETHEE IV as a Decision Analyst's Tool for Site Selection in Civil Engineering" shows how PROMETHEE IV and the Kernel Density Estimator (KDE) could be used to choose available locations for construction, aiming to choose the best locations and to avoid the worst. "Decision Models in E-waste Management and Policy: A Review" reviews decision models in e-waste management and a policy is presented. The last chapter "The Impact of Environmental Regulation and Some Strategies for Improving the Eco-Efficiency of Brazilian Agriculture" provides the application of data envelopment analysis (DEA) and directional distance functions (DDF) to evaluate the impact of environmental regulations on the drop in productivity and eco-efficiency.

This book is an excellent introduction to a comprehensive overview of various methods and applications in decision engineering. This book is designed for use in the classroom (at either the undergraduate or graduate program levels) or for the practicing professional in industry, business, or government. The concepts and techniques presented are applicable to any type of environment.

, Marcelo Seido Nagano
Professor at the São Carlos School of Engineering
University of São Paulo—Brazil

Preface

In many situations the decision makers are concerned with choosing a preferred alternative, considering conflicting objectives and different attributes, which require them to develop a rating system or model to enable to consider all these elements in the decision-making process.

Unquestionable is the importance of building models that allow greater objectivity and confidence in the decision-making process. Professionals in various fields, from engineering and administration have sought to increase their knowledge about such models, given that currently, the information is a fundamental resource to support the decision makers in this context.

Hence, my interest in the topic emerged when I began my Ph.D. in Production Engineering at the University of Pernambuco, Brazil, in which I researched multicriteria decision models applied to partnerships management in the supply chain. Moreover, on this occasion I had the opportunity to meet researchers applying various methods in different contexts of decision. Therefore, I was excited with the possibility of adding to any decision context, methods and models that would make this process more efficient, without losing the inherent subjectivity that cannot be disregarded.

Therefore, when the Springer Publisher asked me to organize a book on decision models for engineering and administration, I sought colleagues from various universities and research institutions, experts in this matter, in order to bring together in a single book different decision situations illustrating how these methods can be applied. It is important to highlight that the intention of this book is not to present the modeling of problems through decision analysis only in terms of technical and analytical characteristics, but also in terms of the support and insight given to the decision makers.

The 16 chapters of this book bring together the knowledge and perceptual experience of professionals from diverse areas as Engineering, Management, Mathematics, Economics, Statistics, and Accounting. These different points of view contribute when they present models with different features suiting the various contexts of decision making at operational, tactical, and strategic levels. Thus, it will be possible to the reader to realize that it is not the problem that should suit the method, but the method should be appropriate to the problem at hand. This aspect becomes essential because every decision must take into account certain variables, hence there is no rule or recipe that applies to all cases. In addition, it should be emphasized the importance of this process when it involves the ideal choice in the case of decisions that will have long-term consequences, configuring strategic decisions.

The purpose of this book is to bring a holistic vision of decision models applied to engineering and management, with special focus on methods of multicriteria decision aid, addressing issues as financial management; production and management processes; supplier selection and management of partnerships; public policies; waste management; energy and water industry; civil engineering and agribusiness.

Although this book is of a theoretical nature, it is also practical because it presents numerical applications and real cases that illustrate the role of decision models presented in the chapters. I emphasize that this book is aimed at students, professionals, and researchers in the various areas cited. A public that is interested in, and at the same time deepens its theoretical knowledge on decision models focused on areas of engineering and management, as well as accessing the applicability of these models in different contexts of decision.

Finally, I would like to take this opportunity to thank to all the contributors of this book, considering the high quality of their chapters. Also, I would like to gratefully acknowledge the funding received from the Brazilian science, technology, and innovation funding agencies, which support some of the research presented in this book.

Patricia Guarnieri

Contents

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Introduction

Patricia Guarnieri

Abstract Decision making in organizations is a recurrent theme, essential for business continuity. Managers from various fields including public, private, industrial, trading, or service sectors are required to make decisions. Consequently, managers need the support of these structured methods in order to engage in effective decision making. In order to provide a comprehensive overview of various methods and applications in decision engineering, this book presents chapters written by a range of experts in the field. It presents conceptual aspects of decision support applications in various areas including finance, supplier selection, civil engineering, process management, water and energy management, agribusiness, public policies, production scheduling and control, and waste management. In addition to this, a special focus is given to methods of multiple criteria decision making. This chapter has the purpose to introduce the other chapters presenting the main approaches of models for decision making in engineering and management areas.

Keywords Decision models · Decision-making models · Engineering · Management

1 Contextualization

Different people need different views of a model and of what it represents, each view having its own cognitive value for acquiring insight and understanding (Greenberg and Murphy 1995). Decisions differ in complexity, information accessibility, time constraints, and so on (Söllner et al. 2014). When individuals are confronted with different problems and situations, they face a decision-making process.

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Making decisions is crucial for organizations. This activity happens all the time, at all levels, and directly influences the performance of the entire organization (Gontijo and Maia 2004). The behavior of a single individual in isolation can never be a high degree of rationality. The number of alternatives that the individual should know and have information about is so vast, which is difficult to admit any approximation of objective rationality (Gontijo and Maia 2004).

To analyze decisions is a logical and systematic way to deal with a wide variety of problems involving the study of alternatives in uncertain environments (Raiffa 1997). The decision analysis has the purpose to provide to decision makers some tools to enable them to advance in solving decision problems in which several factors must be taken into account (Edwards et al. 2007). These factors involve conflicting objectives; thus, one cannot say that in general, all solutions meet all objectives (Vincke 1992; Brans and Mareschal 2005). So, it can be perceived that the decision analysis is normative in theory, however, prescriptive in practice (Edwards et al. 2007).

Besides that, it should be highlighted that the decision analysis covers hard operational research (OP-hard) and also soft operational research (OP-soft). The OP-hard includes mathematical programming, covering all its variations, and it is more related to well-structured problems. On the other hand, the OP-soft is designed to address ill-structured problems and covers methods for structuring these problems; these approaches consider the vagueness of judgments of decision maker (Mingers and Rosenhead 2004). The ill-structured problems can be characterized mainly by the existence of the following: (i) multiple actors; (ii) multiple perspectives; (iii) conflicting interests; (iv) intangible amounts; and (v) key uncertainties (Mingers and Rosenhead 2004). Gomes et al. (2009) emphasize those methods from OP-soft first aims to structure the problem to be solved, while the OP-hard aims, firstly, to solve the problem.

Given the need for rapid response, decision making occurs differently from rational insight; thus, the intuition based on the perception of crucial variables plays a key role (Gontijo and Maia 2004). In addition, it should be emphasized that there is a trend in the combination of these two approaches, which enriches the exploitation of decision problems.

2 Multiple Criteria Decision Making (MCDM) or Multi-criteria Decision Aid (MCDA)

MCDM/MCDA has several neighboring disciplines, such as decision analysis, mathematical programming, DEA, and negotiation analysis. In addition, MCDM/MAUT concepts and techniques are increasingly being applied in diverse engineering fields and other application areas (Wallenius et al. 2008).

MCDM/MCDA approach aims to provide decision makers with some tools to allow them to progress in solving decision problems, where several and often contradictory points of view should be taken into consideration. Brans and Mareschal (2005) state that according to our various human aspirations, it makes no sense, and it is often not fair, to select a decision based on one evaluation criterion only. In most cases, at least technological, economic, environmental, and social criteria should always be taken into account. In addition, it cannot be said that, in general, one decision (solution, action) is better than another, even if it is originated from all points of view. Therefore, the concept of optimization is not appropriate in the context of MCDA (Vincke 1992).

In general, a decision maker acts to maximize a utility or value function that depends on the criteria or attributes. Multiple attribute decision making deals with preferential choice and probabilistic inferences. The main difference between these two is that in the former, decisions are made in relation to a subjective criterion, whereas in the latter, the decision criterion is an objective one. Formally, these domains are similar: The decision maker chooses between two or more options that are characterized by a categorical set of attributes (Söllner et al. 2014).

Wallenius et al. (2008) split the methods for decision making in two main categories: multiple criteria discrete alternative problems and multiple criteria optimization problems. Basically, a multi-criteria decision problem consists of a situation, in which there are at least two action alternatives to be chosen from. The selection process occurs as a result of the desire to meet multiple objectives that often have conflicting relationships. These objectives have associated variables that represent them and allow each alternative to be evaluated based on each objective, which may be called criteria, attributes, or dimensions (Vincke 1992; Roy 1996).

There are some differences between the two categories. Discrete alternative problems are more likely to be modeled with uncertain values for the attributes or criteria than multiple criteria optimization problems. Besides that, many approaches to multiple criteria discrete problems attempt to represent aspects of a decision maker's utility or value function mathematically and then apply these results to estimate the alternatives' (expected) utilities. In multiple criteria optimization, there is usually no attempt to capture the decision maker's utility or value function mathematically (Wallenius et al. 2008).

Usually, experts in MCDM/MCDA split methods into three families: (i) multi-attribute utility theory, (ii) outranking methods, and (iii) interactive methods (Vincke 1992). On the other hand, Roy (1996) calls them, respectively, (i) a single-criterion synthesis approach, which eliminates any incomparability; (ii) an outranking approach, which accepts incomparability; and (iii) an approach of interactive local trial, which uses trial–error interactions. The differences among these approaches based on several authors are described in Table 1.

- **Multi-attribute Utility Theory or Single-Criterion Synthesis Approach**—It derives from the American school of thought; the decision maker's preferences for a particular alternative when evaluated by a set of criteria or indicators are aggregated into a single utility value, which is carried out in an additive manner (with trade-offs); it generates a score for each alternative based on performance criteria, so the best alternatives evaluated are those that obtain the best score. Among some methods of this approach can be cited the MAUT, SMART, TOPSIS, and AHP (Légel and Martel 2002; Almeida 2011).

- **Outranking**—It is derived from the French school of thought; the main objective is the construction of binary relations that represent the decision maker's preferences based on the information available between criteria (without trade-offs) (Légel and Martel 2002). Through a pairwise comparison, there is an alternative which is superior in every criterion, establishing a relationship of overcoming the confrontation between two alternatives. The main methods of this approach are those from families ELECTRE and PROMETHÉE (Légel and Martel 2002; Almeida 2011).
- **Interactive Local Trial**—These methods are mainly developed within the multi-objective linear programming (MOLP), which are characterized by possessing computational steps and be interactive, allowing trade-offs (Légel and Martel 2002). The methods seek an alternative that is clearly superior in all objectives set (dominant), which results in the aggregation of preferences of decision makers after mathematical calculations, interactive and successive evaluation of these solutions, and the possible change in the preference structure in the face of the new available information. Some methods of this approach can be cited: STEM, TRIMAP, ICW, and PARETO RACE (Antunes and Alves 2012).

In this book, several methods from MCDA/MCDM approach were covered; besides that, several methods related to decision making were approached, as presented in Table 1.

Table 1 Main methods approached in chapters of the book

Methods	Description	Related chapters
MAUT—Multiple attribute utility theory	The multi-attribute utility theory method (MAUT) consists in the idea that each alternative is described by a list of attributes, from the utility theory. It can be applied to solve discrete and continuous problems	Chap. 3
ELECTRE—Elimination and choice expressing reality	ELECTRE methods comprise two main procedures: (i) constructing one or several outranking relation(s) and (ii) a procedure for exploiting relations. First of all, the purpose of constructing one or several outranking relation(s) is to compare each pair of actions in a comprehensive way, without trade-offs between criteria	Chaps. 6, 9, 11

(continued)

Table 1 (continued)

Methods	Description	Related chapters
PROMETHÉE—Preference ranking organization method for enrichment evaluations	In Promethée methods, the degree of dominance of one option over another is indicated by an outranking relation). In the evaluation of decision alternatives, the key question is whether there is enough information to state that one alternative is at least as good as another. So, the method enables the selection of a set of options based on several criteria, with the purpose of identifying the pros and the cons of the alternatives and obtaining a ranking among them	Chaps. 7, 10, 13, 14
Group decision	The group decision involves taking into account the divergent needs, opinions, and points of view of several decision makers, in order to find an agreement among them. There are a variety of ways to make decisions as a group: Methods from multi-criteria decision aid, structuration methods, probabilistic and statistical methods, and others can be used in this context	Chap. 8
DEA—Data envelopment analysis	Data envelopment analysis (DEA) is built on the concept of the efficiency of a decision alternative. DEA is used for performance measurement and did not consider the preferences of the decision maker. One of the advantages of their model is that the weight constraints are used to reduce the possibility of having inappropriate input and output factor weights	Chap. 16
SODA—Strategic options development and analysis	This methodology is used in order to structure decision problems. It is based on the construction of the cognitive maps of the actors involved in decision making. It offers to users a transparent interface through which they can explore, learn about, and consequently take more confident decisions to improve, or otherwise change, a problematic situation	Chap. 13

(continued)

Table 1 (continued)

Methods	Description	Related chapters
EKC—Environmental Kuznets curve	This model explores the economic aspects of the relation between economic growth and the quality of the environment based on patterns of environmental changes detected by eight indicators in countries with different income levels. The EKC is a hypothesis drawing relationship between indicators of per capita income and environmental degradation	Chap. 12
Stochastic models	A method of financial modeling in which one or more variables within the model are random. Stochastic modeling is for the purpose of estimating the probability of outcomes within a forecast to predict what conditions might be like under different situations. The random variables are usually constrained by historical data, such as past market returns	Chap. 2
Probabilistic and statistical methods	Probabilistic graphical models have been applied to a wide-ranging set of applications in several areas, enabling efficient inference, learning parameters/structures, and decision making in problems involving a large number of variables and a vast amount of data. These models can take many forms, including but not limited to dynamical systems, statistical models, differential equations, or game theoretic models. These and other types of models can overlap, with a given model involving a variety of abstract structures	Chaps. 4, 5
DSS—Decision support systems	Mathematical or statistical procedures used as decision-making aid. These procedures are often developed through interactive computer-based systems which support decision makers in judgment and choice activities	Chap. 15

Source The author (2014)

3 Concluding Remarks

The structured decision-making process can be based on formal approaches arising from engineering economics, operations research, statistics, and decision theory areas. This process covers since the structuration of an ill-defined problem until to find the optimal solution or the indication of the best alternatives to choose. The analysis of the problem under MCDA/MCDM approach systematizes the decision process in well-defined steps, enabling the decision making.

Over recent years, many authors have proposed different methods and approaches to conduct the choice of best alternatives or actions. However, there is not a consensus of experts in the area regarding the best method. This depends on the decision problem and the particularities of the context involved.

When we model a decision problem through a MCDA/MCDM approach, we try to solve the problem in a holistic way, considering several points of view and conflicting objectives. Thus, applying the scientific knowledge represented by structured methods of decision making, it is feasible analyzing, explaining, and arguing about a decision problem.

Making decisions related to complex systems, as industrial processes, financial, public policies, operations management, supply chain management, waste management, and others in public, private, industrial, trading, or service sectors, is essential to business continuity. Hardly, this kind of decision involves a single criterion, because many variables are involved and often conflicting objectives need to be considered. So, the use of formal and structured approaches constitutes an important and useful tool in decision-making process.

References

Antunes C, Alves M (2012) Programação linear multiobjetivo-métodos interativos e software. Anais do Congreso Latino-Iberoamericano de Investigación Operativa. 24 a 28 de Setembro, Rio de Janeiro, 4725–4736

Almeida AT (2011) O Conhecimento e o Uso de Métodos Multicritério de Apoio a Decisão. Editora Universitária da UFPE, Recife

Brans JP, Mareschal B (2005) Promethee methods. In: Figueira J, Greco S, Ehrgott M (eds) Multiple criteria decision analysis: state of the art surveys. Springer, London, pp 163–196

Edwards W, Miles RF, Von Winterfeldt D (eds) (2007) Advances in decision analysis. Cambridge University Press, New York

Gomes LFAM, Gomes CFS, Almeida AT (2009) Tomada de decisão gerencial: enfoque multicritério. Editora Atlas, Rio de Janeiro

Gontijo AC, Maia CSC (2004) Tomada de decisão, do modelo racional ao comportamental: uma síntese teórica ensaio. Caderno de Pesquisas Em Administração 11(4):13–30

Greenberg HJ, Murphy FH (1995) Views of mathematical programming models and their instances. Decis Support Syst 13(1):3–34

Léger J, Martel JM (2002) A multicriteria assignment procedure for a nominal sorting problematic. Eur J Oper Res 138(2):349–364

Mingers J, Rosenhead J (2004) Problem structuring methods in action. Eur J Oper Res 152 (3):530–554. doi:10.1016/S0377-2217(03)00056-0

Raiffa H (1997) Decision analysis: introductory lectures on choices under uncertainty. Addison Wesley, Reading (Republished by McGraw-Hill)

Roy B (1996) Multicriteria methodology for decision aid. Kluver Academic Publishers, Netherlands

Söllner A, Bröder A, Glöckner A, Betsch T (2014) Single-process versus multiple-strategy models of decision making: evidence from an information intrusion paradigm. Acta Psychol 146 (2014):84–96. doi:10.1016/j.actpsy.2013.12.007

Vincke P (1992) Multicriteria decision-aid. Wiley

Wallenius Jyrki, Dyer James S, Fishburn Peter C, Steuer Ralph E, Zionts Stanley, Deb Kalyanmoy (2008) Multiple criteria decision making, multiattribute utility theory: recent accomplishments and what lies ahead. Manage Sci 54(7):1336–1349. doi:10.1287/mnsc.1070.0838

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Part I
Decision Models in Financial Management

Stochastic Cash Flow Management Models: A Literature Review Since the 1980s

Marcelo Botelho da Costa Moraes, Marcelo Seido Nagano and Vinicius Amorim Sobreiro

Abstract Defining cash balance is a classic problem in firms' financial management. For this reason, the aim of this study is to carry out a literature review, presenting the main cash flow management models from the Baumol and Tobin models in 1950s, to Miller–Orr model in 1960s and their development since the 1980s, focused essentially in stochastic models, with publication in economic, financial, and operation research journals. Thus, this chapter provides a review on cash balance management models in order to obtain a more consistent model on a par with investment analysis, observing the characteristics associated with cash maintenance, as well as diversification of financial applications and resources and the lack of literature in stochastic models for this problem.

Keywords Finance · Cash balance · Cash flow · Cash holding

1 Introduction

Managing the available cash balance is a constant problem in all types of firms, which happens due to the daily inflows and outflows, whether by operating activities of the firm or financial transactions. Therefore, there is a requirement to

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control the financial resources in order to obtain better results for the firm. Considering this, cash management has the following responsibilities: to mobilize, manage, and plan the financial resources of business (Srinivasan and Kim 1986). Thus, using models to support decision-making becomes relevant as they can provide a wider perspective with better results, according to the stated objectives.

Cash balance consists of available funds at any moment in time for the firm. The cash is constantly affected by inflows and outflows from deposits and withdrawals such as income, payments, and investments in the form of expenditure of funds, all conducted by the firm. Consequently, the cash balance is the result of a cash balance at an earlier date modified by the net cash flow, which occurred on that date.

The use of models in the problem of defining the ideal level of available cash funds stems from work by Baumol (1952) and Tobin (1956). The authors proposed that the available cash balance definition is like a *commodity inventory*, in which control can be on a daily, weekly, or monthly basis, depending on the level of detail required by the firm.

The definition of an optimal cash balance follows the inventory models, which considers the financial resources available as an inventory, having certain costs related to its origin and maintenance, but that also derives benefits essential to firms. Thus, the definition of an optimal cash balance has a quantitative approach with the purpose of promoting the optimization of this fund inventory in order to minimize the costs associated with maintenance or lack of cash. Later, Miller and Orr (1966) analyzed the cash balance as having a random variable with an irregular fluctuation and proposed a stochastic model for managing the cash balance.

Despite the importance of the problem, few studies dedicated themselves to elaborate a review of the models in this problem, essentially the work of Gregory (1976), which presented a survey by the models until the mid-1970s focused on variants of the Miller–Orr model, and Srinivasan and Kim (1986), which deals only with deterministic models until the mid-1980s.

2 Literature Review

2.1 The Origin of Cash Flow Management Models

Cash management models were originally presented in Baumol (1952), whereby the author makes a parallel between cash with other firms' inventories. In the case of inventories in general, the most common approach is the economic order quantity (EOQ), which aims to find the best solution between the advantages and disadvantages of having an inventory. Nevertheless, the EOQ has restrictions when using the assumptions of fixed and predictable demand, as well as instant supply when listing an inventory is required.

According to Baumol (1952), a cash inventory is an inventory of a specific form of exchange. In Baumol model, the EOQ is adapted to optimize the cash and the best configuration based on the relationship between opportunity cost and transfer cost. So, the total transfer cost increases when the firm needs to sell bonds to accumulate cash, as the opportunity costs increase when there is a cash balance because it is a resource investment with no income associated (Baumol 1952).

The model performs the cost analysis associated with maintaining cash, for example, the opportunity cost determined by the interest rate that the firm receives or not for its investment and the cost of obtaining money by converting the investment into cash (Baumol 1952). The transfer cost represents expenditure incurred when investing in funds or withdrawals, such as interest rates and taxes. Thus, we demonstrate the model separately as follows:

$$\text{Cost} = \frac{bT}{C} \tag{1}$$

where

b fixed cost identified in investment or withdrawal transactions;
T total cash that is expected to be used in a certain period in net value as, for example, liquid cash flow; and
C initial cash balance;

The cost of holding cash is

$$\text{Cost of holding cash} = iC/2 \tag{2}$$

where

i opportunity cost of holding cash. In this case, the interest rate is defined by financial market; and
$C/2$ average cash balance, assuming that the cash decrease is a constant rate (fixed demand).

Thus, the total cost associated with the cash balance represents the sum of costs of obtaining cash, also known as trading costs, with maintenance costs that represent the opportunity cost of investment.

$$\text{Total Cost} = \frac{bT}{C} + \frac{IC}{2} \tag{3}$$

The best solution determination for cash balance C^* is the value of C in the following expression:

$$-\frac{bT}{C^2} + \frac{i}{2} = 0 \tag{4}$$

So, by the intersection of two straight lines, equalizing the formulas, we obtain the best value of C^* by

$$C^* = \sqrt{\frac{2bT}{i}} \tag{5}$$

However, as indicated by the authors cited, Baumol model has limitations when considering the constant demand for money and there is no receipt during the period, with immediate replacement of the money by withdrawal. Moreover, the model is limited with the uses of only two assets, the cash itself and any particular bond as a form of investment.

Along the same lines of development, Whalen (1966) also presents a model based on the concept of inventory, but uses a preventive approach relative to cash balance that takes into consideration three aspects:

- The cost of illiquidity;
- The opportunity cost of maintaining a precautionary cash balance;
- The average volume and variability of inflows and outflows.

Despite this, the Whalen model has no significant gains over original Baumol model. This is because both models are very similar where the cost of liquidity absence and the opportunity cost of maintaining the precautionary cash balance match, respectively, the transfer cost (obtaining) and opportunity cost (maintenance) of cash (Whalen 1966). Later, Miller and Orr (1966) presented a model that considers the assumption of random cash flows as the normal distribution. Furthermore, the Miller–Orr model considers only two assets, cash and an alternative investment is a low-risk and high-liquidity option, and the cash flow is a random variable as shown in Fig. 1, with decisions of immediate investments in bonds (moment T_1) and the decision of sale of the bonds (moment T_2).

This model attempts to define two limits for the level of cash funds: the minimum and the maximum, so the cash can reach the maximum level, represented by upper bound (h), when a financial investment is made in an amount that provides the cash balance back to best level of cash (z). Furthermore, when the minimum level is

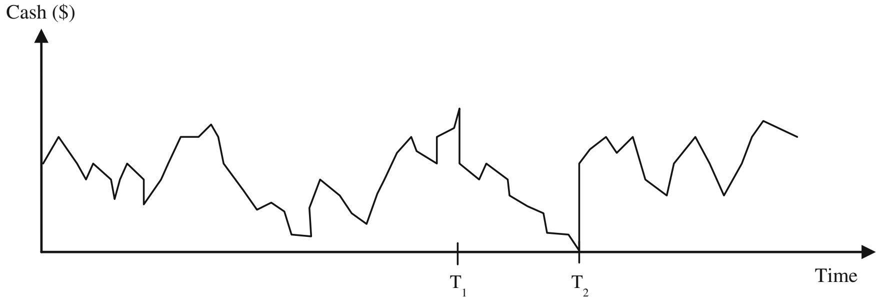

Fig. 1 Cash flow

reached with the lower bound (in the original work, this value is considered zero), a withdrawal should be made to obtain the best level of cash once again Miller and Orr (1966). Therefore, using the net cash flows (inputs minus outputs), the Miller–Orr model makes the optimization of the cash balance possible based on transfer cost (γ) and opportunity (v), obtaining the following formula (Miller and Orr 1966):

$$Z^* = \left(\frac{3\gamma}{4v}\sigma^2\right)^{1/3} \tag{6}$$

$$h^* = 3z \tag{7}$$

The symbol "*" denotes estimated optimal values, and σ^2 represents the variance of historical net cash flows. Thus, the optimal cash balance is

$$\text{Optimal Cash Balance} = 4z/3 \tag{8}$$

Despite the relative gain on the Baumol model, considering the random cash flow, the Miller–Orr model requires the definition of a lower bound as zero or some other positive values as the risk of lack of cash associated with a minimum margin of safety, an administration's choice that is not present in the model. Thus, after the Miller–Orr model, the optimization models were divided between deterministic and stochastic, and the subsequent works up to the 1970s only had modeling variations Gregory (1976).

The models showed no effective and practical solutions to the problem of three assets, the decision between investment in cash, bonds, and shares, for example. The division of investments between shares and bonds is relevant because the bonds tend to yield less and have lower transfer costs, but the development of the models did not consider the time of negotiation of the assets or the best moment to trade shares, and this last problem is an insuperable limitation Gregory (1976).

Analyzing the applicability of the models developed so far, and using simulations to define the cash balance in uncertain conditions, Daellenbach (1974) uses existing models in simulated cash flows. The author concluded that in cases where cash flows are non-stationary series, the optimization models could not make significant gains if the transfer costs are low. Therefore, the large firms perform better because of the financial volume of cash.

2.2 Cash Flow Management Models Since the 1980s

Even with the fall of development of models for this problem in the 1980s, it has not lost its relevance. The studies focused on improving methodological techniques. Since the 1980s, various authors have worked with the cash optimization problem, but because of the uncertainty related to receipts and payments from cash flow resources, what made the result a composition of random variables were implemented models with new approaches, mainly based on stochastic processes.

In this type of research, Tapiero and Zuckerman (1980) presented a stochastic model based on the premise that cash inflows and outflows have random behavior in a compound Poisson process, which consists of probability distribution of summing individual numbers distributed, according to the Poisson probability density function.

Later, Milbourne (1983) came up with a different model separating the transfer costs into two categories, β_1 the proportional cost for currency units to adjust the cash balance up and β_2 the proportional cost for currency units to adjust the cash balance down. Therefore, β_1 consists of withdrawing resources from financial assets for cash and β_2 represents the proportional cost when investing cash in other financial assets, including penalty charges for overdrawing the cash, which demands loans, or penalty charges for not performing certain payments.

From the formulation of Milbourne (1983), Smith (1986) developed a stochastic dynamic model, considering the cash flow as a diffuse process, temporally independent, as a Wiener process, known as Brownian motion. In the late 1990s, Ogden and Sundaram (1998) used the same assumptions of Baumol, considering the regular cash flow with output constant. The model incorporates the possibility of a credit line if the firm has a cash deficit, to solve the lack of cash, considering an interest rate associated with this credit line higher than the interest rate obtained on the investment used by the company. Thus, the problem of cash inflows and outflows (cash flows) according to stochastic processes is

$$f(S_n) = \begin{cases} S^- & S_n \leq S^- \\ S_n & S^- < S_n < S^+ \\ S^+ & S_n \geq S^+ \end{cases} \tag{9}$$

where the transferred amount of money at the beginning of each period $n = 1, 2, 3, \ldots$ is obtained by the transfer rule according to the model applied. This means that the amount of cash balance (S_n) at the beginning of period n is unchanged if it is within the upper (S^+) and lower (S^-) limits; otherwise, it should be adjusted to the extrapolated limit Hinderer and Waldmann (2001) in a similar way to the Miller–Orr model. More recently, some authors have been working on this problem, including Pacheco et al. (2000), who developed a genetic algorithm to determine investments in financial products available on the market based on the projected cash flow, obtaining the maximum return for specific periods.

Considering the cash balance problem as a possible use of the general and stationary Markov model in Hinderer and Waldmann (2001), the authors use a model for Markov chain processes in random environments that have a stationary process as, for example, low variation over time. Another technique used to solve this problem is linear programming. In this case, the cash flow can be developed on a specific basis of periodicity from the initial cash balance and supports input cash and a payment schedule based on estimated costs Barbosa and Pimentel (2001).

The model developed by Barbosa and Pimentel (2001) was very successful as it dealt with civil construction projects where the outflows are very predictable when planning construction work as, for example, a lower degree of randomization of cash flows. Computational approaches by Pacheco et al. (2000) and Barbosa and Pimentel (2001) tend to facilitate the practical application for firms enabling them to use software more easily.

Even with the changes in the design of the models discussed, there are some technical difficulties in defining cash balance policy or obtaining the ideal range or amount of cash. This is because the models use an approach of discrete time, even considering cash as a Markov chain, which depends on the amount existing beforehand.

This problem, with the linear condition of maintaining costs of cash, as we assume fixed proportional costs, can be avoided by reformulating continuous time, where the cash fund varies according to a *Brownian* motion with an average μ and variance σ^2. Therefore, the model is able to provide a band (range defined by upper and lower limits) of cash balance, indicating an optimal control policy in isolated moments of time Baccarin (2002).

Changing the focus of the optimization problem, Baccarin (2002) no longer searches to maximize the profitability of using financial resources or even minimizing the cost of opting to use the resource in the form of cash, but obtains the optimal level of liquidity, which presupposes that there is a negative cash balance. Their results indicate that the penalty charge is finite and the lower bound tends to be always below zero.

Another modeling variation is in Premachandra (2004), where the author develops a model of diffuse approximation for problems with two assets as proposed in the classical models. In this model, the assumptions of normal distribution of net cash flows and fixed transfer costs are relaxed in order to obtain a model closer to reality and with results significantly higher than the Miller-Orr model.

The model also uses the upper and lower bounds, and the optimal level of cash (z) is adopted by Miller and Orr, but considering the small time gap between the investment of cash and withdrawing it. In this case, with buy and sell bonds operations, we calculate the time on an hourly basis and the cost of maintaining the cash balance daily where m_1 and m_2 are the densities of probabilities of lower and upper limits, respectively, and the appropriate boundary conditions are given by $-m_2$ and m_1, as shown by Premachandra (2004). Moreover, the α in the model is a infinitesimal variation of the diffusion process, for example, the rate of oscillation of the variance of daily cash balance and β the infinitesimal mean of the diffusion process, for example, the rate of oscillation from cash balance daily average.

So taking the values b as the upper limit, a as the lower limit, and an integration constant c, the weighted daily cash balance (ABC—average daily cash balance) is

$$\begin{aligned} ABC &= \int_a^c x\frac{\lambda m_1}{\beta}\left[-1+e^{\frac{-\beta(x-a)}{a}}\right]\mathrm{d}x + \int_c^b x\frac{\lambda m_1}{\beta}\left[-1+e^{\frac{-\beta(x-b)}{a}}\right]\mathrm{d}x + m_2 b + m_1 a \\ &= -\frac{\lambda m_1}{2\beta}\left(c^2-a^2\right)+\frac{\lambda m_2}{2\beta}\left(b^2-c^2\right)+X(c)-Y(c) \end{aligned} \tag{10}$$

where

$$X(c) = \frac{\lambda m_1 \alpha (c y_2 - a)}{2\beta^2} - \frac{\lambda m_1 \alpha^{2(\gamma_2 - 1)}}{4\beta^3} + m_2 b + m_1 a \tag{11}$$

$$Y(c) = \frac{\lambda m_2 a (b - c\gamma_2)}{2\beta^2} - \frac{\lambda m_2 a^{2(1-\gamma_1)}}{4\beta^3} \tag{12}$$

Thus, cash flows were simulated (with inputs and outputs) under normal distribution with mean (μ) and variance (σ^2) at different magnitudes, as well as using different transfer costs for investments and withdrawals, obtaining lower costs and making it possible for the model itself to identify the upper and lower bounds Premachandra (2004). This is an advantage over the Miller–Orr model, which does not define the lower bound.

Along these lines of stochastic development, Volosov et al. (2005) present a stochastic programming model in two stages, based on scenario trees, which consider not only the problem of cash balance, but also the exposure to international currency, addressing the risk of exchange rate variation. In this model, the authors consider cash flows coming from different currencies, relating to the aspect of existing foreign exchange and the need for hedging. Thus, the authors obtain positive results in determining the optimal cash balance together with the definitions on how to use the hedge, even in a limited way.

The study conducted by Yao et al. (2006) presents a different formulation, considering the demand for money according to fuzzy logic concepts, developing a single-period model as, for example, without using past data due to historical data not being able to provide a cash demand forecast. In Yao, Chen, and Lu's model, a stochastic inventory similar to the single-period model is used where the inventory of one day cannot be used for the next day as it loses the value and is considered the opportunity cost. Therefore, the administrator must set the cash balance at a level where the value of the cumulative distribution function is equal to the cost/rate of interest.

This type of modeling considers the relationship between the costs of leftover financial resources and the cost penalty for the lack, but it is different when considering a fuzzy environment. More recently, Gormley and Meade (2007) have differentiated their work by presenting a dynamic policy for cash balance that minimizes transfer costs when cash flows are not independent or identically distributed in a general cost structure. By using this methodology, the authors used historical data to develop a time series model to forecast cash flows, promoting a conditional expectation of future cash flows and obtaining results in the reduced transfer cost. In this model, called the dynamic single policy (DSP), there is no need for the flow to be identically distributed and it is as follows:

$$E(w_{t+\tau} | W_t, W_{t-1}, \ldots) \neq E(w_t) = \text{Constant} \tag{13}$$

where
$w_t \in (-\infty, \infty)$ is an exogenous modification in the cash balance held at date (t).

There is no need to assume a distribution of cash flow, but the methodology requires a historical cash flow model for adaptation and τ corresponds to the amount of time in the future in which is desired the adjustment of cash. Thus, the DSP model calculates the costs associated with cash flow, divided into Gormley and Meade (2007):

- Holding cost: h;
- Shortage cost: u;

Transfer cost is divided into the following:

- Fixed transfer cost into account: γ_0^+;
- Fixed transfer cost from account: γ_0^-;
- Variable transfer cost into account:γ_1^+;
- Variable transfer cost from account: γ_1^-;

In this case, the authors considered that every transfer has an associated cost, which varies according to the type of operation, whether in investing cash for another asset or withdrawing from the asset for cash. Moreover, this transfer cost has a fixed amount per transaction, usually associated with bank fees or brokerage, and a variable value that typically represents a percentage of commissions or taxes related to operation. Then, the cash balance (O) on date $t+1$ is

$$O_{t+1} = O_t + K_t + w_t \tag{14}$$

where
K represents the changes made by the management to invest and withdraw; and
w represents an exogenous change of balance from uncontrolled inflows and outflows (cash flow).

The transfer cost of money (γ) each day (t) within the period is provided as follows:

$$\Gamma(K_t) = \begin{cases} \gamma_0^- - \gamma_1^- K_t, & K_t < 0, \\ 0, & K_t = 0, \\ \gamma_0^+ - \gamma_1^+ K_t, & K_t > 0, \end{cases} \tag{15}$$

The holding cost (h) and shortage cost (u) are associated with the respective percentages of financial costs established. After formatting the DSP model, Gormley and Meade (2007) used data from a multinational company and a genetic algorithm model applied to solving continuous problems proposed by Chelouad and Siarry apud (Gormley and Meade 2007) to obtain the parameters that minimize the total cost (holding, shortage, and transfer) of cash holding, obtaining significant results, especially in a time horizon longer than 2 days.

Following this same uncertain stochastic problem model, Liu and Xin (2013) presented an adaptive algorithm with characteristics of changing the management policies at the beginning of each period to know the upper and lower demands for money, even without the knowledge of the probability distribution of demand from cash.

In another recent model, Baccarin (2009) develops the best cash balance using a standard n-dimensional Wiener process adapted to this problem using the impulse control method. The great contribution of this methodology is the multidimensional application, which eliminates the restriction on two options of assets (cash or bonds) since it is the restriction on only two financial assets, which rarely occurs in practice.

In this way, Baccarin (2009) describes the function of cost control for two bank accounts. The author assumes that those cash inflows and outflows which cannot be predicted have no systematic trend; that is, we set $b_1 = b_2 = 0$, suppose the cash stock dynamics corresponding to these cash flows are independent, with a common standard deviation. The cost function expression is as follows:

$$C(\xi_1, \xi_2) = C + c_1(|\xi_1 + \xi_2|) + c_2(|\xi_2|) \tag{16}$$

where

$C > 0$	is a fixed cost;
$c_1(\lvert\xi_1 + \xi_2\rvert)$	is a variable cost related to investments of high-liquidity purchase and sale, from accounts 1 and 2, with the corresponding random vectors ξ_i of the impulse control;
$c_2(\lvert\xi_2\rvert)$	is a variable cost paid by transferring money between different accounts, from account 1 to account 2.

Furthermore, the Baccarin model uses nonlinear functions to determine the transfer costs and maintenance/penalty in cash. Despite these advantages, the model uses stochastic process techniques, which have large computational costs when developing complex models Baccarin (2009).

The problems related to the risk of lack of cash and liquidity preference are recovered in the work of Mierzejewski (2010), where the author develops a stochastic model considering the premise of the demand for cash balance with normal distribution and applied the value-at-risk (VaR) methodology, with the limitation of market equilibrium for the cash flows and portfolio investments used, from an average rate of return.

In another model, the authors Melo and Bilich (2011) propose the use of dynamic programming to minimize the cost of the cash, considered together the cost of rupture cash. In this model, the cash flow has two parts: a deterministic part, by which the firm expects to have receipts and payments, and other stochastic. Thus, the lowest cost is

$$C_{\Delta t} = \left\{ \sum_{i=1}^{n} \left[\int_{-\infty}^{\infty} \alpha_{\Delta t}\left(B_{i,\Delta t}\right) \gamma_{i,\Delta t} P\left(B_{i,\Delta t}\right) \mathrm{d}B_{i,\Delta t} \right] \right\} \tag{17}$$

where
$C_{\Delta t} = 0$ is the minimum total cost;

Existing are N blocks with (N intervals of stochastic cash flows). So the cash flow of the previous period $B_{\Delta t-1}$ is added to the expected cash flow (deterministic), to the stochastic net cash flow and to the variable rescue decision on investment $(X_{\Delta t})$, obtaining the current cash flow $B_{\Delta t}$.

The result $(B_{\Delta t})$ is multiplied by the probability $P\left(B_{i,\Delta t}\right)$, which represents the expectation of the cash balance. The interest rate that represents the cost of lack or remains of cash (depending on the positive/negative flow) $\gamma_{i,\Delta t}$ is applied. Thus, the value $X_{\Delta t}$ acts in minimizing the cost function (Melo and Bilich 2011). However, the major limitation of this model is found in the definition of the intervals corresponding to stochastic flows and determining the probability associated with them. The authors suggest the use of artificial intelligence techniques as possible applications for prediction, performing the fit of the model variables.

Considering this, from the original work to the most current, the theoretical conceptualization of optimizing the cash balance problem still has practical limitations in its application, such as restrictions in applying the model and ways of development primarily focused on stochastic models.

The major limitation of stochastic models is the need of prior knowledge about the distribution of cash flows Kachani and Langella (2005). This demonstrates the importance of searching for references on the subject and delineating models developed in this point of view, opening up perspectives for new approaches and application of computational tools for this problem. We summarize the most important literature studies concerning the cash flow management problem since the 1980s in Table 1.

3 New Perspectives

The literature on the cash balance problem shows that from the 1980s, research that deals with reasons that cause firms to maintain cash resources is presented essentially to scientific journals in the field of economics, accounting, and finance.

Table 1 Selected studies on stochastic cash flow management models

Authors	Research summary	Journal/conference	Subject of journal/conference
Baumol (1952)	Proposes that the available cash balance is a commodity inventory	Quarterly Journal of Economics	Economics and finance
Tobin (1956)	Adjusts the Baumol model, so the number of transactions becomes a positive integer value	The Review of Economics and Statistics	Economics and finance
Miller and Orr (1966)	Analyze the cash balance as having a random variable with an irregular fluctuation and proposed a stochastic model for managing the cash balance	Quarterly Journal of Economics	Economics and finance
Whalen (1966)	Presents a model based on the concept of inventory considering the cost of illiquidity, the opportunity cost of maintaining a precautionary cash balance and the average volume and variability of inflows and outflows	Quarterly Journal of Economics	Economics and finance
Daellenbach (1974)	Concludes that in cases where cash flows are non-stationary series, the optimization models cannot make significance gains if the transfer costs are low	Journal of Financial and Quantitative Analysis	Economics and finance
Gregory (1976)	Presents a survey by the models until the mid-1970s focused on variants of the Miller and Orr (1966)	Omega	Operational research and computational optimization
Tapiero and Zuckerman (1980)	Present a stochastic model based on the premise that cash inflows and outflows have random behavior	Journal of Banking and Finance	Economics and finance
Milbourne (1983)	Presents a model separating the transfer costs into two categories, in other words, cost for currency units to adjust the cash balance up and cash balance down	International Economic Review	Economics and finance
Srinivasan and Kim (1986)	Present the principles of deterministic models until the mid-1980s	Omega	Operational research and computational optimization

(continued)

Table 1 (continued)

Authors	Research summary	Journal/conference	Subject of journal/ conference
Smith (1986)	Develops a stochastic dynamic model, considering the cash flow as a diffuse process	The Review of Economic Studies	Economics and finance
Ogden and Sundaram (1998)	Propose the utilization of a credit line if the firm gets a cash deficit considering an interest rate associated with this credit line and the assumptions of Baumol	Journal of Financial and Strategic Decisions	Economics and finance
Pacheco et al. (2000)	Develop a genetic algorithm to determine investments in financial products available on the market based on the projected cash flow	6th International Conference of Society for Computational Economics on Computing in Economics and Finance	Economics and finance
Hinderer and Waldmann (2001)	Propose the utilization of Markov chains in the problem	European Journal of Operational Research	Economics and finance
Barbosa and Pimentel (2001)	Develop and applied a model in civil construction projects very successfully	Construction Management and Economics	Economics and finance
Baccarin (2002)	Proposes a modeling variation that changes the focus of the optimization problem	Decision Economics Finance	Economics and finance
Premachandra (2004)	Shows a model considering the assumptions of normal distribution of net cash flows and that the fixed transfer costs are relaxed in order to obtain a model closer to reality	European Journal of Operational Research	Operational research and computational optimization
Volosov et al. (2005)	Develop a stochastic programming model in two states, based on scenario trees, for the problem of cash balance	Computational Optimization and Applications	Operational research and computational optimization
Yao et al. (2006)	Show a single-period model, considering the demand for money according to fuzzy logic concepts, for the problem of cash balance	European Journal of Operational Research	Operational research and computational optimization

(continued)

Table 1 (continued)

Authors	Research summary	Journal/conference	Subject of journal/conference
Gormley and Meade (2007)	Propose the utilization of dynamic policy for cash balance that minimizes transfer costs when cash flows are not independent or identically distributed in a general cost structure	European Journal of Operational Research	Operational research and computational optimization
Liu and Xin (2008)	Propose an adaptive algorithm with characteristics of changing the management policies at the beginning of each period to know the upper and lower demands for money	Fourth International Conference on Natural Computation	Operational research and computational optimization
Baccarin (2009)	Presents a standard *n*-dimensional Wiener process using the impulse control method, for the problem of cash balance	European Journal of Operational Research	Operational research and computational optimization
Mierzejewski (2010)	Develops a stochastic model considering the premise of the demand for cash balance with normal distribution and applied the value at risk (VaR)	IMA Journal of Management Mathematics	Operational research and computational optimization
Melo and Bilich (2011)	Propose the use of dynamic programming to minimize the cost of cash, considering the cost de rupture cash	Journal of Economics And Finance	Economics and finance

Concerning the focus of studies on developing models for managing the cash balance, we have a revival since 2000 mostly in journals of the areas of operational research, computing, and management sciences.

Considering this, the more recent models focus on the efficiency of optimization, but do not observe all aspects of managing cash. Therefore, cash management decision must have the same importance like other investment decisions, observing the aspects of profitability, liquidity, and risk:

- Profitability: The existence of cash itself does not generate profit for the firm, but it is necessary to develop its activity. Thus, observing the cost associated with cash, the firm can attempt to improve its profitability by minimizing the associated costs;
- Liquidity: The investment in cash has total liquidity, but financial investments (typically bonds), which are the option to direct the excess cash and obtain cash when there is a need to withdraw it, may not have a ready market and this is a strong limitation for traditional models; and
- Risk: We must observe the risk by both the occurrence of cash shortage, where there is a need to take funds from third parties, and from overtrading, when the firm does not have lines of credit compared to their need for cash and insolvency may incur.

Observing these aspects, the development of models should consider investing cash resources in more than one option besides cash, with returns, minimum periods of investment/withdrawal (liquidity) and transfer costs, fixed and variable, and different for each option. Furthermore, the possibility of obtaining financial resources in case of cash deficit should be observed, once again with financial costs (interest) and transfer costs different for each funding source.

Moreover, the possibility of financial leverage, something which given the cash flow conditions and financial and investment options, as well as the opportunity and financial costs, may indicate to the firm to maintain a negative cash balance as being the best alternative. Therefore, the new developing models must meet these needs simultaneously, which exist in practice, but we not observed in recent cash management models.

The use of multiobjective functions with a combination of three factors to analyze investments (risk, profitability, and liquidity), according to the probability of the cash balance at date t being less than the maximum cash shortage than that of the firm, is able to support given the final cash flow at date $t-1$, which serves the assumption of a stochastic process and certain time limits to withdraw the investment i and the maximum cash shortage value less than zero (assumption of negative cash) or ultimately equal to zero as, for example, when the firm has no immediate lines to credit.

It is important to note that the minimization of the total risk of cash would result in zero probability of there being a cash balance below the maximum cash shortage (or a negative cash balance in case of maximum cash shortage equal to zero). This rarely occurs in practice, since it implies a high concentration of cash balance, and therefore, the definition of risk profiles to be minimized is acceptable.

Traditionally, cash management models indicate a choice between maintaining the cash resource and an investment option, usually a highly liquid asset (bonds), something that hampers the practical application of existing models, as investment options have differentiated profitability, risk, and liquidity. Moreover, the framework must foresee the use of more than one source of funds in cases of cash deficit, with different time limits and financial costs.

Applying different probability distributions simultaneously, despite the use in some studies of Poisson distribution or Brownian motion (Wiener process), the literature essentially uses the normal distribution, without comparing the models in samples with different distributions. The Poisson distribution, for example, is relevant in cases of concentrating payments or receipts over specific periods, which is what justifies its application.

On the other hand, the meta-heuristics and evolutionary computational models in this problem have not been investigated enough, using only genetic algorithms. The models presented in the literature mostly use stochastic modeling. Moreover, this option is relevant because it is easy to develop the algorithm to different patterns of cash flow distribution as there is no need to know the distribuition of the cash flow because the model can adapt based on historical or projected data.

4 Conclusions

Managing the cash balance is important in business administration, but rarely do we apply the techniques presented in this study in practice. Much of this neglect is due to the difficulty in developing models closer to reality.

Considering this, the literature review shows the importance of cash balance within firms, but the development of cash management models are still bound to formulations developed over nearly five decades, without improving the used model. Furthermore, the view of the cash balance is still limited and not regarded as an investment, which has a negative profitability (defined by total cost of the cash), immediate liquidity, and risk associated with cash deficit. Thus, it is necessary to understand the cash balance together with other financial investments as a portfolio investment and examines the investment choices in financial products according to their variable liquidity, profitability, and associated risk.

Another relevant aspect to us is the methodology in developing cash management models. The literature shows a clear preference for stochastic models, and the researchers do not use computer models.

The use of evolutionary computational algorithms, not only genetic algorithms, can reduce limitations when developing more complex models, reducing the constraints presented in this work and making computational implementation easier in accounting and financial management systems within firms.

We can also analyze the distribution of article in the journal's areas. Originally, the articles were presented in journals of economics and finance, but, with the evolution of methods and computer applications in 2000s, the major area of publication has been the operational research and computational optimization. This demonstrates a greater concern about the method, but not with the problem's formulation.

Finally, this is a classic problem in business, involving economics, accounting, and finance, and it should return to be the focus of discussions in these areas, as the existing limitations concerning the models and methods can be eliminated. We must discuss the cash balance problem not only about the method involved in optimization but also in practical application.

References

Baccarin S (2002) Optimal impulse control for cash management with quadratic holding-penalty costs. Decisions Econ Finan 25(1):19–32

Baccarin S (2009) Optimal impulse control for a multidimensional cash management system with generalized cost functions. Eur J Oper Res 196(1):198–206

Barbosa PSF, Pimentel PR (2001) A linear programming model for cash flow management in the Brazilian construction industry. Constr Manage Econ 19(5):469–479

Baumol WJ (1952) The transactions demand for cash: an inventory theoretic approach. Q J Econ, 545–556

Daellenbach HG (1974) Are cash management optimization models worth while? J Financ Quant Anal 9(4):607–626

Gormley FM, Meade N (2007) The utility of cash flow forecasts in the management of corporate cash balances. Eur J Oper Res 182(2):923–935

Gregory G (1976) Cash flow models: a review. Omega 4(6):643–656

Hinderer K, Waldmann KH (2001) Cash management in a randomly varying environment. Eur J Oper Res 130(3):468–485

Kachani S, Langella J (2005) A robust optimization approach to capital rationing and capital budgeting. Eng Econ 50(3):195–229

Liu B, Xin C (2008) An online model for managing cash: an alternative approach to the Miller-Orr model. In: 2013 international conference on computing, networking and communications (ICNC). p 314-317

Melo MAS, Bilich F (2011) Expectancy balance model for cash flow. J Econ Finan 37(2):240–252

Mierzejewski F (2010) A model of equilibrium in markets of cash balances. IMA J Manage Math 22(3):253–270

Milbourne R (1983) Optimal money holding under uncertainty. Int Econ Rev, 685–698

Srinivasan V, Kim YH (1986) Deterministic cash flow management: state of the art and research directions. Omega 14(2):145–166

Tobin J (1956) The interest-elasticity of transactions demand for cash. Rev Econ Stat, 241–247

Miller MH, Orr D (1966) A model of the demand for money by firms. Q J Econ, 413–435

Whalen EL (1966) A rationalization of the precautionary demand for cash. Q J Econ, 314–324

Tapiero CS, Zuckerman D (1980) A note on the optimal control of a cash balance problem. J Bank Finance 4(4):345–352

Smith GW (1986) A dynamic Baumol-Tobin model of money demand. Review Econ Stud 53 (3):465–469

Ogden WA, Sundaram S (1998) A model for optimal utilization of a firm's line of credit. J Finan Strateg Decis, 27–36

Pacheco MA, Noronha M, Vellasco M, Lopes C (2000) Cash flow planning and optimization through genetic algorithms. In: 6th international conference of the society for computing in economics and finance, Society for Computational Economics

Premachandra IM (2004) A diffusion approximation model for managing cash in firms: an alternative approach to the Miller-Orr model. Eur J Oper Res 157(1):218–226
Volosov K, Mitra G, Spagnolo F, Lucas C (2005) Treasury management model with foreign exchange exposure. Computational Optimization and Applications 32(1–2):179–207
Yao JS, Chen MS, Lu HF (2006) A fuzzy stochastic single-period model for cash management. Eur J Oper Res 170(1):72–90

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Multi-attribute Utility Model Based on the Maximum Entropy Principle Applied in the Evaluation of the Financial Performance of Brazilian Banks

Ivan Ricardo Gartner

Abstract This paper aims to present a methodology for modeling the financial performance of Brazilian banks. The methodology is based on multi-attribute utility methods that are applied in the aggregation of financial ratios. The weights of these ratios are obtained by the principle of maximum entropy, with the intention of making an objective and non-biased analysis. The methodology is applied to samples of Brazilian banks in the period from 2004 to 2013, and the results are analyzed using a scale of ten risk groups. The methodology proves to be valid in analyzing the financial performance of banks and can be used to support the formulation of industry performance restrictions for problems of portfolio optimization, resource allocation, and credit analysis.

Keywords Financial performance · Maximum entropy principle · Multi-attribute utility model · Performance risk in banking

1 Introduction

The financial performance quality of banking institutions is crucial to guarantee the stability of economic systems. Any deterioration in the financial status of a bank can cause their clients and creditors to suffer losses, with possible ramifications within the banking system as a whole, due to wider fallout effects.

It is for this reason that central banks and other financial system regulating bodies worldwide have sought to act to prevent banks with financial difficulties to participate in the market, in an effort to avoid shock waves affecting the security of the financial system as a whole.

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Since national financial systems are becoming increasingly interconnected, the possibility that financial fragility and the resulting domestic banking crises can now trigger negative repercussions on a global scale has led to the organization of international agreements, most notably Basel III (or the Third Basel Accord).

The Basel Accords are generally used in cases involving maximum levels of financial risk exposure, notably by establishing regulatory sums of capital to ensure a bank has a guaranteed margin to cover possible debts resulting from imminent liquidation. In addition, the Basel Accords provide a wide range of financial management tools, including mechanisms to measure credit risk.

Although the Basel Accords provide a wide range of management tools, no definitive model yet exists to evaluate financial banking performance. This type of evaluation tends to be carried out according to specific norms established by each central bank or government agency responsible for supervising the banking sector.

One approach used by many banking supervisory bodies is the CAMELS classification system, which consists of six different categories, including capital adequacy, asset quality, management capacity, earnings, liquidity, and market risk sensitivity (Koch and MacDonald 2000).

The CAMELS approach, which was originally designed to classify the overall condition of American banks, has also been used in the area of academic studies, such as those carried out by Kao and Liu (2004), Koetter et al. (2007), and Fethi and Pasiouras (2010).

One of the criticisms levelled against the CAMELS methodology was made by Kao and Liu (2004), who say that this classification system measures various financial indicators extracted from a bank's regular account statements, which are aggregated on the basis of various weighting procedures, which may be biased since these involve subjectivity.

Adopting more transparent and less biased procedures is essential to ensure that proactive and reactive actions are planned and taken to ensure that the financial performance of a vulnerable bank does not jeopardize the stability of the economic system in which it is inserted. So, it is essential to obtain information about the financial performance of a vulnerable bank in comparison with the performance of other banks so that overall standards of performance may be monitored.

Such monitoring can be carried out by means of a process of performance appraisal based on a benchmarking approach. By using this approach, common appraisal criteria are defined, and the results obtained by the bank can be compared to those of the best banks within the system.

In this context, since transparency and clarity are sought in the assessment process, this paper aims to present a methodology that can measure and analyze the financial performance of banks, so as to meet the non-bias and objective requirements of a benchmarking type of analysis.

For this, we propose to construct a financial performance index, by taking into account the principle indicators that form the basis of the CAMELS system, which is calculated from the financial statements published by the banks. Since each one of these indicators has its own dimensional analysis, it was decided to model their comparability and aggregation by means of multi-attribute utility methods, using the displaced ideal theory. This produces a weighted additive linear function, in which the weights were obtained objectively, through a non-linear optimization process based on the maximum entropy principle.

Although the proposed methodology is an alternative approach to the usual statistical correlation methods, this forms part of a group of optimization tools that are used in the field of operational research, which has shown enormous advances in the last few decades in providing models for corporative evaluation and risk management problems.

Once the proposed methodology has been applied to evaluate the financial performance of banks, it is proposed that a complementary analysis of the findings is made, so as to find out if a relationship exists between bank performance and risk classification, which can provide decision-making guidelines for the different elements that interact with the banks analyzed, notably the regulatory bodies.

This work is organized as follows: Sect. 2 includes a short summary of the theoretical references related to the construction of risk analysis indexes, based on the economic–financial indicators taken from bank statements, as well as specific questions about the extended analyses of banks. In Sect. 3, we present our methodological approach, with a description of the financial performance index modeling and the maximum entropy optimization procedure for generating the weights. Section 4 presents the empirical procedures, with an analysis of the application results and the analysis expansion of the performance risk classifications. Finally, we present our conclusions and recommendations for the application of this methodology, as well as proposals for further research studies and applications.

2 Literature Review

The financial performance of companies is based on economic and financial indicators that are calculated by using the financial statements published in specialist media outlets. While this financial information is used to guide decisive corporative procedures, it is also used to promote analysis and decisive procedures that occur outside the companies, involving groups that are interested in the corporation, but who usually do not take part in its decision-making proceedings.

In the case of banks, in addition to shareholders, there is a wide range of interest (stakeholders) in obtaining information that will make it possible to measure a certain bank's financial performance, including in particular regulatory bodies and other banks with which the bank in question maintains business relationships.

In general terms, these elements help to identify the level of efficiency with which a bank uses its capital in comparison to other banks, so as to identify its ability to survive within the market and to gauge any risk of its insolvency or bankruptcy. The dimensionality of risks of insolvency or bankruptcy was the principle reasons for the development of traditional methodology to analyze economic–financial indicators, as can be seen in the work by Altman (1968), which is considered to be a classic in the area. In his seminal work, Altman used a multiple discriminant analysis and a selection of companies, with the view to constructing a single-criterion function of synthesis *Z*, which involves a weighted additive linear function composed of five financial indicators. The objective of this function is to measure the level of a company's financial health, making it possible to compare this with other companies, since the sampling involves other companies within the same field of activity.

Ever since then, Altman's work has motivated the development of many other studies and research works, notably those applied to the analysis of credit risk, that have been based on a wide range of modeling methods and procedures, which have surpassed those based on correlational statistical models operationalized by regression analysis.

In an environment of artificial intelligence, insolvency and bankruptcy risk analyses have been carried out by using neural networks (Angelini and Giacomo 2008) and Bayesian networks (Bonafede and Giudici 2007), for instance. In terms of operational research methods, particular reference is made to linear programming models (Freed and Glover 2007), simulation models (Board et al. 2003), multi-criteria decision-aid methods (Mareschal and Brans 1991), multiple criteria hierarchy analytical models (Doumpos et al. 2002), and data envelopment analysis (Cielen et al. 2004).

Among the operational research tools available, data envelopment analysis has gained major significance, especially when evaluating the efficiency and performance in the banking sector. This can be seen in the study developed by Fethi and Pasiouras (2010), who carried out a wide-ranging review of operational research and applied artificial intelligence methods and highlighted the importance of a data envelopment analysis in efficiency studies.

Although studies involving banks have been mainly directed toward measuring their efficiency by means of data envelopment analysis, it is important to establish that their objectives are very different to those of a financial performance analysis. An analysis of efficiency is based on a comparison of the relevant input–output ratio, which means it only has an indirect relationship with performance and risk. On the other hand, the results of a financial performance analysis can be extrapolated when establishing risk categories, notably for the purpose of advising guide regulatory bodies about the possibility of a banking default and subsequent repercussions for the stability of the economic system.

3 Decision Model

The proposed decision model to evaluate the financial performance of banks is applied in seven stages, as shown in Table 1. These stages describe general procedures applied to problems involving multiple objectives (see Keeney and Raiffa 1976), which were adapted to the decision-making context analyzed and to the entropy optimization procedures used in this study.

Table 1 Multi-attribute utility model based on maximum entropy principle methodology stages

Step	Description	Action
1	Contextualization of the decision problem	Identification of the decision problem Definition of the theoretical framework Definition of empirical procedures
2	Identification of criteria for analysis	Definition of indicators for analysis Definition of the optimal objective for each indicator Definition of the value functions for the indicators through standardization
3	Aggregation of variables in the performance function (index)	Formulation of the weighted additive function
4	Estimation of weights for the performance function (index)	Calculation of weights by the maximum entropy optimization process
5	Calculation of the performance function for observation units (banks)	Calculation of the performance index for each bank in the sample
6	Analysis of the results	Risk analysis of the performance indices
7	Recommendations for the decision-making process	Recommendation of preventive and corrective actions

The contextualization of the decision-making process (stage 1) refers to the motivation and theoretical–empirical framework of this paper, which offers a methodology to assess the financial performance of banks, based on a procedure that reduces the risk of producing a subjective and biased analysis. The later stages of this analysis (2–7) are presented further in this paper.

3.1 *Functional and Algebraic Formulas of the Financial Performance Index F*

For the purpose of this research paper, the financial performance of banks can be summarized as financial performance index *F*, which is based on the previously mentioned CAMEL classification system, bearing in mind that the element related to market sensitivity (S) has been excluded. When defining the indicators that compose this index, the proposals put forward by Koch and MacDonald (2000) and Koetter et al. (2007) have been taken into account.

In accordance with the CAMEL classification system, the performance of the *i*th bank (F_i) may be defined as a function of the five groups of indicators, which summarize capital adequacy (c), asset quality (a), management capacity (m), ability to generate earnings (e), and liquidity (l), represented as follows:

$$F_i = f(c_i, a_i, m_i, e_i, l_i) \tag{1}$$

The capital adequacy of a bank (c_i) can be measured by two indicators, which are as follows:

- Indicator of capital adequacy (ca_i), that is measured by the ratio of total equity (E_i) against the total assets (A_i) of the bank analyzed, or $ca_i = E_i/A_i$.
- Indicator of leverage (cl_i), that is measured by the ratio of total debts (D_i) against the total equity (E_i) of the bank analyzed, or $cl_i = D_i/E_i$.

The asset quality of a bank (a_i) can be measured by the credit risk indicator (cr_i), which is calculated by the ratio of net loan loss provision (LP_i) against the total loans (CC_i) of the bank analyzed, or $cr_i = |LP_i|/CC_i$.

The management capacity of a bank (m_i) can be measured by two indicators, which are as follows:

- Indicator of employee productivity(ep_i), that can be measured by the ratio of net income (NI_i) against the total number of employees (EN_i) of the bank analyzed, or $ep_i = NI_i/EN_i$.
- Indicator of agencies productivity (ap_i), that can be measured by the ratio of net income (NI_i) against the number of agencies (AG_i) of the bank analyzed, or $ap_i = NI_i/AG_i$.

The ability to generate earnings of a bank (e_i) can be measured by three indicators, which are as follows:

- Indicator of net income (ni_i), that can be measured by the ratio of net income (NI_i) against the total asset (A_i) of the bank, or $ni_i = NI_i/A_i$.
- Indicator of operating income (oi_i), that can be measured by the ratio of interest income (II_i) and the total asset (A_i) of the bank, or $oi_i = II_i/A_i$.
- Indicator of diversified income (di_i), that can be measured by the ratio of non-interest income (NII_i) against the total income (TI_i) of the bank, or $di_i = NII_i/TI_i$.

The liquidity of a bank (l_i) can be measured directly by the ratio of the sum of cash and interbanking asset $(CIBA_i)$ against the total asset (A_i) of the bank, or $li_i = CIBA/A_i$.

Detailing the indicators makes it possible for function (Eq. 1) to be rewritten as:

$$F_i = f(ca_i, cl_i, cr_i, ep_i, ap_i, ni_i, oi_i, di_i, li_i) \quad (2)$$

Considering that the composition of the financial performance index F_i assumes the characteristics of linear additives, as well as ratio factors w to differentiate the importance of the indicators, as represented in the following algebraic form:

$$F_i = w_1ca_i + w_2cl_i + w_3cr_i + w_4ep_i + w_5ap_i + w_6ni_i + w_7oi_i + w_8di_i + w_9li_i \quad (3)$$

The standardization of equation (Eq. 3) can be made by replacing indicators for the generic term x:

$$F_i = w_1x_{i1} + w_2x_{i2} + w_3x_{i3} + w_4x_{i4} + w_5x_{i5} + w_6x_{i6} + w_7x_{i7} + w_8x_{i8} + w_9x_{i9} \quad (4)$$

in that each indicator identified by the notation $j(j = 1, \ldots, 9)$ can be seen in an aggregated form with:

$$F_i = \sum_{i=1}^{n}\sum_{j=1}^{9} w_j x_{ij}\,, \quad \text{for} \sum_{j=1}^{9} w_j = 1 \quad \text{and} \quad 0 \leq w_j \leq 1. \quad (5)$$

3.2 Multi-attribute Model and the Theory of the Displaced Ideal

Although all x_{ij} indicators that form index F_i were taken from the financial statements of the banks analyzed and are essentially economic–financial criterion, each one has its own dimension, meaning, and objective in the analysis. This means that index F_i is characterized by dimensional multiplicity, which model requires specific tools, notably those based on multiple criteria decision-making methods.

Of existing methods, it was decided to use the multi-attribute utility method, which presents good adhesion in situations where the objective is to construct indexes, since this uses a single-criterion synthesis approach, as shown in equation (Eq. 5).

In accordance with the requirements of the single-criterion synthesis model, it was decided to use the modeling proposed by Jessop (1999, 2004), which meant that F_i was transformed into a simple linear utility function. This can be operationalized in (Eq. 5) by including a value function of u_j in x_{ij}, resulting in

$$F_i = \sum_{i=1}^{n}\sum_{j=1}^{9} w_j u_j\left(x_{ij}\right) \quad (6)$$

where $u_j\left(x_{ij}\right)$ is the value function of indicator j of company i.

The use of value function $u_j\left(x_{ij}\right)$ has two objectives in this model. The first is to restrict the value of index F_i in interval [0, 1], since values 1 and 0 represent, respectively, the highest and lowest possible performance for this index. The data limitation for interval [0, 1] is a necessary condition for the entropy maximization procedure, which is detailed in Sect. 3.3. The second objective is to include a measurement of comparability in this evaluation to show the maximum and minimum performances obtained by each bank i within the sector analyzed. This comparability measurement can be operationalized by means of the theory of the displaced ideal, as shown in the work of Diakoulaki et al. (1992, 1995) and Jessop (1999, 2004). The theory of the displaced ideal assumes that the evaluation takes into account the performance differentials that exist between the banks in relation to the maximum obtained within the sector, which meet the principles of benchmarking, that is to say, a comparison based on reference levels. Thus, the required standards for an evaluation are defined so as to monitor the continued improvement of the bank's performance, taking into account its economic restrictions and current technology.

For the value observed in each indicator j of bank i, a membership function u_j is defined, which maps values x_{ij} in interval [0, 1]. This function $u_j(x_{ij})$ shows if the performance of bank analyzed i is:

- close to the ideal value $\max_i u_j(x_{ij})$, which represents the best indicator j performance in the group of banks analyzed;
- far from the anti-ideal value $\min_i u_j(x_{ij})$, which represents the worst indicator j performance in the group of banks analyzed.

For each bank i, the value of $u_j(x_{ij})$ is defined in relation to the optimization operator of indicator j. For those indicators whose operator represents performance maximization, as is the case of indicators *ca* (x_1), *ep* (x_4), *ap* (x_5), *ni* (x_6), *oi* (x_7), *di* (x_8), *li* (x_9), the ideal mark is the maximum value. So, the value function is calculated as follows:

$$u_j(x_{ij}) = x_{ij} - \min_i x_{ij} / \max_i x_{ij} - \min_i x_{ij} \tag{7}$$

In those cases where the ideal mark is the minimum value, as in the case of leverage indicators *cl* (x_2) and credit risk indicators *cr* (x_3), the value function takes on the following form:

$$u_j(x_{ij}) = \max_i x_{ij} - x_{ij} / \max_i x_{ij} - \min_i x_{ij} \tag{8}$$

where $\max_i u_j(x_{ij})$ corresponds to $\max\{x_{1j}, x_{2j}, x_{3j}, \ldots, x_{nj}\}$ and $\min_i u_j(x_{ij})$ refers to $\min\{x_{1j}, x_{2j}, x_{3j}, \ldots, x_{nj}\}$, in that in both cases $j = 1, \ldots, 9$.

As a result, u_j produces a value of 1 for the banks with the best performance, as observed in indicator x_{ij} and a value of 0 for the bank with the worst performance, bearing in mind that banks with other performance rates will be given intermediate values in interval [0, 1].

3.3 Calculation of the Vector of Optimal Weights W^*

In the multi-criteria decision-making group of methods, the levels of importance assigned in relation to the variables, known as weights (w_j), are usually obtained by using two types of approach: subjective and objective. Subjective approaches are recommended for complex and decisive questions that need to explicitly show the preferences and values of the decision makers. In these cases, methods such as the *Analytic Hierarchy Process* (Saaty 1990) and MacBeth (Bana e Costa and Chagas 2004) are recommended.

Based on the assumption that an evaluation of the performance of banks should be objective, and therefore free of any form of bias, for the purpose of this paper, it was decided to adopt an objective approach when calculating weights. Among the objective approaches, we should underline the operational research methods used where the weights are attributed based on the different values assumed by the variable in the data series observed, by means of models of mathematical programming.

This focus on the different values assumed is required in cases where there are problems involved in evaluating the performance of banks, since variables with the greatest coefficient variation in the data series observed should be given greater importance in relation to the analysis and vice versa. That is to say, the more widely spread bank performances are in relation to a variable, the greater weight this variable should have in an overall assessment.

This diffusion of values associated with a variable can be seen as a sign of the level of disorder of the data vector. Thus, the greater the level of disorder in the vector values observed by the variable, the greater its weight will be. As a result, a suitable method to extract weights in situations where there is fuzzy information should be based on the maximum entropy principle (Hwang and Yoon 1981; Zeleny 1982; Jessop 1999, 2004; Xu 2004).

Among these authors, the work of Jessop (2004) presents a proposal where a maximum entropy principle can be applied, where the least biased classifications among the alternatives analyzed are taken into account, in what is known as the *maxEntScores* or the maximum entropy scores. In this paper, scores are defined as the value functions of the performance of each bank in indicators $(u_j(x_{ij}))$.

According to Jessop (2004, p. 12), the entropy of an arbitrary vector Z is calculated by:

$$H(Z) = \ln\left(\sum_{i=1}^{n} z_i\right) - \sum_{i=1}^{n} z_i \ln(z_i) \Big/ \sum_{i=1}^{n} z_i \tag{9}$$

So, the vector of optimal weights $(\mathbf{w}^*)$ is obtained by adapting the equation (Eq. 9) proposed by Jessop to index calculation function F_i (Eq. 6), which will produce the following non-linear optimization problem:

$$\max\ H(X) = \ln\left(\sum_{i=1}^{n}\sum_{j=1}^{9} w_j u_j(x_{ij})\right) - \sum_{i=1}^{n}\left[\sum_{j=1}^{9} w_j u_j(x_{ij}) \cdot \ln\left(\sum_{j=1}^{9} w_j u_j(x_{ij})\right)\right] \Big/ \sum_{i=1}^{n}\sum_{j=1}^{9} w_j u_j(x_{ij}) \tag{10}$$

s.t.:

$$\sum_{j=1}^{9} w_j = 1 \tag{r.1}$$

$$w_j \geq 0 \tag{r.2}$$

The original proposal put forward by Jessop (2004) made it possible to include restrictions related to optimization problems, especially in cases where there are judgement matrices for decision-making preferences and values. Since in this instance, it is our aim to develop an entirely objective model, only unit restriction of the vector of weights **w** (r.1) and their non-negativity values (r.2) will be considered.

3.4 A Matrix Form for a F_i Financial Performance Index

In accordance with the matrix equivalent to equation (Eq. 6), whereas the vector of optimal weights $\mathbf{w}^*$ obtained from (Eq. 10), the calculation for the index vector **f** for the banks can be obtained by:

$$\mathbf{f} = \mathbf{w}^{*\mathbf{T}}\mathbf{U} \tag{11}$$

where $\mathbf{w}^{*\mathbf{T}}$ is the transposed vector for optimal weights $\left[w_j^*\right]_{9\times 1}$ and **U** is the matrix of the performance of the banks in the value indicator function $\left[u_j(x_{ij})\right]_{n\times 9}$, in that the expansion of this matrix notation can take the following form:

$$\begin{pmatrix} F_1 \\ F_2 \\ \vdots \\ F_{n-1} \\ F_n \end{pmatrix} = \left(w_1^*, w_2^*, \ldots, w_9^*\right) \times \begin{pmatrix} u_1(x_{11}) & u_2(x_{12}) & \cdots & u_9(x_{19}) \\ u_1(x_{21}) & u_2(x_{22}) & \cdots & u_9(x_{29}) \\ \vdots & \vdots & \ddots & \vdots \\ u_1(x_{n_{-1}1}) & u_2(x_{n_{-1}2}) & \cdots & u_9(x_{n_{-1}9}) \\ u_1(x_{n1}) & u_2(x_{n2}) & \cdots & u_9(x_{n9}) \end{pmatrix}$$

4 Application of the Decision Model

4.1 Population and Sample

The financial performance index F_i was used with the group of banks I, which form a conglomerate composed of at least one commercial or multiple banking institution with a trading portfolio, covering the period between 2004 and 2013 (see Table 2).

Table 2 Population and sample of Brazilian banks researched—2004–2013

Description/year	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004
Population of banks[a]										
• Number of banks	1.309	1.351	1.466	1.490	1.530	1.579	1.578	1.561	1.556	1.556
• Total assets (R$ billion)	6.533	5.931	5.100	4.350	3.582	3.274	2.536	1.982	1.658	1.437
Sample[b]										
• Number of banks	96	99	101	101	100	101	101	104	104	108
• Total assets (R$ billion)	5.507	5.016	4.303	3.666	3.065	2.883	2.245	1.727	1.43	1.224
Representativeness of the sample (%)	84.3	84.6	84.4	84.3	85.6	88.1	88.5	87.1	86.2	85.2
Available sample[c]										
• Number of banks	82	85	92	91	94	96	96	98	99	99
• Total assets (R$ billion)	5.479	5.002	4.297	3.654	3.059	2.881	2.242	1.724	1.427	1.220
Representativeness of the sample (%)	83.9	84.3	84.3	84.0	85.4	88.0	88.4	87.0	86.1	84.9

[a] Comprises the groups of banks I, II, III, and IV
[b] Comprises the group of banks I
[c] Banks with invalid information were excluded
Source BACEN—Banco Central do Brasil (2014)

This group of banks represents a significant share of the total assets held by the Brazilian banking sector, representing values of between 83.9 % (2013) and 88.4 % (2007). This data was obtained from the Brazilian Central Bank (BACEN 2014).

For the construction of the economic indicators described in Sect. 3.1, the following information was obtained: total asset, total equity, total debts, net income, number of employees, number of agencies, total loans, net loan loss provision, interest income, non-interest income, sum of cash, and interbanking asset. It should be said that the total asset analyzed corresponds to the sum total of current assets, long-term tangible assets, and fixed assets, once financial applications in buyback (repo) transactions had been deducted.

4.2 Application of Methodology

The financial indicators calculated were normalized according to (Eq. 7) and (Eq. 8), to sustain the optimization process described in (Eq. 10), which operates the entropy performance maximization for each indicator j. The results of the optimization processes generated for each of the years analyzed are shown in Table 3.

Columns 2 and 3 in Table 3 show the original distribution of the weights and their entropy value (2.1972), so as to measure the occurrence of added information through optimization procedures. Entropy H of a given weight w_j was calculated by adapting the equation proposed by Jaynes (2003) for discrete random variables:

$$H(w_j) = -w_j \ln w_j \tag{12}$$

And the total entropy of the vector of weights $\mathbf{w}$ is the result of the sum total of the various w_j:

$$H(w) = \sum_{j=1}^{9} -w_j \ln w_j \tag{13}$$

The original vector of weights $(\mathbf{w}^0)$ shows maximum entropy, since the weights are uniformly distributed. Values for optimal weights $(\mathbf{w}^*)$ can be seen in columns 9 and 10 and were obtained by optimization process (Eq. 10) and its respective entropies $(H(w^*))$. As can be seen, the optimal weights are distributed non-uniformly, and their entropic values are lower than the maximum entropy value (2.1972).

This behavior of the vectors of optimal weights shows that the optimization process captured the performance differential of each of the indicators included in this analysis, which reflects the combination of conditions affecting of the banking sector in each of the periods analyzed. Thus, it can be seen that the maximum entropy optimization process met the requirements of the different levels of importance of each indicator as a result of the distribution of performances observed, which guarantees the objectivity of this evaluation, since there are no subjective interventions when establishing these weights.

The use of matrix model (Eq. 12) produced index F_i for the sampling of banks for the years between 2004 and 2013, as can be seen in the data shown in Table 4. Table 4 shows that some of the banks are not listed for every year of research, which does not negatively affect the analysis, since these sampling are highly representative of the sector.

Data contained in Table 4 should be given a relative interpretation, depending on the position occupied by a particular rating in relation to the series of sector indexes. In addition, the fact that indexes F_i are distributed on interval [0, 1] means that an analysis should be made in the light of a beta probability distribution.

4.3 Risk Analysis of the Index F_i According to the Beta Probability Distribution

The normalization procedures described in Eqs. (7) and (8) established that index F_i has a finite distribution limit on interval [0, 1]. The statistical treatment of the distribution of index F_i can be applied by means of a beta distribution, which is

Table 3 Optimal weights and entropy of the decision model

			2013		2012		2011		2010		2009	
w_j	w_j^0	$H(w_j^0)$	w_j^*	$H(w_j^*)$	w_j^*	$H(w_j^*)$	w_j^*	$H(w_j^*)$	w_j^*	$H(w_j^*)$	w_j^*	$H(w_j^*)$
w_1	0.1111	0.2441	0.1906	0.3159	0.2339	0.3398	0.1133	0.2468	0.2192	0.3327	0.2121	0.3289
w_2	0.1111	0.2441	0.0505	0.1508	0.0533	0.1563	0.0276	0.0992	0.0538	0.1573	0.0544	0.1583
w_3	0.1111	0.2441	0.0435	0.1363	0.0520	0.1538	0.0248	0.0917	0.0604	0.1695	0.0505	0.1508
w_4	0.1111	0.2441	0.3472	0.3673	0.2816	0.3569	0.3518	0.3675	0.2160	0.3310	0.1973	0.3202
w_5	0.1111	0.2441	0.0613	0.1711	0.0704	0.1868	0.0731	0.1912	0.0587	0.1664	0.1308	0.2661
w_6	0.1111	0.2441	0.0494	0.1486	0.0476	0.1449	0.0393	0.1272	0.0537	0.1571	0.0533	0.1564
w_7	0.1111	0.2441	0.0516	0.1529	0.0565	0.1624	0.0400	0.1287	0.0700	0.1862	0.0573	0.1638
w_8	0,1111	0.2441	0.0600	0.1688	0.0745	0.1934	0.2451	0.3446	0.0658	0.1791	0.0619	0.1722
w_9	0,1111	0.2441	0.1460	0.2809	0.1302	0.2655	0.0849	0.2094	0.2024	0.3233	0.1824	0.3104
∑	1.0000	2.1972	1.0000	1.8926	1.0000	1.9597	1.0000	1.8064	1.0000	2.0025	1.0000	2.0270

	2008		2007		2006		2005		2004	
w_j	w_j^*	$H(w_j^*)$	w_j^*	$H(w_j^*)$	w_j^*	$H(w_j^*)$	w_j^*	$H(w_j^*)$	w_j^*	$H(w_j^*)$
w_1	0.1855	0.3125	0.1463	0.2812	0.1824	0.3104	0.1204	0.2549	0.1334	0.2687
w_2	0.0416	0.1322	0.0321	0.1104	0.0436	0.1365	0.0311	0.1080	0.0661	0.1796
w_3	0.0422	0.1335	0.0336	0.1141	0.0402	0.1292	0.0285	0.1014	0.0437	0.1367
w_4	0.2990	0.3610	0.3447	0.3671	0.2210	0.3336	0.3077	0.3627	0.1138	0.2473
w_5	0.0842	0.2084	0.1170	0.2510	0.0516	0.1529	0.0914	0.2186	0.1108	0.2438
w_6	0.0465	0.1426	0.0591	0.1672	0.0602	0.1691	0.0414	0.1318	0.0610	0.1706
w_7	0.0655	0.1786	0.0430	0.1353	0.0960	0.2250	0.0448	0.1392	0.0630	0.1741
w_8	0.0359	0.1195	0.1049	0.2366	0.0496	0.1491	0.0274	0.0987	0.0906	0.2176
w_9	0.1997	0.3217	0.1192	0.2536	0.2553	0.3486	0.3073	0.3626	0.3176	0.3643
∑	1.0000	1.9100	1.0000	1.9165	1.0000	1.9545	1.0000	1.7778	1.0000	2.0027

Table 4 F_i performance ratings calculated for the sampling of Brazilian banks

N	Banks	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004
		F_i	F_i	F_i	F_i	F_i	F_i	F_i	F_i	F_i	F_i
1	ABC-BRASIL	0,3309	0,3702	0,1865	0,3993	0.3852	0,3057	0,2109	0,2835	0,1923	0,3555
2	ABN AMRO							0,1894	0,2755	0,1789	0,3171
3	ALFA	0,4333	0,3513	0,1750	0,3735	0,3503	0,2682	0,2201	0,2670	0,1845	0,3281
4	AMEX									0,1562	0,3058
5	ARBI	0,3497	0,4526	0,1983	0,4386	0,3796	0,2212	0,1781	0,3539	0,2265	0,2570
6	AZTECA	0,3524	0,4388	0,2158	0,6218	0,6240	0,6184				
7	BANCAP				0,6954	0,6293	0,5001		0,5187	0,3586	0,5378
8	BANCNACION						0,3794	0,2902	0,4322	0,2344	0,3567
9	BANCO CR2		0,4647	0,1903	0,4621	0,4483	0,3909	0,2621	0,4738	0,2924	
10	BANCOOB	0,3025	0,3574	0,1703	0,3711	0,3373	0,2540	0,1892	0,2748	0,1766	0,3040
11	BANESE	0,3110	0,3412	0,1689	0,3663	0,3460	0,3019	0,1845	0,2904	0,1797	0,3540
12	BANESTES	0,3275	0,4141	0,1999	0,4621	0,4178	0,3461	0,2490	0,3434	0,2015	0,3188
13	BANIF	0,2338	0,2666	0,1657	0,3730	0,3348	0,2679	0,2624	0,2760	0,1639	
14	BANKBOSTON									0,2038	0,3752
15	BANPARÁ	0,3342	0,3755	0,1915	0,4256	0,3925	0,3142	0,2095	0,2880	0,1868	0,3222
16	BANRISUL	0,2857	0,3428	0,1690	0,3738	0,3839	0,3045	0,2043	0,2875	0,1651	0,3046
17	BARCLAYS		0,4086	0,1820			0,4255	0,2322	0,3108	0,2144	0,3881
18	BASA	0,3222	0,3771	0,1840	0,4021	0,3928	0,3182	0,2249	0,3212	0,2140	0,3539
19	BASEMSA				0,3780	0,4001	0,2847	0,2606	0,4010		
20	BB	0,3063	0,3567	0,1718	0,3810	0,3881	0,3031	0,1921	0,2722	0,1745	0,3172
21	BBM	0,3670	0,3985	0,2145	0,4262	0,3595	0,2726	0,2310	0,2582	0,1709	0,3272
22	BCGB	0,3341		0,1936	0,4749	0,4692					
23	BCO JOHN DEERE									0,1919	0,3330

(continued)

Table 4 (continued)

N	Banks	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004
		F_i	F_i	F_i	F_i	F_i	F_i	F_i	F_i	F_i	F_i
24	BCOMURUGUAI				0,3918	0,3935	0,2939	0,2057	0,3713	0,1581	0,3203
25	BEC									0,2186	0,3843
26	BEPI						0,3562	0,2489	0,3494	0,2034	0,3523
27	BESC							0,1778	0,2680	0,1498	0,3214
28	BGN						0,2466	0,2167	0,2506	0,1603	0,3452
29	BIC	0,3068	0,3396	0,1813	0,3949	0,3863	0,3064	0,1957	0,2576	0,1642	0,3164
30	BMC								0,2812	0,1825	0,3251
31	BMG	0,2985	0,3256	0,2075	0,4220	0,4456	0,3259	0,2512	0,3450	0,2527	0,4210
32	BNB	0,3187	0,3513	0,1632	0,3862	0,3798	0,2989	0,2122	0,2821	0,1749	0,3087
33	BNP PARIBAS	0,3205	0,3851	0,1841	0,3689	0,3877	0,2743	0,2227	0,2890	0,2308	0,3698
34	BONSUCESSO	0,3144	0,3416	0,1573	0,4189	0,4105	0,3370	0,2810	0,3895	0,2773	0,4029
35	BPN BRASIL	0,3493	0,3896	0,1362	0,3370	0,3576	0,2933	0,2197	0,3634		
36	BRACCE	0,3860	0,3724	0,2654	0,3874						
37	BRADESCO	0,3229	0,3698	0,1708	0,3811	0,4054	0,3002	0,2026	0,2897	0,1977	0,3497
38	BRASCAN		0,2788	0,1590	0,3476	0,3717	0,3277	0,1852	0,3104	0,2756	0,3575
39	BRASIL PLURAL	0,4488									
40	BRB	0,2885	0,3316	0,1591	0,3784	0,3755	0,2761	0,1809	0,2886	0,1775	0,3199
41	BTG PACTUAL	0,4084	0,4608	0,2848	0,5131	0,6475	0,3368	0,3556	0,3559	0,1662	0,4210
42	BTMUB				0,4445	0,5433	0,3389	0,2877	0,4039		
43	BVA			0,1642	0,3630	0,3469	0,2703	0,1961	*0,2305*	*0,1002*	0,3688
44	CACIQUE							*0,1367*	0,3322	0,2607	0,3428
45	CAPITAL	0,6112		0,3066							
46	CARGILL	0,4477	0,4991	0,2342	0,4659	0,4674	0,3113	0,1836	0,2896	0,3013	

(continued)

Table 4 (continued)

N	Banks	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004
		F_i	F_i	F_i	F_i	F_i	F_i	F_i	F_i	F_i	F_i
47	CEDULA	0,4759	0,5185	0,2248	0,4749	0,5055	0,3928	0,2654	0,3061	0,2281	0,4034
48	CEF	0,2411	0,3013	0,1373	0,3195	0,3239	0,2567	0,1621	0,2482	0,1485	0,2798
49	CHINA	0,3316	0,4549	0,2653							
50	CITIBANK	0,3211	0,3462	0,1873	0,3859	0,3693	0,2547	0,2228	0,2816	0,1877	0,3255
51	CLASSICO			*0,6044*	*0,7589*	*0,7283*	*0,7117*	0,5619	*0,6659*	*0,6152*	
52	CONCÓRDIA					0,4200	0,3567				
53	CONTINENTAL	0,3059									
54	CREDIBEL				0,2573	0,3632	0,2762	0,1944	0,2973	0,2062	0,2862
55	CREDIT AGRICOLE	0,3958	0,4555	0,2431	0,5817	0,4741	0,3653	0,2584			
56	CREDIT LYONNAIS								0,5113	0,2250	0,3160
57	CREDIT SUISSE	*0,7216*	*0,7137*	0,3591	0,5911	0,5159	0,4422	*0,7205*	0,4469	0,3080	0,3594
58	CRUZEIRO DO SUL			0,1592	0,3979	0,3765	0,2965	0,2659	0,2794	0,1614	0,4834
59	DAYCOVAL	0,3370	0,3985	0,2016	0,4512	0,4756	0,3630	0,2766	0,3516	0,2612	0,3765
60	DBB BM				0,4714	0,3561	0,2966	0,2621			
61	DEUTSCHE	0,3283	0,3542	0,1988	0,3661	0,3655	0,3745	0,1972	0,2763	0,2653	0,3112
62	DRESDNER								0,3381	0,1691	0,3053
63	EMBLEMA									0,1992	0,5064
64	FATOR	0,3275	0,4086	0,1501	0,4479	0,4231	0,2842	0,3676		0,2748	0,5106
65	FIBRA	0,2466	0,3204	0,1388	0,3660	0,4747	0,2787	0,3094	0,2832	0,4810	*0,6221*
66	FICSA		0,3065	0,1296	0,4600	0,4120	0,3327	0,2638	0,3032	0,1865	0,3525
67	GE CAPITAL				0,3484	0,3753	0,2714	0,2632	0,2367	0,1343	0,3390
68	GERADOR	0,2468	0,3384	0,1789							
69	GERDAU					0,4343	0,2855	0,2139	0,3018	0,2241	0,3543

(continued)

Table 4 (continued)

N	Banks	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004
		F_i	F_i	F_i	F_i	F_i	F_i	F_i	F_i	F_i	F_i
70	GUANABARA	0,3852	0,4021	0,2034	0,4459	0,4348	0,3187	0,2129	0,3251	0,2405	0,4533
71	HSBC	0,2824	0,3319	0,1499	0,3581	0,3763	0,2791	0,1933	0,2884	0,1841	0,3171
72	IBIBANK						0,2747	0,1696	0,2909	0,2272	0,3591
73	INDUSTRIAL	0,3429	0,3722	0,1669	0,3863	0,3774	0,3094	0,1997	0,3706	0,2515	0,3587
74	INDUSVAL	0,2957	0,3600	0,1650	0,3501	0,3796	0,2979	0,2316	0,3075	0,2068	0,3884
75	ING	0,4111	0,4330	0,2679	0,5140	0,4967	0,3045	0,3381	0,3462	0,1454	0,2595
76	INTERCAP		0,3929	0,2023	0,3912	0,3872	0,3091	0,3278	0,2951	0,1910	0,3644
77	INTERMEDIUM	0,3242	0,3762	0,1984	0,4491	0,5182	0,4284				
78	ITAU	0,3124	0,3577	0,1733	0,3655	0,3895	0,2827	0,2205	0,3091	0,1953	0,3615
79	JBS BANCO				0,3734	0,4191	0,3693				
80	JOHN DEERE	0,3145	0,3530	0,1879	0,3717	0,3246	0,2826	0,1919	0,2651		
81	JP MORGAN	0,3741	0,3893	0,1807	0,3739	0,3789	0,3595	0,2992	0,2858	0,2214	0,3474
82	KDB BRASIL		0,3202	0,1649		*0,2356*	0,2742	0,1907	0,3219		
83	KEB BRASIL	0,4161	0,4683	0,2511	0,5547	0,4614	0,3604	0,3213	0,4633	0,3036	0,4924
84	LA PROVINCIA	0,5215	0,5600	0,2946	0,6419	0,5552	0,4677	0,3230	0,5050	0,3530	0,4132
85	LEMON					0,3742	0,2586	0,2284	0,3468	0,2423	0,3842
86	LUSO BRASILEIRO	*0,1660*	0,3649	0,1357	0,3826	0,3582	0,2829	0,2205	0,3240	0,1944	0,3565
87	MALUCELLI	0,3919	0,4602	0,2279	0,4307	0,4783	0,3607	0,2950			
88	MATONE				0,2931	0,4078	0,1921	0,2432	0,3564	0,2325	0,3467
89	MÁXIMA	0,2853	0,3430	0,1803	0,3484	0,3730	0,2604	0,4073	0,4108	0,2944	0,4972
90	MERCANTIL	0,2600	0,3609	0,1824	0,4354	0,4125	0,3134	0,2303	0,3163	0,2055	0,3626
91	MERRILL LYNCH	0,3068	0,4391	0,2911							
92	MIZUHO	0,3513									
93	MODAL	0,3075	0,3823	0,1751	0,4255	0,3806	0,3103	0,2244	0,3237	0,1933	0,3214

(continued)

Table 4 (continued)

N	Banks	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004
		F_i	F_i	F_i	F_i	F_i	F_i	F_i	F_i	F_i	F_i
94	MORADA				0,4025	0,3595	0,2527	0,2283	0,3166	0,1946	0,3297
95	NACION ARG	0,4309	0,4471	0,4432	0,5343	0,5063					
96	NATIXIS					0,5428					
97	NBC BANK		0,3433	0,1604							
98	NOSSA CAIXA						0,2581	0,1651	0,2430	0,1591	0,2935
99	ORIGINAL	0,4657	0,5100	0,2721							
100	PANAMERICANO	0,2400	0,2757	0,1518	*0,1229*	0,4710					
101	PARANA								0,3187	0,2702	0,3853
102	PEBB										0,5122
103	PECUNIA								0,3351	0,2371	0,4084
104	PINE	0,3160	0,3445	0,1667	0,3795	0,3530	0,2897	0,2011	0,2858	0,1914	0,3416
105	POTTENCIAL	0,3152	0,5074	0,3195	0,5951	0,5781	0,4230	0,2682	0,4393	0,2431	0,3941
106	PRIMUS										0,3365
107	PROSPER			0,1150	0,3042	0,3411	*0,1528*	0,1937			
108	RABOBANK	0,3164	0,3816	0,1822	0,4242	0,4042	0,2758	0,2163	0,2780	0,1509	0,2867
109	RANDON	0,3381	0,3657	0,1901	0,5051						
110	RENDIMENTO	0,3885	0,4000	0,2162	0,4688	0,4089	0,3359	0,2292	0,3395	0,2293	0,3655
111	RENNER	0,3477	0,3647	0,1880	0,4254	0,4149	0,3297	0,2307	0,3326	0,2185	0,3800
112	REP OR URUG	0,5933	0,5663	0,3015	0,6202	0,5561	0,4602	0,3386	0,4576	0,3001	0,3860
113	RIBEIRAO PRETO	0,3909		0,1904	0,4001	0,3639	0,2880	0,2001	0,3346	0,2172	0,3695
114	RODOBENS	0,3533	0,3680	0,1975							
115	RURAL		0,3024	0,1390	0,3923	0,3700	0,2941	0,2049	0,2571	0,1612	0,3361
116	SAFRA	0,3081	0,3553	0,1867	0,4219	0,4093	0,2582	0,1796	0,2565	0,1918	0,3449

(continued)

Table 4 (continued)

N	Banks	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004
		F_i	F_i	F_i	F_i	F_i	F_i	F_i	F_i	F_i	F_i
117	SANTANDER	0,3272	0,3501	0,2535	0,3849	0,3888	0,2908	0,2266	0,2639	0,1823	0,3429
118	SANTOS - S/Int,										0,2813
119	SCHAHIN				0,3922	0,3676	0,2976	0,2183	0,3054	0,2009	0,3322
120	SCOTIABANK	0,4105	0,5600	0,2715							
121	SEMEAR	0,2757	0,3370	*0,0927*							
122	SICREDI	0,3348	0,3622	0,1934	0,4223	0,3515	0,2698	0,2317	0,4672	0,2648	0,4592
123	SMBC				0,5119	0,4167	0,3126	0,2729	0,2728	0,2202	0,3209
124	SOCIETE GENERALE	0,2848	*0,2599*	0,1128	0,3842	0,3421	0,2060	0,2977	0,2881	0,1732	0,2970
125	SOCOPA	0,3600	0,4003	0,1852	0,3836	0,3574	0,3182	0,2821	0,2906	0,1943	0,3366
126	SOFISA		0,3833	0,1931	0,3554	0,3617	0,2871	0,2093	0,3085	0,2191	0,3630
127	SS						0,3185	0,2761	0,3153	0,2202	0,2771
128	SUMITOMO MITSUI	0,3786	0,4298	0,2158							
129	TOKYO-MITSUBISHI	0,3841	0,4272	0,2462						0,2438	0,3861
130	TOPÁZIO	0,2858		0,1674	0,4258	0,4447					
131	TRIANGULO	0,3342	0,3766	0,1869	0,4152	0,4013	0,3253	0,2092	0,3207	0,2164	0,3494
132	UBS WARBURG								0,4534		
133	UNIBANCO							0,2244	0,3035	0,1936	0,4065
134	UNION										*0,2235*
135	VOTORANTIM	0,2787	0,3068	0,1409	0,3920	0,4156	0,2850	0,2563	0,3722	0,2914	0,5026
136	VR							0,2368	0,3138	0,2035	0,3646
137	WESTLB		0,3907	0,1987	0,4310	0,4023	0,2977	0,2332	0,3051	0,1718	0,3812
138	WOORI BANK	0,4426	0,5463								
	Max	0,7216	0,7137	0,6044	0,7589	0,7283	0,7117	0,7205	0,6659	0,6152	0,6221
	Min	0,1660	0,2599	0,0927	0,1229	0,2356	0,1528	0,1367	0,2305	0,1002	0,2235

sufficiently versatile to represent proportion or probability data, which are defined on a continual interval between 0 and 1.

In accordance with Johnson et al. (1995) and Nadarajah and Kotz (2007), Beta distribution belongs to a flexible class of distributions, where the way distribution is applied depends on parameters α and β, where $\alpha, \beta > 1$, in that such parameters work together to determine the positioning of the mode and the symmetry of the distribution. Thus, a random variable X has a beta distribution with parameters α and β ($X \sim Beta(\alpha, \beta)$), if its density function assumes the form:

$$p(x|\alpha,\beta) = x^{\alpha-1}(1-x)^{\beta-1}\Big/B(\alpha,\beta), \quad \text{for } 0<x<1 \text{ and } \alpha,\beta>1 \tag{14}$$

where B is a beta function, which is equal to the ratio for the gamma functions (Γ):

$$B(\alpha,\beta) = \Gamma(\alpha+\beta)/\Gamma(\alpha)\Gamma(\beta) \tag{15}$$

The theoretical values for the average (expected value $E(X)$), variance, and mode of a random variable X with a beta distribution are calculated as follows:

$$E(X) = \alpha/\alpha+\beta \tag{16}$$

$$\text{Standard deviation}(X) = \left(\alpha\beta \,/(\alpha+\beta)^2(\alpha+\beta+1)(\alpha+\beta+1)\right)^{1/2} \tag{17}$$

$$\text{Mode}(X) = \alpha-1/\alpha+\beta-2 \tag{18}$$

The critical point in modeling data according to a beta distribution is when estimating parameters α and β. In this research paper, these parameters were estimated by using the maximum-likelihood method (MLE), operationalized with software R (version 3.1.1). The results of these operations are shown in Table 5, which support the corresponding risk analysis.

Table 5 presents a calculation of the risk groups for the sampling of banks during the period between 2004 and 2013. The dimensioning of the density functions of the cumulative probabilities of calculated indexes $F(F_i)$ can be seen in the third column for each period of analysis. The cumulative density functions make it possible to construct a scale of ten groups used to analyze the levels of risk in the financial performance of the banks analyzed. In order to do this, it was established that the closer F_i is to the minimum point of the distribution, the greater the financial risk this represented with regards to the performance of bank i and vice versa in relation to the maximum point, bearing in mind the division of $F(F_i)$ into ten sections (see the fourth column for each period of analysis in Table 5), as follows:

- Entries in the first section are interpreted as situations of extreme risk, Group I;
- Entries in the second to third sections are interpreted as high-risk situations, Groups II and III, respectively;

Table 5 Risk groups calculated for the sampling of Brazilian banks

2013				2012				2011				2010				2009			
N	F_i	$F(F_i)$	Risk	N	F_i	$F(F_i)$	Risk	N	F_i	$F(F_i)$	Risk	N	F_i	$F(F_i)$	Risk	N	F_i	$F(F_i)$	Risk
86	0.1660	0.0000	I	124	0.2599	0.0000	I	121	0.0927	0.0000	I	100	0.1229	0.0000	I	82	0.2356	0.0000	I
13	0.2338	0.0004	I	13	0.2666	0.0000	I	124	0.1128	0.0001	I	54	0.2573	0.0066	I	48	0.3239	0.0003	I
100	0.2400	0.0009	I	100	0.2757	0.0000	I	107	0.1150	0.0002	I	88	0.2931	0.0410	I	80	0.3246	0.0003	I
48	0.2411	0.0010	I	38	0.2788	0.0000	I	66	0.1296	0.0045	I	107	0.3042	0.0635	I	13	0.3348	0.0011	I
65	0.2466	0.0019	I	48	0.3013	0.0000	I	86	0.1357	0.0114	I	48	0.3195	0.1073	II	10	0.3373	0.0015	I
68	0.2468	0.0020	I	115	0.3024	0.0000	I	35	0.1362	0.0121	I	35	0.3370	0.1769	II	107	0.3411	0.0023	I
90	0.2600	0.0069	I	66	0.3065	0.0000	I	48	0.1373	0.0141	I	38	0.3476	0.2294	III	124	0.3421	0.0025	I
121	0.2757	0.0225	I	135	0.3068	0.0000	I	65	0.1388	0.0170	I	89	0.3484	0.2335	III	11	0.3460	0.0037	I
135	0.2787	0.0272	I	82	0.3202	0.0000	I	115	0.1390	0.0173	I	67	0.3484	0.2335	III	43	0.3469	0.0040	I
71	0.2824	0.0341	I	65	0.3204	0.0000	I	135	0.1409	0.0219	I	74	0.3501	0.2430	III	3	0.3503	0.0055	I
124	0.2848	0.0394	I	31	0.3256	0.0000	I	71	0.1499	0.0541	I	126	0.3554	0.2724	III	122	0.3515	0.0062	I
89	0.2853	0.0406	I	40	0.3316	0.0001	I	64	0.1501	0.0552	I	71	0.3581	0.2880	III	104	0.3530	0.0071	I
16	0.2857	0.0415	I	71	0.3319	0.0002	I	100	0.1518	0.0635	I	43	0.3630	0.3176	IV	60	0.3561	0.0093	I
130	0.2858	0.0417	I	121	0.3370	0.0004	I	34	0.1573	0.0974	I	78	0.3655	0.3329	IV	125	0.3574	0.0103	I
40	0.2885	0.0485	I	68	0.3384	0.0004	I	38	0.1590	0.1093	II	65	0.3660	0.3360	IV	35	0.3576	0.0104	I
74	0.2957	0.0704	I	29	0.3396	0.0005	I	40	0.1591	0.1103	II	61	0.3661	0.3365	IV	86	0.3582	0.0110	I
31	0.2985	0.0805	I	11	0.3412	0.0007	I	58	0.1592	0.1109	II	11	0.3663	0.3377	IV	94	0.3595	0.0122	I
10	0.3025	0.0965	I	34	0.3416	0.0007	I	97	0.1604	0.1198	II	33	0.3689	0.3542	IV	21	0.3595	0.0122	I
53	0.3059	0.1118	II	16	0.3428	0.0008	I	32	0.1632	0.1430	II	10	0.3711	0.3678	IV	126	0.3617	0.0145	I
20	0.3063	0.1135	II	89	0.3430	0.0009	I	43	0.1642	0.1516	II	80	0.3717	0.3719	IV	54	0.3632	0.0163	I
91	0.3068	0.1159	II	97	0.3433	0.0009	I	82	0.1649	0.1577	II	13	0.3730	0.3804	IV	113	0.3639	0.0172	I
29	0.3068	0.1159	II	104	0.3445	0.0010	I	74	0.1650	0.1587	II	79	0.3734	0.3827	IV	61	0.3655	0.0194	I
93	0.3075	0.1191	II	50	0.3462	0.0013	I	13	0.1657	0.1653	II	3	0.3735	0.3836	IV	119	0.3676	0.0226	I
116	0.3081	0.1220	II	117	0.3501	0.0022	I	104	0.1667	0.1750	II	16	0.3738	0.3855	IV	50	0.3693	0.0255	I
11	0.3110	0.1368	II	3	0.3513	0.0025	I	73	0.1669	0.1766	II	81	0.3739	0.3858	IV	115	0.3700	0.0266	I
78	0.3124	0.1447	II	32	0.3513	0.0025	I	130	0.1674	0.1813	II	19	0.3780	0.4125	V	38	0.3717	0.0299	I
34	0.3144	0.1555	II	80	0.3530	0.0031	I	11	0.1689	0.1968	II	40	0.3784	0.4151	V	89	0.3730	0.0327	I
80	0.3145	0.1563	II	61	0.3542	0.0035	I	16	0.1690	0.1978	II	104	0.3795	0.4224	V	85	0.3742	0.0353	I
105	0.3152	0.1606	II	116	0.3553	0.0040	I	10	0.1703	0.2103	III	20	0.3810	0.4322	V	67	0.3753	0.0378	I
104	0.3160	0.1649	II	20	0.3567	0.0047	I	37	0.1708	0.2162	III	37	0.3811	0.4331	V	40	0.3755	0.0383	I
108	0.3164	0.1672	II	10	0.3574	0.0050	I	20	0.1718	0.2265	III	86	0.3826	0.4430	V	71	0.3763	0.0403	I
32	0.3187	0.1813	II	78	0.3577	0.0052	I	78	0.1733	0.2436	III	125	0.3836	0.4498	V	58	0.3765	0.0408	I
33	0.3205	0.1927	II	74	0.3600	0.0067	I	3	0.1750	0.2619	III	124	0.3842	0.4536	V	73	0.3774	0.0432	I
50	0.3211	0.1969	II	90	0.3609	0.0073	I	93	0.1751	0.2630	III	117	0.3849	0.4584	V	81	0.3789	0.0473	I
18	0.3222	0.2041	III	122	0.3622	0.0084	I	68	0.1789	0.3081	IV	50	0.3859	0.4649	V	5	0.3796	0.0494	I
37	0.3229	0.2085	III	111	0.3647	0.0106	I	89	0.1803	0.3251	IV	32	0.3862	0.4668	V	74	0.3796	0.0494	I
77	0.3242	0.2178	III	86	0.3649	0.0109	I	81	0.1807	0.3294	IV	73	0.3863	0.4675	V	32	0.3798	0.0498	I
117	0.3272	0.2384	III	109	0.3657	0.0117	I	29	0.1813	0.3364	IV	36	0.3874	0.4748	V	93	0.3806	0.0524	I
12	0.3275	0.2403	III	114	0.3680	0.0145	I	17	0.1820	0.3450	IV	76	0.3912	0.5002	VI	16	0.3839	0.0633	I
64	0.3275	0.2405	III	37	0.3698	0.0170	I	108	0.1822	0.3482	IV	24	0.3918	0.5042	VI	1	0.3852	0.0681	I
61	0.3283	0.2461	III	1	0.3702	0.0176	I	90	0.1824	0.3501	IV	135	0.3920	0.5058	VI	29	0.3863	0.0723	I
1	0.3309	0.2659	III	73	0.3722	0.0209	I	18	0.1840	0.3705	IV	119	0.3922	0.5067	VI	76	0.3872	0.0756	I
49	0.3316	0.2706	III	36	0.3724	0.0211	I	33	0.1841	0.3707	IV	115	0.3923	0.5077	VI	33	0.3877	0.0777	I
22	0.3341	0.2901	III	15	0.3755	0.0274	I	125	0.1852	0.3849	IV	29	0.3949	0.5248	VI	20	0.3881	0.0795	I
131	0.3342	0.2906	III	77	0.3762	0.0289	I	1	0.1865	0.4017	V	58	0.3979	0.5443	VI	117	0.3888	0.0826	I
15	0.3342	0.2909	III	131	0.3766	0.0297	I	116	0.1867	0.4035	V	1	0.3993	0.5539	VI	78	0.3895	0.0856	I
122	0.3348	0.2954	III	18	0.3771	0.0308	I	131	0.1869	0.4063	V	113	0.4001	0.5591	VI	15	0.3925	0.0995	I
59	0.3370	0.3130	IV	108	0.3816	0.0432	I	50	0.1873	0.4121	V	18	0.4021	0.5719	VI	18	0.3928	0.1006	II
109	0.3381	0.3218	IV	93	0.3823	0.0454	I	80	0.1879	0.4192	V	94	0.4025	0.5746	VI	24	0.3935	0.1041	II
73	0.3429	0.3609	IV	126	0.3833	0.0487	I	111	0.1880	0.4207	V	131	0.4152	0.6547	VII	19	0.4001	0.1408	II
111	0.3477	0.4017	V	33	0.3851	0.0552	I	109	0.1901	0.4469	V	34	0.4189	0.6768	VII	131	0.4013	0.1487	II
35	0.3493	0.4152	V	81	0.3893	0.0724	I	9	0.1903	0.4488	V	116	0.4219	0.6939	VII	137	0.4023	0.1551	II
5	0.3497	0.4185	V	35	0.3896	0.0735	I	113	0.1904	0.4509	V	31	0.4220	0.6946	VII	108	0.4042	0.1672	II
92	0.3513	0.4326	V	137	0.3907	0.0785	I	15	0.1915	0.4649	V	122	0.4223	0.6963	VII	37	0.4054	0.1755	II
6	0.3524	0.4424	V	76	0.3929	0.0895	I	126	0.1931	0.4845	V	108	0.4242	0.7074	VIII	88	0.4078	0.1930	II
114	0.3533	0.4499	V	21	0.3985	0.1225	II	122	0.1934	0.4887	V	111	0.4254	0.7141	VIII	110	0.4089	0.2011	III
125	0.3600	0.5077	VI	59	0.3985	0.1227	II	22	0.1936	0.4905	V	93	0.4255	0.7147	VIII	116	0.4093	0.2042	III
21	0.3670	0.5672	VI	110	0.4000	0.1327	II	114	0.1975	0.5389	VI	15	0.4256	0.7153	VIII	34	0.4105	0.2132	III
81	0.3741	0.6254	VII	125	0.4003	0.1343	II	5	0.1983	0.5481	VI	130	0.4258	0.7163	VIII	66	0.4120	0.2256	III
128	0.3786	0.6608	VII	70	0.4021	0.1471	II	77	0.1984	0.5505	VI	21	0.4262	0.7187	VIII	90	0.4125	0.2295	III
129	0.3841	0.7024	VIII	17	0.4086	0.1985	II	137	0.1987	0.5537	VI	87	0.4307	0.7430	VIII	111	0.4149	0.2495	III
70	0.3852	0.7101	VIII	64	0.4086	0.1991	II	61	0.1988	0.5546	VI	137	0.4310	0.7445	VIII	135	0.4156	0.2547	III
36	0.3860	0.7161	VIII	12	0.4141	0.2493	III	12	0.1999	0.5677	VI	90	0.4354	0.7672	VIII	123	0.4167	0.2642	III
110	0.3885	0.7331	VIII	129	0.4272	0.3894	IV	59	0.2016	0.5880	VI	5	0.4386	0.7830	VIII	12	0.4178	0.2739	III
113	0.3909	0.7495	VIII	128	0.4298	0.4185	IV	76	0.2023	0.5963	VI	42	0.4445	0.8101	IX	79	0.4191	0.2858	III
87	0.3919	0.7558	VIII	75	0.4330	0.4567	V	70	0.2034	0.6089	VII	70	0.4459	0.8163	IX	52	0.4200	0.2935	III
55	0.3958	0.7809	VIII	6	0.4388	0.5239	VI	31	0.2075	0.6548	VII	64	0.4479	0.8249	IX	64	0.4231	0.3222	IV
41	0.4084	0.8495	IX	91	0.4391	0.5277	VI	21	0.2145	0.7260	VIII	77	0.4491	0.8301	IX	69	0.4343	0.4333	V
120	0.4105	0.8595	IX	95	0.4471	0.6193	VII	6	0.2158	0.7386	VIII	59	0.4512	0.8387	IX	70	0.4348	0.4388	V
75	0.4111	0.8619	IX	5	0.4526	0.6773	VII	128	0.2158	0.7388	VIII	66	0.4600	0.8716	IX	130	0.4447	0.5401	VI
83	0.4161	0.8832	IX	49	0.4549	0.7015	VIII	110	0.2162	0.7418	VIII	12	0.4621	0.8786	IX	31	0.4456	0.5484	VI
95	0.4309	0.9324	X	55	0.4555	0.7067	VIII	47	0.2248	0.8135	IX	9	0.4621	0.8786	IX	9	0.4483	0.5759	VI
3	0.4333	0.9386	X	87	0.4602	0.7516	VIII	87	0.2279	0.8357	IX	46	0.4659	0.8909	IX	83	0.4614	0.7006	VIII
138	0.4426	0.9585	X	41	0.4608	0.7571	VIII	46	0.2342	0.8745	IX	110	0.4688	0.8995	IX	46	0.4674	0.7506	VIII
46	0.4477	0.9669	X	9	0.4647	0.7908	VIII	55	0.2431	0.9168	X	60	0.4714	0.9070	X	22	0.4692	0.7653	VIII
39	0.4488	0.9685	X	83	0.4683	0.8193	IX	129	0.2462	0.9286	X	22	0.4749	0.9161	X	100	0.4710	0.7790	VIII
99	0.4657	0.9863	X	46	0.4991	0.9633	X	83	0.2511	0.9445	X	47	0.4749	0.9162	X	55	0.4741	0.8018	IX
47	0.4759	0.9922	X	105	0.5074	0.9789	X	117	0.2535	0.9508	X	109	0.5051	0.9704	X	65	0.4747	0.8060	IX
84	0.5215	0.9997	X	99	0.5100	0.9823	X	49	0.2653	0.9746	X	123	0.5119	0.9774	X	59	0.4756	0.8118	IX
112	0.5933	1.0000	X	47	0.5185	0.9907	X	36	0.2654	0.9748	X	41	0.5131	0.9785	X	87	0.4783	0.8298	IX
45	0.6112	1.0000	X	138	0.5463	0.9992	X	75	0.2679	0.9782	X	75	0.5140	0.9793	X	75	0.4967	0.9220	X
57	0.7216	1.0000	X	84	0.5600	0.9998	X	120	0.2715	0.9825	X	95	0.5343	0.9917	X	47	0.5055	0.9499	X
				120	0.5600	0.9998	X	99	0.2721	0.9831	X	83	0.5547	0.9971	X	95	0.5063	0.9520	X
				112	0.5663	0.9999	X	41	0.2848	0.9926	X	55	0.5817	0.9995	X	57	0.5159	0.9720	X
				57	0.7137	1.0000	X	91	0.2911	0.9952	X	57	0.5911	0.9997	X	77	0.5182	0.9755	X
								84	0.2946	0.9963	X	105	0.5951	0.9998	X	96	0.5428	0.9955	X
								112	0.3015	0.9978	X	112	0.6202	1.0000	X	42	0.5433	0.9957	X
								45	0.3066	0.9985	X	6	0.6218	1.0000	X	84	0.5552	0.9984	X
								105	0.3195	0.9995	X	84	0.6419	1.0000	X	112	0.5561	0.9985	X
								57	0.3591	1.0000	X	7	0.6954	1.0000	X	105	0.5781	0.9998	X
								95	0.4432	1.0000	X	51	0.7589	1.0000	X	6	0.6240	1.0000	X
								51	0.6044	1.0000	X					7	0.6293	1.0000	X
																41	0.6475	1.0000	X
																51	0.7283	1.0000	X

(continued)

2008				2007				2006				2005				2004			
N	F_i	$F(F_i)$	*Risk*	*N*	F_i	$F(F_i)$	*Risk*	*N*	F_i	$F(F_i)$	*Risk*	*N*	F_i	$F(F_i)$	*Risk*	*N*	F_i	$F(F_i)$	*Risk*
107	0.1528	0.0000	I	44	0.1367	0.0000	I	43	0.2305	0v0000	I	43	0.1002	0.0000	I	134	0.2235	0.0000	I
88	0.1921	0.0000	I	48	0.1621	0.0000	I	67	0.2367	0.0000	I	67	0.1343	0.0007	I	5	0.2570	0.0000	I
124	0.2060	0.0001	I	98	0.1651	0.0000	I	98	0.2430	0.0000	I	75	0.1454	0.0051	I	75	0.2595	0.0000	I
5	0.2212	0.0008	I	72	0.1696	0.0001	I	48	0.2482	0.0000	I	48	0.1485	0.0080	I	127	0.2771	0.0000	I
28	0.2466	0.0119	I	27	0.1778	0.0006	I	28	0.2506	0.0000	I	27	0.1498	0.0096	I	48	0.2798	0.0000	I
94	0.2527	0.0194	I	5	0.1781	0.0007	I	116	0.2565	0.0000	I	108	0.1509	0.0110	I	118	0.2813	0.0000	I
10	0.2540	0.0215	I	116	0.1796	0.0008	I	115	0.2571	0.0000	I	4	0.1562	0.0207	I	54	0.2862	0.0001	I
50	0.2547	0.0226	I	40	0.1809	0.0011	I	29	0.2576	0.0000	I	24	0.1581	0.0255	I	108	0.2867	0.0001	I
48	0.2567	0.0261	I	46	0.1836	0.0016	I	21	0.2582	0.0000	I	98	0.1591	0.0284	I	98	0.2935	0.0005	I
98	0.2581	0.0288	I	11	0.1845	0.0018	I	117	0.2639	0.0000	I	28	0.1603	0.0320	I	124	0.2970	0.0009	I
116	0.2582	0.0290	I	38	0.1852	0.0020	I	80	0.2651	0.0000	I	115	0.1612	0.0350	I	10	0.3040	0.0030	I
85	0.2586	0.0298	I	10	0.1892	0.0034	I	3	0.2670	0.0000	I	58	0.1614	0.0355	I	16	0.3046	0.0032	I
89	0.2604	0.0337	I	2	0.1894	0.0036	I	27	0.2680	0.0000	I	13	0.1639	0.0450	I	62	0.3053	0.0036	I
13	0.2679	0.0540	I	82	0.1907	0.0042	I	20	0.2722	0.0000	I	29	0.1642	0.0460	I	4	0.3058	0.0039	I
3	0.2682	0.0549	I	80	0.1919	0.0048	I	123	0.2728	0.0000	I	16	0.1651	0.0500	I	32	0.3087	0.0059	I
122	0.2698	0.0603	I	20	0.1921	0.0049	I	10	0.2748	0.0000	I	41	0.1662	0.0549	I	61	0.3112	0.0083	I
43	0.2703	0.0622	I	71	0.1933	0.0057	I	2	0.2755	0.0000	I	62	0.1691	0.0697	I	56	0.3160	0.0150	I
67	0.2714	0.0659	I	107	0.1937	0.0059	I	13	0.2760	0.0000	I	21	0.1709	0.0798	I	29	0.3164	0.0157	I
21	0.2726	0.0706	I	54	0.1944	0.0065	I	61	0.2763	0.0000	I	137	0.1718	0.0848	I	2	0.3171	0.0171	I
82	0.2742	0.0770	I	29	0.1957	0.0074	I	108	0.2780	0.0001	I	124	0.1732	0.0939	I	71	0.3171	0.0172	I
33	0.2743	0.0771	I	43	0.1961	0.0078	I	58	0.2794	0.0001	I	20	0.1745	0.1030	II	20	0.3172	0.0174	I
72	0.2747	0.0790	I	61	0.1972	0.0088	I	30	0.2812	0.0001	I	32	0.1749	0.1058	II	12	0.3188	0.0208	I
108	0.2758	0.0837	I	73	0.1997	0.0113	I	50	0.2816	0.0001	I	10	0.1766	0.1181	II	40	0.3199	0.0235	I
40	0.2761	0.0851	I	113	0.2001	0.0118	I	32	0.2821	0.0001	I	40	0.1775	0.1252	II	24	0.3203	0.0246	I
54	0.2762	0.0854	I	104	0.2011	0.0130	I	65	0.2832	0.0002	I	2	0.1789	0.1360	II	123	0.3209	0.0262	I
65	0.2787	0.0965	I	37	0.2026	0.0150	I	1	0.2835	0.0002	I	11	0.1797	0.1428	II	93	0.3214	0.0275	I
71	0.2791	0.0988	I	16	0.2043	0.0174	I	104	0.2858	0.0003	I	117	0.1823	0.1658	II	27	0.3214	0.0277	I
80	0.2826	0.1164	II	115	0.2049	0.0184	I	81	0.2858	0.0003	I	30	0.1825	0.1675	II	15	0.3222	0.0298	I
78	0.2827	0.1172	II	24	0.2057	0.0197	I	16	0.2875	0.0004	I	71	0.1841	0.1821	II	30	0.3251	0.0401	I
86	0.2829	0.1179	II	131	0.2092	0.0264	I	15	0.2880	0.0004	I	3	0.1845	0.1859	II	50	0.3255	0.0417	I
64	0.2842	0.1255	II	126	0.2093	0.0266	I	124	0.2881	0.0004	I	66	0.1865	0.2057	III	21	0.3272	0.0488	I
19	0.2847	0.1280	II	15	0.2095	0.0271	I	71	0.2884	0.0005	I	15	0.1868	0.2097	III	3	0.3281	0.0528	I
135	0.2850	0.1299	II	1	0.2109	0.0303	I	40	0.2886	0.0005	I	50	0.1877	0.2187	III	94	0.3297	0.0610	I
69	0.2855	0.1326	II	32	0.2122	0.0335	I	33	0.2890	0.0005	I	76	0.1910	0.2544	III	119	0.3322	0.0756	I
126	0.2871	0.1424	II	70	0.2129	0.0351	I	46	0.2896	0.0006	I	104	0.1914	0.2587	III	23	0.3330	0.0806	I
113	0.2880	0.1477	II	69	0.2139	0.0379	I	37	0.2897	0.0006	I	116	0.1918	0.2628	III	115	0.3361	0.1022	II
104	0.2897	0.1582	II	108	0.2163	0.0450	I	11	0.2904	0.0007	I	23	0.1919	0.2644	III	106	0.3365	0.1057	II
117	0.2908	0.1656	II	28	0.2167	0.0461	I	125	0.2906	0.0007	I	1	0.1923	0.2688	III	125	0.3366	0.1061	II
35	0.2933	0.1821	II	119	0.2183	0.0516	I	72	0.2909	0.0007	I	93	0.1933	0.2801	III	67	0.3390	0.1259	II
24	0.2939	0.1867	II	35	0.2197	0.0564	I	76	0.2951	0.0015	I	133	0.1936	0.2831	III	104	0.3416	0.1508	II
115	0.2941	0.1882	II	3	0.2201	0.0577	I	54	0.2973	0.0021	I	125	0.1943	0.2922	III	44	0.3428	0.1624	II
58	0.2965	0.2056	III	78	0.2205	0.0591	I	69	0.3018	0.0039	I	86	0.1944	0.2933	III	117	0.3429	0.1639	II
60	0.2966	0.2062	III	86	0.2205	0.0592	I	66	0.3032	0.0047	I	94	0.1946	0.2956	III	116	0.3449	0.1844	II
119	0.2976	0.2137	III	33	0.2227	0.0678	I	133	0.3035	0.0049	I	78	0.1953	0.3036	IV	28	0.3452	0.1884	II
137	0.2977	0.2146	III	50	0.2228	0.0683	I	137	0.3051	0.0060	I	37	0.1977	0.3320	IV	88	0.3467	0.2059	III
74	0.2979	0.2162	III	133	0.2244	0.0751	I	119	0.3054	0.0062	I	63	0.1992	0.3508	IV	81	0.3474	0.2142	III
32	0.2989	0.2239	III	93	0.2244	0.0753	I	47	0.3061	0.0068	I	119	0.2009	0.3722	IV	131	0.3494	0.2382	III
37	0.3002	0.2342	III	18	0.2249	0.0772	I	74	0.3075	0.0081	I	12	0.2015	0.3790	IV	37	0.3497	0.2424	III
11	0.3019	0.2473	III	117	0.2266	0.0852	I	126	0.3085	0.0090	I	26	0.2034	0.4025	V	26	0.3523	0.2769	III
20	0.3031	0.2571	III	94	0.2283	0.0935	I	78	0.3091	0.0097	I	136	0.2035	0.4040	V	66	0.3525	0.2801	III
16	0.3045	0.2687	III	85	0.2284	0.0937	I	38	0.3104	0.0113	I	14	0.2038	0.4079	V	18	0.3539	0.2990	III
75	0.3045	0.2688	III	110	0.2292	0.0978	I	17	0.3108	0.0117	I	90	0.2055	0.4288	V	11	0.3540	0.3002	IV
1	0.3057	0.2787	III	90	0.2303	0.1036	II	136	0.3138	0.0161	I	54	0.2062	0.4384	V	69	0.3543	0.3038	IV
29	0.3064	0.2846	III	111	0.2307	0.1058	II	127	0.3153	0.0188	I	74	0.2068	0.4461	V	1	0.3555	0.3214	IV
76	0.3091	0.3085	IV	21	0.2310	0.1076	II	90	0.3163	0.0208	I	18	0.2140	0.5360	VI	86	0.3565	0.3357	IV
73	0.3094	0.3108	IV	74	0.2316	0.1107	II	94	0.3166	0.0216	I	17	0.2144	0.5409	VI	8	0.3567	0.3392	IV
93	0.3103	0.3187	IV	122	0.2317	0.1113	II	101	0.3187	0.0263	I	131	0.2164	0.5648	VI	38	0.3575	0.3506	IV
46	0.3113	0.3281	IV	17	0.2322	0.1142	II	131	0.3207	0.0315	I	113	0.2172	0.5743	VI	73	0.3587	0.3693	IV
123	0.3126	0.3402	IV	137	0.2332	0.1204	II	18	0.3212	0.0329	I	111	0.2185	0.5898	VI	72	0.3591	0.3746	IV
90	0.3134	0.3469	IV	136	0.2368	0.1425	II	82	0.3219	0.0352	I	25	0.2186	0.5913	VI	57	0.3594	0.3791	IV
15	0.3142	0.3547	IV	88	0.2432	0.1870	II	93	0.3237	0.0410	I	126	0.2191	0.5972	VI	78	0.3615	0.4115	V
18	0.3182	0.3918	IV	26	0.2489	0.2313	III	86	0.3240	0.0421	I	123	0.2202	0.6093	VII	90	0.3626	0.4291	V
125	0.3182	0.3918	IV	12	0.2490	0.2324	III	70	0.3251	0.0460	I	127	0.2202	0.6101	VII	126	0.3630	0.4357	V
127	0.3185	0.3946	IV	31	0.2512	0.2503	III	44	0.3322	0.0789	I	81	0.2214	0.6235	VII	76	0.3644	0.4562	V
70	0.3187	0.3966	IV	135	0.2563	0.2953	III	111	0.3326	0.0808	I	69	0.2241	0.6537	VII	136	0.3646	0.4607	V
131	0.3253	0.4595	V	55	0.2584	0.3143	IV	113	0.3346	0.0929	I	56	0.2250	0.6632	VII	110	0.3655	0.4749	V
31	0.3259	0.4652	V	19	0.2606	0.3347	IV	103	0.3351	0.0961	I	5	0.2265	0.6794	VII	43	0.3688	0.5256	VI
38	0.3277	0.4822	V	9	0.2621	0.3492	IV	62	0.3381	0.1160	II	72	0.2272	0.6869	VII	113	0.3695	0.5365	VI
111	0.3297	0.5019	VI	60	0.2621	0.3492	IV	110	0.3395	0.1262	II	47	0.2281	0.6958	VII	33	0.3698	0.5408	VI
66	0.3327	0.5299	VI	13	0.2624	0.3515	IV	12	0.3434	0.1577	II	110	0.2293	0.7079	VIII	14	0.3752	0.6236	VII
110	0.3359	0.5602	VI	67	0.2632	0.3590	IV	31	0.3450	0.1715	II	33	0.2308	0.7230	VIII	59	0.3765	0.6415	VII
41	0.3368	0.5683	VI	66	0.2638	0.3653	IV	75	0.3462	0.1828	II	88	0.2325	0.7397	VIII	111	0.3800	0.6911	VII
34	0.3370	0.5705	VI	47	0.2654	0.3806	IV	85	0.3468	0.1886	II	8	0.2344	0.7567	VIII	137	0.3812	0.7068	VIII
42	0.3389	0.5883	VI	58	0.2659	0.3846	IV	26	0.3494	0.2138	III	103	0.2371	0.7803	VIII	85	0.3842	0.7449	VIII
12	0.3461	0.6522	VII	105	0.2682	0.4076	V	59	0.3516	0.2376	III	70	0.2405	0.8074	IX	25	0.3843	0.7462	VIII
26	0.3562	0.7331	VIII	123	0.2729	0.4531	V	5	0.3539	0.2623	III	85	0.2423	0.8215	IX	101	0.3853	0.7587	VIII
52	0.3567	0.7373	VIII	127	0.2761	0.4831	V	41	0.3559	0.2854	III	105	0.2431	0.8270	IX	112	0.3860	0.7661	VIII
81	0.3595	0.7578	VIII	59	0.2766	0.4887	V	88	0.3564	0.2915	III	129	0.2438	0.8323	IX	129	0.3861	0.7677	VIII
83	0.3604	0.7637	VIII	34	0.2810	0.5306	VI	35	0.3634	0.3764	IV	73	0.2515	0.8800	IX	17	0.3881	0.7899	VIII
87	0.3607	0.7657	VIII	125	0.2821	0.5406	VI	73	0.3706	0.4700	V	31	0.2527	0.8862	IX	74	0.3884	0.7934	VIII
59	0.3630	0.7818	VIII	42	0.2877	0.5930	VI	24	0.3713	0.4782	V	44	0.2607	0.9230	X	105	0.3941	0.8499	IX
55	0.3653	0.7968	VIII	8	0.2902	0.6149	VII	135	0.3722	0.4906	V	59	0.2612	0.9246	X	34	0.4029	0.9137	X
79	0.3693	0.8216	IX	87	0.2950	0.6562	VII	34	0.3895	0.7016	VIII	122	0.2648	0.9375	X	47	0.4034	0.9169	X
61	0.3745	0.8504	IX	124	0.2977	0.6786	VII	19	0.4010	0.8130	IX	61	0.2653	0.9390	X	133	0.4065	0.9334	X
8	0.3794	0.8744	IX	81	0.2992	0.6914	VII	42	0.4039	0.8361	IX	101	0.2702	0.9533	X	103	0.4084	0.9419	X
9	0.3909	0.9195	X	65	0.3094	0.7666	VIII	89	0.4108	0.8828	IX	64	0.2748	0.9638	X	84	0.4132	0.9601	X
47	0.3928	0.9257	X	83	0.3213	0.8380	IX	8	0.4322	0.9670	X	38	0.2756	0.9655	X	31	0.4210	0.9795	X
105	0.4230	0.9825	X	84	0.3230	0.8469	IX	105	0.4393	0.9799	X	34	0.2773	0.9687	X	41	0.4210	0.9795	X
17	0.4255	0.9847	X	76	0.3278	0.8701	IX	57	0.4469	0.9887	X	135	0.2914	0.9870	X	70	0.4533	0.9994	X
77	0.4284	0.9871	X	75	0.3381	0.9109	X	132	0.4534	0.9934	X	9	0.2924	0.9878	X	122	0.4592	0.9998	X
57	0.4422	0.9943	X	112	0.3386	0.9125	X	112	0.4576	0.9954	X	89	0.2944	0.9893	X	58	0.4834	1.0000	X
112	0.4602	0.9983	X	41	0.3556	0.9563	X	83	0.4633	0.9973	X	112	0.3001	0.9928	X	83	0.4924	1.0000	X
84	0.4677	0.9990	X	64	0.3676	0.9747	X	122	0.4672	0.9981	X	46	0.3013	0.9934	X	89	0.4972	1.0000	X
7	0.5001	0.9999	X	89	0.4073	0.9971	X	9	0.4738	0.9990	X	83	0.3036	0.9944	X	135	0.5026	1.0000	X
6	0.6184	1.0000	X	51	0.5619	1.0000	X	84	0.5050	1.0000	X	57	0.3080	0.9959	X	63	0.5064	1.0000	X
51	0.7117	1.0000	X	57	0.7205	1.0000	X	56	0.5113	1.0000	X	84	0.3530	0.9999	X	64	0.5106	1.0000	X
								7	0.5187	1.0000	X	7	0.3586	1.0000	X	102	0.5122	1.0000	X
								51	0.6659	1.0000	X	65	0.4810	1.0000	X	7	0.5378	1.0000	X
												51	0.6152	1.0000	X	65	0.6221	1.0000	X

- Entries in the fourth to fifth sections are interpreted as moderate-risk situations with a tendency toward a high risk, Groups IV and V, respectively;
- Entries in the sixth to ninth sections are interpreted as moderate-risk situations with a tendency toward a low risk, Groups VI, VII, VIII, and IX, respectively;
- Entries in the tenth section are interpreted as low-risk situations, Group X.

According to Table 5, the numbers shown in the first column (*N*) for each period of analysis refer to the banks, while observing the numbers shown in Table 4 (column *N*). This type of data presentation makes it possible to follow the changes that have occurred over the years in the financial performance risk classifications for banks.

Table 6 was designed to facilitate a risk analysis.

Based on Table 6, an analysis can be made according to the financial performance risk groups of banks analyzed:

- Risk group X: On average, 15 % of the banks analyzed in this sampling are classified as representing a low risk. There was a reduction in the number of banks classified as being a low risk between 2007 and 2008, probably as a result of the global economic crisis;
- Risk groups VI to IX: On average, nearly 17 % of the banks analyzed in this sampling are grouped as representing a moderate risk with a tendency toward a low risk. Atypical behavior was observed in 2010, when nearly 40 % of the banks analyzed were included in this group;
- Risk groups IV and V: On average, nearly 13 % of the banks analyzed in this sampling were grouped as representing a moderate risk with a tendency toward a high risk. Atypical behavior was observed in 2010 and 2011, when these banks represented a concentration of 25 and 29 %, respectively, in these groups;
- Risk groups II and III: On average, nearly 19 % of the banks analyzed in this sampling were classified as being a high risk. In the final year analysis (2013), there was a greater concentration of banks included in this group, representing 35 % of the total; and
- Risk group I: The extreme risk category applies to the largest number of banks analyzed in this sampling, representing an average of 36 % of the total. However, this risk group presents very unequal samples of data, with peaks of concentration in 2012 (65 %), 2009 (50 %), 2007 (54 %), and 2006 (68 %).

As a way of analyzing the efficiency of the financial performance risk classifications proposed by the model presented in this paper, an analysis was made of seven banks that were placed in extrajudicial liquidation or were liquidated by the Central Bank of Brazil during our period of research:

- Mercantil Bank (N. 90): This bank had been placed in extrajudicial receivership since 1996 and was liquidated in 2012. This bank was classified according to our Risk Groups I (2013), I (2012), IV (2011), VIII (2010), III (2009), IV (2008), II (2007), I (2006), V (2005), and V (2004). The only inappropriate classification occurred in 2010; otherwise all the other classifications were consistent with the Central Bank's own assessment of this bank.

Table 6 Distribution of banks by risk groups—2004–2013

Risk group	2013			2012			2011			2010			2009		
	R	*N*	%	*R*	*N*	%	*R*	*N*	%	*R*	*N*	%	*R*	*N*	%
Extreme	I	18	22	I	55	65	I	14	15	I	4	4	I	47	50
High	II	16	20	II	7	8	II	14	15	II	2	2	II	8	9
High	III	13	16	III	1	1	III	6	7	III	6	7	III	11	12
Moderate (to high)	IV	3	4	IV	2	2	IV	10	11	IV	13	14	IV	1	1
Moderate (to high)	V	6	7	V	1	1	V	13	14	V	13	14	V	2	2
Moderate (to low)	VI	2	2	VI	2	2	VI	8	9	VI	11	12	VI	3	3
Moderate (to low)	VII	2	2	VII	2	2	VII	2	2	VII	5	5	VII	–	0
Moderate (to low)	VIII	7	9	VIII	5	6	VIII	4	4	VIII	10	11	VIII	4	4
Moderate (to low)	IX	4	5	IX	1	1	IX	3	3	IX	10	11	IX	4	4
Low	X	11	13	X	9	11	X	18	20	X	17	19	X	14	15
	∑	82	100	∑	85	100	∑	92	100	∑	91	100	∑	94	100
Risk group	2008			2007			2006			2005			2004		
	R	N	%	R	N	%	R	N	%	R	N	%	R	N	%
Extreme	I	27	28	I	52	54	I	67	68	I	20	20	I	35	35
High	II	14	15	II	9	9	II	6	6	II	10	10	II	9	9
High	III	13	14	III	4	4	III	5	5	III	13	13	III	7	7
Moderate (to high)	IV	11	11	IV	9	9	IV	1	1	IV	5	5	IV	9	9
Moderate (to high)	V	3	3	V	4	4	V	3	3	V	6	6	V	6	6
Moderate (to low)	VI	6	6	VI	3	3	VI	–	0	VI	7	7	VI	3	3
Moderate (to low)	VII	1	1	VII	4	4	VII	–	0	VII	8	8	VII	3	3
Moderate (to low)	VIII	7	7	VIII	1	1	VIII	1	1	VIII	5	5	VIII	8	8
Moderate (to low)	IX	3	3	IX	3	3	IX	3	3	IX	6	6	IX	1	1
Low	X	11	11	X	7	7	X	12	12	X	19	19	X	18	18
	∑	96	100	∑	96	100	∑	98	100	∑	99	100	∑	99	100

- Santos Bank (N. 118): This bank was placed in extrajudicial receivership in 2005 and was liquidated in the same year. This bank was classified according to our Risk Group I (2004), which is consistent with the Central Bank's own assessment of this bank.
- Morada Bank (N. 94): This bank was placed in extrajudicial receivership in 2011. This bank was classified according to our Risk Groups IV (2010), I (2009), I (2008), I (2007), I (2006), III (2005), and I (2004), which is consistent with the Central Bank's own assessment of this bank.
- Cruzeiro do Sul Bank (N. 58): This bank was placed in extrajudicial receivership in 2012. This bank was classified according to our Risk Groups II (2011), IV (2010), I (2009), III (2008), IV (2007), I (2006), I (2005), and X (2004), which is consistent with the Central Bank's own assessment of this bank, the only exception being the classification made for the year 2004.
- Prosper Bank (N. 107): This bank was placed in extrajudicial receivership in 2012. The bank was classified according to our Risk Group I in 2011, 2010, 2009, 2008, and 2007, which is consistent with the Central Bank's own assessment of this bank.
- BVA (N. 43): This bank was placed in extrajudicial receivership in 2013. The bank was classified according to our Risk Groups IV (2011), I (2010), I (2009), I (2008), I (2007), I (2006), I (2005), and IV (2004), which is consistent with the Central Bank's own assessment of this bank.
- Rural Bank (N. 115): This bank was placed in extrajudicial receivership in 2013. The bank was classified according to our Risk Groups I (2012), I (2011), IV (2010), I (2009), II (2008), I (2007), I (2006), I (2005), and II (2004), which is consistent with the Central Bank's own assessment of this bank.

5 Concluding Remarks

The methodology proposed as a model for a financial performance index (F) was presented as an alternative to the risk analysis models which are based on correlational studies, especially those that do not require that the observed data assume some sort of specific probability distribution.

This methodology, which is grounded in multi-attribute utility models can significantly contribute in situations where the aim is to construct a model that is designed according to principles of objectivity. In order to do this, the differences between the relative importance of the analysis indicators was obtained by using a maximum entropy optimization process, which takes into account the functions of observed values. Thus, an unbiased intra-sector process was obtained to evaluate performance, which can also be used by the monetary authorities to monitor the financial performance of banks with the purpose of minimizing systematic risks.

With regards to the financial performance analysis carried out on those banks included in our sampling, it was established that the zones of risk in this sector follow the extremes of the distributions, since the closer a bank's financial performance is to the lowest threshold, the higher the risks involved and vice versa. Ten intra-sector risk groups were created for the purpose of this analysis, and a special analysis was also carried out in the case of seven banks that were, or are currently, in a situation of extrajudicial receivership. In these cases, the evaluations recommended by our research model were consistent with the diagnosis made by the Central Bank as regards the vulnerable state of these banks.

The methodological procedures proposed in this article can be applied in a variety of different situations and especially to support an investment analysis. With regards the optimization of investment portfolios, the historical pattern of the performance indexes in the sector can promote the creation of restrictions for problems related to the question of minimizing risks that affect portfolios. In the same way, comparative performance indexes in the sector can help to define restriction functions to problems of resource allocation, credit concessions, and analysis, among others, both in intra-sector terms as well as in different sectors of the economy.

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References

Altman EI (1968) Financial ratios, discriminant analysis and the prediction of corporate bankruptcy. J Finance 23(4):589–609

Angelini E, Giacomo T (2008) A neural network approach for credit risk evaluation. J Q Rev Econ Finance. doi:10.1016/j.qref.2007.04.001

BACEN—Banco Central do Brasil (2014) 50 maiores bancos e o consolidado do Sistema Financeiro Nacional. http://www4.bcb.gov.br/top50/port/top50.asp. Accessed 20 May 2014

Bana e Costa CA, Chagas MP (2004) A career choice problem: an example of how to use MACBETH to build a quantitative value model based on qualitative value judgments. Eur J Oper Res. doi:10.1016/S0377-2217(03)00155-3

Board J, Sutcliffe C, Ziemba WT (2003) Applying operations research techniques to financial markets. Interfaces. doi:10.1287/inte.33.2.12.14465

Bonafede CE, Giudici P (2007) Bayesian networks for enterprise risk assessment. J Phys. doi:10.1016/j.physa.2007.02.065

Cielen A, Peeters L, Vanhoof K (2004) Bankruptcy prediction using a data envelopment analysis. Eur J Oper Res. doi: 10.1016/S0377-2217(03)00186-3

Diakoulaki D, Mavrotas G, Papayannakis L (1992) A multicriteria approach for evaluating the performance of industrial firms. Int J Manage Sci. doi:10.1016/0305-0483(92)90021-X

Diakoulaki D, Mavrotas G, Papayannakis L (1995) Determining objective weights in multiple criteria problems: the critic method. Comput Oper Res. doi:10.1016/0305-0548(94)00059-H

Doumpos M, Kosmidou K, Baourakis G, Zopounidis C (2002) Credit risk assessment using a multicriterial hierarchical discrimination approach: a comparative analysis. Eur J Oper Res 138:392–412

Fethi MD, Pasiouras F (2010) Assessing bank efficiency and performance with operational research and artificial intelligence techniques: a survey. Eur J Oper Res. doi:10.1016/j.ejor.2009.08.003

Freed N, Glover F (2007) Evaluating alternative linear programming models to solve the two-group discriminant problem. Decis Sci. doi:10.1111/j.1540-5915.1986.tb00218.x

Hwang CL, Yoon K (1981) Multiple attribute decision making: methods and applications. Springer, Berlin

Jaynes ET (2003) Probability theory: the logic of science. University Press, Cambridge

Jessop A (2004) Minimally biased weight determination in personnel selection. Eur J Oper Res. doi:10.1016/S0377-2217(03)00163-2

Jessop A (1999) Entropy in multiattribute problems. J Multi-Criteria Decis Anal. doi:10.1002/(SICI)1099-1360(199903)8:2<61:AID-MCDA230>3.0.CO;2-P

Johnson NL, Kotz S, Balakrishnan N (1995) Continuous univariate distributions vol 2, 2nd edn. Wiley, New York

Kao C, Liu ST (2004) Predicting bank performance with financial forecasts: a case of Taiwan commercial banks. J Bank Fin. doi:10.1016/j.jbankfin.2003.09.008

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

Koetter M, Bos JWB, Heid F, Kolari JW, Kool CJM, Porath D (2007) Accounting for distress in bank mergers. J Bank Fin. doi:10.1016/j.jbankfin.2006.12.009

Koch TW, MacDonald SS (2000) Bank management, 4th edn. Dryden Press, Orlando

Mareschal B, Brans JP (1991) Bankadviser: an industrial evaluation system. Eur J Oper Res 54:318–324

Nadarajah S, Samuel Kotz (2007) Two generalized beta distributions. Appl Econ. doi:10.1080.00036840500428062

Saaty TL (1990) How to make a decision: the analytic hierarchy process. Eur J Oper Res 48 (1):9–26

Xu X (2004) A note on the subjective and objective integrated approach to determine attribute weights. Eur J Oper Res. doi:10.1016/S0377-2217(03)00146-2

Zeleny M (1982) Multiple criteria decision making. Mc-Graw-Hill, New York

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Decision Models in Credit Risk Management

Herbert Kimura, Leonardo Fernando Cruz Basso and Eduardo Kazuo Kayo

Abstract Economic crises that emerge from systemic risks suggest that credit risk management in banks is paramount not only for the survival of companies themselves but also for a resilient worldwide economy. Although regulators establish strictly standards for financial institutions, i.e., capital requirements and management best practices, unpredictability of market behavior and complexity of financial products may have strong impact on corporate performance, jeopardizing institutions, and even economies. In this chapter, we will explore decision models to manage credit risks, focusing on probabilistic and statistical methods that are coupled with machine learning techniques. In particular, we discuss and compare two ensemble methods, bagging and boosting, in studies of application scoring.

Keywords Financial risks · Credit risks · Ensemble methods · Machine learning techniques · Bagging · Boosting

1 Introduction

With the development of financial and capital markets, credit operations have become more voluminous and complex, implying the need for advances in mechanisms and models for risk measurement and management.

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Given the increasing importance and sophistication of credit transactions and the consequent vulnerability of the financial system to systemic crises, international and local regulatory bodies are developing guidelines and establishing rules concerning exposure to credit risk by financial institutions.

For example, the Basel Committee on Banking Supervision (BCBS) has published several guidelines to be adopted by banks worldwide, including mechanisms for credit risk management (Schooner and Talor 2010).

More specifically, the BCBS establishes as a relevant pillar the need for equity capital to cope with the degree of exposure to different types of risk (BIS 2006), including market and credit risk. Based on the BCBS guidelines, central banks in many countries are requiring regulatory capital for financial institutions in order to support financial losses due to defaults by borrowers and the degradation of credit quality of bank's assets.

In particular, retail credit risk plays a relevant role to financial institutions (Burns 2002), since risk in retail business could be seem as homogeneous due to diversification, and may result in significant savings in regulatory capital. In addition, banks that comply to their proprietary models of default probability estimation may also be allowed to adopt internal mechanisms to calculate regulatory capital requirements, reducing capital charge.

This study aims to analyze effective decision models for credit risk analysis of retail portfolios. Using machine learning algorithms, this chapter assesses computationally intensive algorithms to classify an individual as good or bad borrower.

In this study, algorithms could be adopted to analyze credit risk of wholesale portfolios, which provide more data and are more commonly prone to automated process for credit application of small loan amounts. However, computational learning mechanisms are most useful for retail portfolios.

Considering the various types of machine learning algorithms, this research studies the applicability of two ensemble methods, bagging and boosting, in credit risk analysis. Ensemble methods are computational mechanisms based on machine learning meant to improve traditional classification models. For instance, according to Freund and Schapire (1999), boosting, a traditional ensemble method combined with simple discrimination techniques (hit rate slightly higher than 55 %), could reach up to 99 % of correct classifications.

The adoption of ensemble methods in credit has been analyzed, for instance, by (Lai et al. 2006; Alfaro et al. 2008; Hsieh and Hung 2010). Their results have verified the efficacy of machine learning methods in real-life problems.

This chapter analyzes one example that shows how different classification techniques can be adopted by comparing the hit ratio of traditional and ensemble methods on a set of credit applications.

2 Theoretical Background

According to Johnson and Wichern (2007), discrimination and classification correspond to multivariate techniques that seek to separate distinct sets of objects or observations and that allow to allocate new objects or observations into predefined groups.

Although the concepts of discrimination and classification are similar, Johnson and Wichern (2007) establish that discrimination is associated with describing different characteristics from the observation of distinct populations known in an exploratory approach. Classification, on the other hand, is more related to allocating observations in classes, with a less exploratory perspective. According to Klecka (1980), classification is an activity in which discriminant variables or discriminant functions are used to predict the group to which a given observation is most likely to belong.

Therefore, the usefulness of discrimination and classification in credit analysis is evident. It provides not only an understanding of the characteristics that discriminate, for example, good from bad borrowers, but also models that allocate potential borrowers in groups. In this case, a priori assumptions on relationships between specific characteristics of borrowers and default risk are unnecessary.

The seminal study by Fisher (1936) associated with the identification of discriminant functions of species of flowers has given rise to relevant works on credit risk. For example, Durand (1941) focused on the analysis of automobile credit loans, and Altman (1968) associated it to predict business failures.

The discussion in this study focuses on general techniques that might improve credit analysis and that do not need to distinguish discrimination from classification. However, from a practical point of view, the ultimate goal of automated credit scoring models, more particularly the analysis of application scoring, is associated with classification, since the decision to grant the loan depends on the group to which a potential borrower is rated.

2.1 Traditional Discrimination Techniques

From the discrimination point of view, credit analysis aims to study possible relationships between variables $\mathbf{X}$ representing n characteristics $X_1, X_2, \cdots, X_n$ of borrowers and a variable Y representing their credit quality.

In loan application studies, credit quality is commonly defined by a variable having a numerical scale score or a rating score, with ordinal variables; or by good/bad credit indicators, with nominal or categorical variables.

The main objective of this research is to develop a system for automated decision processes. Therefore, this study focuses on problems in which Y is a dichotomous variable, with (i) good borrower and (ii) bad borrower categories or groups. Of the several multivariate statistic-oriented classification techniques currently available (Klecka 1980), this study discusses briefly discriminant analysis, logistic regression, and recursive partitioning algorithm.

2.1.1 Discriminant analysis

Discriminant analysis aims to determine the relationship between a categorical variable and a set of interval scale variables (Jobson 1992). By developing a multivariate linear function discriminant analysis shows variables that segregate or distinguish groups of observations through scores (Klecka 1980).

According to credit-related studies, discriminant analysis generates one or more functions in order to better classify potential borrowers. From the mathematical point of view, the analysis of two groups (e.g., performing and non-performing loans) might require a discriminant function expressed as:

$$Y = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_3 + \cdots + a_n x_n$$

where

Y is the dependent variable, i.e., the score obtained by an observation;
$a_0, \ldots, a_n$ are coefficients that indicate the influence of each independent variable in the classification of an observation; and
$x_1, \ldots, x_n$ are independent variable values associated with a given observation.

Thus, based on the coefficient values and the associated independent variables, a discriminant function determines a more accurate score for any particular group. Portfolio credit analysis of retail loan applications adopts variables to encompass registration data or other information or characteristics of a potential borrower. Individuals with higher scores tend to have better ratings, indicating better credit quality and lower default probability.

The main assumptions of discriminant analysis include the following: (i) A discriminant variable cannot be a linear combination of other independent variables; (ii) the variance–covariance matrices of each group must be equal; and (iii) the independent variables have a multivariate normal distribution (Klecka 1980).

It is worthy noting that discriminant analysis is one of the most common borrower classification techniques in application scoring models, after the studies of Altman (1968) verified its efficacy.

2.1.2 Logistic regression

Many social phenomena are discrete or qualitative, in contrast to situations that require an ongoing measurement process of quantitative data (Pampel 2000). Credit quality classification focusing on good or bad borrowers is typically qualitative and represents a binary phenomenon.

In a dichotomous model, logistic regression is an alternative to discriminant analysis in order to classify of potential borrowers. In logistic regression, the dependent variable Y is defined as a binary variable with 0 or 1 values, and the independent variables $\mathbf{X}$ are associated with the characteristics or events of each group.

Without loss of generality, group 0 could be defined as good-borrowing individuals, and group 1 as non-payers or bad borrowers. A logistic function shows the default probability of a given individual:

$$P_i[Y = 1|\mathbf{X} = \mathbf{x_i}] = \frac{1}{1 + e^{-Z}}$$

where

P_i is the probability of individual i belong to the default group;
$Z = b_0 + b_1x_1 + b_2x_2 + \cdots + b_nx$ is a score in which the coefficients can be estimated from a sample, for instance.

Considering the use of logistic regression analysis for credit analysis, P_i is the probability of a counterpart i be a bad borrower. It is also subject to several independent variables $\mathbf{X}$ related to relevant characteristics that may affect credit quality.

When the assumptions of discriminant analysis and logistic regression are observed, both methods give comparable results. However, when the normality assumptions of the variables or variance–covariance matrix equality between groups are not observed, results might differ considerably. Logistic regression, given its less restrictive assumptions, is a technique widely used by the market for credit analysis.

2.1.3 Recursive partitioning algorithm

A less traditional technique for discrimination between groups, the recursive partitioning algorithm involves a classification tree-based non-parametric modeling (Thomas et al. 2002).

According to Feldesman (2002), classification trees have several advantages compared to parametric models: (i) they do not require data transformations, such as logit function in logistic regression analysis; (ii) missing observations do not require special treatment; and (iii) a successful classification does not depend on normality assumptions of variables or equal variance–covariance matrices between groups, such as in discriminant analysis.

The foundations of recursive partitioning algorithm lie in the subdivision of a set of observations into two parts, like branches of a tree, so that subsequent subgroups are increasingly homogeneous (Thomas et al. 2002). The subdivision is based on reference values by variables that explain the differences among the groups. Observations with higher values than the reference values are allocated in a group, while observations with lower values are classified into another group.

Thus, for each relevant variable, the algorithm sets a reference value that will define the subgroup. For example, if the discriminant variable X is continuous, its algorithm generates a cutoff value k. As a result, both groups are comprised by observations with a value $X < k$ and $X \geq k$, respectively. The definition of the cutoff value k is relevant in the classification tree model.

When the discriminant variable X is categorical, the algorithm checks all the possible splits into two categories and defines a measurement to classify the groups (Thomas et al. 2002). By repeating this procedure for several relevant variables, one can build a set of simple rules based on higher or lower values compared to a reference value for each discriminant variable. Observation can be classified into a final group according to this set of rules.

Classification trees allow an intuitive and easy representation of the elements that explain each group (Breiman et al. 1984). Credit analysis studies that adopt the classification tree model are not as common as the parametric model-based ones, but are found, for example, in Coffman (1986).

For discrimination among groups, discriminant analysis and logistic regression are parametric statistical techniques; the possible relationships between the borrower's characteristics and credit quality are likely to be analyzed by means of the independent variables' coefficients in the model. In the case of partition algorithms or decision trees, which adopt mainly non-parametric techniques, the explanatory variable-associated cutoff identifies the good and the bad borrowers. However, depending on how complex the recursive partitioning model is, assessing the influence of each variable to explain credit quality might be difficult.

2.2 Classification Techniques

Considering the distinction suggested by Johnson and Wichern (2007), one could argue that discrimination has the merit of allowing, under a more exploratory aspect, the evaluation of specific characteristics that may explain the inclusion of a observation within a particular group.

However, in some situations, explaining reasons for a variable to influence credit quality is less relevant than the actual rating itself. For example, under a practical perspective, if a given financial institution needs to analyze a large number of credit applications, it might need to develop an automated mechanism for quick and accurate classification rather than a discrimination pattern to explain how variables influence a possible default.

Regarding classification applicability and guidance, machine learning is an artificial intelligence field that aims to develop algorithms for computer programs or systems to learn from experience or data (Langley 1995).

Machine learning techniques, such as neural network algorithms and decision trees, are an alternative to traditional statistical methods, which often rely on mechanisms with extremely restrictive assumptions, such as normality, linearity, and independence of explanatory variables (Kuzey et al. 2014).

It is worth mentioning that recursive partitioning-based algorithms (e.g., decision trees within certain limits, especially related to a small number of variables and to the simplicity of the model), could also create discrimination mechanisms. Chien et al. (2006), for example, establish a classification tree model based on discriminant functions. In contrast, traditional neural networks are typical observation-based classification techniques, as their underlying model is encapsulated in a black box (Ugalde et al. 2013).

From a more focused paradigm to pattern recognition for classification, the machine learning approach is, according to computer science literature, a set of algorithms specifically designed to assess computationally intensive problems, exploring extremely large databases of banks (Khandani et al. 2010).

From the credit analysis perspective, therefore, the machine learning methods are increasingly useful, given the computers' increasing processing power that, in turn, speeds up pattern recognition of good and bad payers. It is worth noting that loan databases of financial institutions could surpass ten million transactions, each one involving several variables, including borrower registration and transaction-related data.

This study focuses on machine learning techniques known as ensemble methods. According to Opitz and Maclin (1999), an ensemble consists of a set of individually trained functions whose predictions are combined to classify new observations. That is, the basic idea of the ensemble construction approach is to make predictions from an overall mechanism by integrating multiple models, which generates more accurate and reliable estimates (Rokach 2009).

According to Bühlmann and Yu (2003), Tukey (1977) introduces a linear regression model applied first to the original data, and then applied to errors, as the source of ensemble methods. Thus, applying a technique several times to the data and errors is an example of ensemble method. Considering the development of statistical theory and increasingly powerful computational machines, model combinations might be deployed in more complex applications.

Several authors, such as Breiman (1996), Bauer and Kohavi (1999), and Maclin and Opitz (1997), pointed substantial improvements in classification using ensemble methods. Considering its performance gains for classification, ensemble methods or ensemble learning methods are one of the mostly accepted streams of research in supervised learning (Mokeddem and Belbachir 2009).

Hsieh and Hung (2010) mention that ensemble methodology has been used in many areas of knowledge. For example, Tan et al. (2003) apply ensemble methods in bioinformatics and protein classification problems in several classes. In geography and sociology, Bruzzone et al. (2004) detect the land cover by combining image classification functions. Maimon and Rokach (2004) use ensemble decision tree techniques for mining manufacturing data.

The number of finance studies that adopt ensemble methods has also increased. For example, Leigh et al. (2002) make predictions on New York Stock Exchange values through technical analysis pattern recognition, neural networks, and genetic algorithms. Lai et al. (2007) study value-at-risk positions in crude oil gathering through ensemble methods that adopt wavelet analysis and artificial neural networks.

Regarding ensemble methods for credit applications, Lai et al. (2006) adopted neural reliability-based networks, Alfaro et al. (2008) adopted neural networks in bankruptcy analysis, and Hsieh and Hung (2010) assessed credit scores by combining neural networks, Bayesian networks, and support vector machines.

This study analyzes two traditional ensemble-based algorithms: bagging and boosting. According to Dietterich (2000), the two most popular ensemble techniques are bagging or bootstrap aggregation, developed by Breiman (1996); and boosting, first proposed by Freund and Schapire (1998). The best known algorithms are based on the AdaBoost family of algorithms. Boosting is also known as arcing (resampling and combining adaptive), due to Breiman's work (1998) that brought new ways of understanding and using boosting algorithms.

Within the context of ensemble methods, bagging and boosting are two general mechanisms aimed to enhance the performance of a particular learning algorithm called basic algorithm (Freund and Schapire 1998). These methods reduce estimation error variances (Tumer and Ghosh 2001) but do not necessarily increase bias (Rokach 2005), providing gains both from the statistical theory perspective and the real-world applicability perspective. Bartlett and Shawe-Taylor (1999) reported that such methods may even reduce bias.

According to Freund and Schapire (1998), bagging and boosting algorithms are similar in the sense that they incorporate modified versions of the basic algorithm subject to disturbances in the sample. Both methods are based on resampling techniques that obtain different training datasets for each of the model classifiers (Opitz and Maclin 1999). In the case of classification problems, the set of training data allows establishing matching or classification rules derived from a majority vote, for example.

The algorithms may also show significant differences. The main difference implies that, in bagging, disturbances are introduced randomly and independently, while boosting shows serial and deterministic disturbances. The best choice depends heavily on all other previously generated rules (Freund and Schapire 1998).

Next, this work introduces the fundamentals of bagging and boosting methods for credit score. Similar ensemble method applications have been assessed by other authors, e.g., Paleologo et al. (2010), who study credit score for bagging, and Xie et al. (2009), who analyze boosting applied with logistic regression.

2.2.1 Bagging

Bagging is a technique developed to reduce variance and has called the attention due to its simple implementation and due to the popular bootstrap method.

The bagging algorithm follows the discussion in Breiman (1996).

1. Consider initially a classification model, based on pairs(X_i, Y_i), $i = 1, .., n$, representing the observation, and where $X_i \in \mathbb{R}^d$ indicates the d independent variables that explain the classification of a given group.
2. The target function is $P[Y = j|X = x](j = 0, 1, \ldots, J - 1)$ in the case of a classification problem in J groups, $Y_i \in \{0, 1, \ldots, J - 1\}$. The classification function estimator is $\hat{g}(.) = h_n((X_1, Y_1,), (X_2, Y_2), \ldots, (X_\mathrm{n}, Y_\mathrm{n}))(.) : \mathbb{R}^\mathrm{d} \rightarrow \mathbb{R}$, where h_n is a model used to classify the observation into the groups.
3. The classification function can be, for instance, a traditional discrimination technique, e.g., discriminant analysis, logistic regression, or recursive partitioning model.
4. Build a random bootstrap sample $(X_1^{*,}, Y_1^*)$, …, (X_n^*, Y_n^*) from the original sample (X_1, Y_1), …, (X_n, Y_n).

5. Calculate the bootstrap estimator $\hat{g}^*(.)$ using the plug-in principle, i.e., $\hat{g}^* = h_n \left(\left(X_1^*, Y_1^*\right), \ldots, \left(X_n^*, Y_n^*\right)\right)(.)$
6. Repeat steps 2 and 3 M times. Frequently, M is chosen to be 50 or 100, implying that M estimators are $\hat{g}^{*k}(.)(k = 1, \ldots, M)$.
7. The bagged estimator is given by $\hat{g}_{\text{Bag}}(.) = M^{-1} \sum_{k=1}^{M} \hat{g}^{*k}(.)$, which is an estimate of $\hat{g}_{\text{Bag}}(.) = E^*[\hat{g}^*(.)]$.

   In application scoring problems, each bootstrapped sample implies coefficient estimates when the bagging procedure is coupled with discriminant analysis or logistic regression, or estimates of cutoff values in a decision tree when bagging and recursive partitioning algorithm are coupled. Since M different classifications are generated in bagging due to differences in the bootstrapped samples, one common mechanism to classify a new individual is by majority votes of the classification derived from the many $\hat{g}^{*k}(.)$ classification functions.

2.2.2 Boosting

Boosting is an ensemble technique that aggregates a series of simple methods, known as weak classifiers, due to their low performance in classifying objects, thus generating a combination that leads to a classification rule with a better performance (Freund and Schapire 1998).

In contrast with bagging, boosting relies on classifiers and subsamples that are sequentially obtained. In every step, training data are rebalanced to give more weight to incorrectly classified observations (Skurichina and Duin 2002). Therefore, the algorithm rapidly focuses on observations that could be more difficult to be analyzed our classified.

The description of the AdaBoost algorithm here is based on Freund and Schapire (1999) study. Consider $Y = \{-1, +1\}$ as possible classification problem values. In a credit application context, for instance, a negative value may represent a bad borrower, and a positive value may represent a good borrower.

Boosting implies a repeated execution of a weak learning mechanism, e.g., discriminant analysis, logistic regression, or a decision tree approach, using subsamples of the original set. Differently from bagging, which generates uniform random samples with reposition, choosing new subsamples in boosting depends on a probability distribution that is different for each step, reflecting the mistakes and successes from the weak classification functions.

A boosting algorithm can be described as in Freund and Schapire (1999).

1. Define weights $D_t(i)$ of the training sample. Initially, the weights, i.e., the probability of choosing any observation, are equal. Thus, given $(x_i, y_i), \ldots, (x_m, y_m)$, so $x_i \in X, y_i \in Y = \{-1, +1\}$, $D_1(i) = \frac{1}{m}$.
2. Establish a weak hypothesis or function h_t that allows a simple classification of a given element in -1 or $+1$, i.e., $h_t : X \rightarrow \{-1, +1\}$. This function can be, for instance, a traditional statistical technique such as recursive partitioning algorithm.

3. The classification function has an error $\varepsilon_t = \Pr_{i \sim D_t}[h_t(x_i) \neq y_i] = \sum_{i:h_t(x_i) \neq y_i} D_t(i)$, i.e., the error is the total sum of probabilities in which the weak function leads to wrong classifications in relation to the true values in the sample. It is important to emphasize that the error is measured by this distribution D_t, in which the weak function was used.
4. Once the weak hypothesis h_t has been established, boosting defines a parameter α_t that measures the relative importance of h_t. The higher is the error ε_t, the lower is α_t and less important h_t is in the classification problem. In boosting, the relative importance for each weak classification function is given by $\alpha_t = \frac{1}{2} \ln\left(\frac{1-\varepsilon_t}{\varepsilon_t}\right)$.
5. The distribution D_t is updated by increasing the weight of the observations that are wrongly classified by h_t, and by decreasing the weight of the observations that are correctly classified, following the equation $D_{t+1}(i) = \frac{D_t(i)}{Z_i} \times \begin{cases} e^{-\alpha t} & \text{if } h_t(x_i) = y_i \\ e^{\alpha t} & \text{if } h_t\ (x_i) \neq y_i \end{cases}$, where Z_t is a normalization factor, so that D_{t+1} is a probability distribution. Therefore, for each successive boosting step, the observations that are not correctly classified will be more likely to be selected in the new subsample.
6. The last hypothesis or classification function is h_t. The final classification model H is defined by the weak function in each step weighted by α_t, i.e., $H(x) = \text{sign}\left(\sum_{t=1}^{T} \alpha_t h_t(x)\right)$.

   For the retail loan application, an individual is considered a good borrower if $H(x)$ has a positive sign. A bad borrower shall have a negative value for $H(x)$.

3 Results

In order to show how these ensemble methods of machine learning work, a credit transaction database in the UCI Machine Learning Repository of the Center for Machine Learning and Intelligent Systems at the University of California at Irvine (Bache and Lichman 2013) was used. This database, also used by Quinlan (1987) and Quinlan (1992), encompasses credit card applications in Australia and consists of 690 observations of 15 variables.

Given the confidentiality of information, the database provides only the values and information on the scale of the variables. The individuals are not identified, as well as the observation or variable meaning. The credit quality-related variable has two categories: good borrower (G) and bad borrower (B). Limited information ensures data confidentiality, but does not affect the analysis, considering the research objective associated with the classification of observations using various quantitative techniques.

After analysis of the database, missing data were eliminated, resulting in 653 valid observations in the final sample. In order to run the analysis, we focused on 7 variables to classify individuals: 6 continuous and 1 nominal comprising two categories. We aim to study how the machine learning mechanisms behave in classification problems with a limited number of information.

The final sample observations were divided randomly into two subsamples (training and validation sets), with virtually the same amount of elements. A script written in R was used, taking into account the characteristics of each technique, and confusion matrices were generated for both the training and the testing subsamples.

The classification results were introduced through (i) discriminant analysis, (ii) logistic regression analysis, (iii) recursive partitioning algorithm, (iv) bagging, and (v) boosting, for different number of iterations (*N*). The ensemble methods analyzed were coupled with recursive partitioning algorithm.

Tables 1 and 2 show the classification results, in absolute and in percentage terms, for the training and validation samples, respectively. Table 3 shows the overall classification results, with hit and error ratios.

This study's dataset implies some relevant results. Discriminant analysis and logistic regression results were identical, in accordance with Press and Wilson's (Press and Wilson 1978) argument that, for most studies, the two methods are unlikely to lead to significantly different results.

Interestingly, for good borrowers, discriminant analysis and logistic regression show better classification results (25 %) in the testing subsample, vis-à-vis the training subsample (21 %). Therefore, for the good borrower group, the traditional parametric models are more consistent with the validation sample when compared to the calibration sample.

However, for the bad borrower group, accuracy levels decrease for all techniques. Recursive partitioning algorithm, bagging, and boosting mechanisms show a lower hit ratio for the good borrower group as well.

An overall analysis shows that all techniques, with the exception of discriminant analysis and logistic regression, are subject to performance loss when the classification rule using the training subsample is applied to the testing subsample.

In the training dataset, classification results from the recursive partitioning algorithm, bagging, and boosting are quite superior to the discriminant analysis and logistic regression outcomes. Whereas the traditional parametric models lead to an overall 74 % hit ratio, the non-parametric methods correspond to at least 83 % of the correct classifications. This accuracy increase, resulting from an automated computational procedure, may strongly affect banks, since loan application analysis, using just computational resources, could be significantly improved.

Regarding boosting, the higher the number of allowed iterations, the better the classification results for the training, i.e., the calibration dataset. Results show an accuracy rate of 93 %, which is much higher than the traditional statistical technique accuracy rate, 74 %.

However, it is important to highlight that the performance of the models did not vary significantly in the testing sample for any technique. Hit ratio is quite

Table 1 Classification results—absolute numbers

N = 10	LDA	LR	RPA	BAG	BOOS	LDA	LR	RPA	BAG	BOOS
Training sample	Predicted = good					Predicted = bad				
Actual = good	69	69	109	111	104	75	75	35	33	40
Actual = bad	11	11	18	12	16	171	171	164	170	166
Testing sample	Predicted = good					Predicted = bad				
Actual = good	82	82	107	94	99	70	70	45	58	53
Actual = bad	10	10	34	28	31	165	165	141	147	144
N = 50	LDA	LR	RPA	BAG	BOOS	LDA	LR	RPA	BAG	BOOS
Training sample	Predicted = good					Predicted = bad				
Actual = good	69	69	109	111	119	75	75	35	33	25
Actual = bad	11	11	18	11	10	171	171	164	171	172
Testing sample	Predicted = good					Predicted = bad				
Actual = good	82	82	107	95	107	70	70	45	57	45
Actual = bad	10	10	34	29	35	165	165	141	146	140
N = 100	LDA	LR	RPA	BAG	BOOS	LDA	LR	RPA	BAG	BOOS
Training sample	Predicted = good					Predicted = bad				
Actual = good	69	69	109	108	129	75	75	35	36	15
Actual = bad	11	11	18	10	7	171	171	164	172	175
Testing sample	Predicted = good					Predicted = bad				
Actual = good	82	82	107	101	109	70	70	45	51	43
Actual = bad	10	10	34	29	36	165	165	141	146	139

Obs.: *LDA* Linear discriminant analysis, *LR* Logistic regression, *RPA* Recursive partitioning algorithm, *BAG* bagging, and *BOOST* boosting

Table 2 Classification results—percentage

N = 10	LDA (%)	LR (%)	RPA (%)	BAG (%)	BOOS (%)	LDA (%)	LR (%)	RPA (%)	BAG (%)	BOOS (%)
Training sample	Predicted = good					Predicted = bad				
Actual = good	21	21	33	34	32	23	23	11	10	12
Actual = bad	3	3	6	4	5	52	52	50	52	51
Testing sample	Predicted = good					Predicted = bad				
Actual = good	25	25	33	29	30	21	21	14	18	16
Actual = bad	3	3	10	9	9	50	50	43	45	44
N = 50	LDA (%)	LR (%)	RPA (%)	BAG (%)	BOOS (%)	LDA (%)	LR (%)	RPA (%)	BAG (%)	BOOS (%)
Training sample	Predicted = good					Predicted = bad				
Actual = good	21	21	33	34	37	23	23	11	10	8
Actual = bad	3	3	6	3	3	52	52	50	52	53
Testing sample	Predicted = good					Predicted = bad				
Actual = good	25	25	33	29	33	21	21	14	17	14
Actual = bad	3	3	10	9	11	50	50	43	45	43
N = 100	LDA (%)	LR (%)	RPA (%)	BAG (%)	BOOS (%)	LDA (%)	LR (%)	RPA (%)	BAG (%)	BOOS (%)
Training sample	Predicted = good					Predicted = bad				
Actual = good	21	21	33	33	40	23	23	11	11	5
Actual = bad	3	3	6	3	2	52	52	50	53	54
Testing sample	Predicted = good					Predicted = bad				
Actual = good	25	25	33	31	33	21	21	14	16	13
Actual = bad	3	3	10	9	11	50	50	43	45	43

Table 3 Overall classification results

N = 10	Ratio	LDA (%)	LR (%)	RPA (%)	BAG (%)	BOOS (%)
Training sample	Right	74	74	84	86	83
	Wrong	26	26	16	14	17
Testing sample	Right	76	76	76	74	74
	Wrong	24	24	24	26	26
N = 50	Ratio	LDA (%)	LR (%)	RPA (%)	BAG (%)	BOOS (%)
Training sample	Right	74	74	84	87	89
	Wrong	26	26	16	13	11
Testing sample	Right	76	76	76	74	76
	Wrong	24	24	24	26	24
N = 100	Ratio	LDA (%)	LR (%)	RPA (%)	BAG (%)	BOOS (%)
Training sample	Right	74	74	84	86	93
	Wrong	26	26	16	14	7
Testing sample	Right	76	76	76	76	76
	Wrong	24	24	24	24	24

insensitive to the method or the number of iterations in the ensemble models. Moreover, forecasting results are compatible to those using more simple techniques.

Even worse, in the testing sample, ensemble methods showed poor performance, especially when bad borrowers were predicted as good borrowers. This misclassification can lead to significant credit losses, since the automated decision would suggest the approval of a loan to a borrower who would default.

These results suggest that, in the case of the Australian credit card database, although ensemble methods could be seen as an improved model of an existing dataset, their contribution to predict credit quality in an out-of-sample analysis is not clear.

4 Final Comments

This chapter aimed to discuss decision models for retail credit risk. In particular, potential uses of two ensemble methods, bagging and boosting, to application scoring were assessed. Based on unsupervised machine learning algorithms, these ensemble methods could implement decision models for automated response to loan applications.

Using a dataset of credit card applications and compared to traditional discriminant analysis and logistic regression, decision models that rely on computational algorithms such as ensemble methods could enhance the accuracy rate of borrower classification.

Results show that, specifically for the training subsample, bagging and especially boosting significantly improve the classification hit ratio. However, for the testing subsample, ensemble techniques coupled with recursive partitioning algorithm convey only marginally better classifications. The error rate for classifying bad borrowers as good ones showed significant problems in the ensemble methods used in this study. Thus, although these machine learning techniques are likely to be more accurate in the training dataset, their impact for analyzing new loans applications is not robust.

Even though the computational techniques studied here did not significantly improve the hit ratio, it is important to highlight that even a minimum increase in the rate of correct classifications might result in relevant savings for a financial institution with millions of trades in its retail portfolio.

Therefore, automated decision models, especially for large banks, could result in economic value and a simpler analysis of credit applications. This study assessed bagging and boosting, two of the most common ensemble methods. Several other machine learning mechanisms, such as neural networks, support vector machines, and Bayesian networks, might also be adopted to analyze credit risk.

Due to the complex default process and the financial market dynamics, managers and decision makers could take advantage of innovations in both computational performance and quantitative methods, eventually developing automated decision models that could contribute to the credit analysis process.

References

Alfaro E, Garcia N, Gámez M, Elizondo D (2008) Bankruptcy forecasting: an empirical comparison of AdaBoost and neural networks. Decis Support Syst 45(1):110–122

Altman E (1968) Financial ratios, discriminant analysis and the prediction of corporate bankruptcy. J Finance 23(4):589–609

Bache K, Lichman M (2013) UCI machine learning repository, School of Information and Computer Science. University of California, Irvine. http://archive.ics.uci.edu/ml. Accessed 10 Sep 2014

Bartlett PL, Shawe-Taylor J (1999) Generalization performance of support vector machines and other pattern classifiers. In: Schölkopf B, Burges CJC, Smola AJ (eds) Advances in Kernel Methods—Support Vector Learning. MIT Press, Cambridge, pp 43–54

Bauer E, Kohavi R (1999) An empirical comparison of voting classification algorithms: bagging, boosting, and variants. Mach Learn 36:105–139

BIS (2006) Bank of International Settlements. Basel II: International Convergence of Capital Measurement and Capital Standards: A Revised Framework—Comprehensive version. http://www.bis.org/publ/bcbs128.pdf. Accessed 10 Sep 2014

Breiman L (1996) Bagging predictors. Mach Learn 24:123–140

Breiman L (1998) Arcing classifiers. Ann Stat 26(3):801–849

Breiman L, Freidman JH, Olshen RA, Stone CJ (1984) Classification and regression trees. Wadsworth International Group, Wadsworth

Bruzzone L, Cossu R, Vernazza G (2004) Detection of land-cover transitions by combining multidate classifiers. Pattern Recogn Lett 25(13):1491–1500

Bühlmann P, Yu B (2003) Boosting with the L2 loss: regression and classification. J Am Stat Assoc 98:324–339
Burns P (2002) Retail credit risk modeling and the Basel Capital Accord. Discussion paper, Payment Cards Center. https://www.philadelphiafed.org/consumer-credit-and-payments/payment-cards-center/publications/discussion-papers/2002/CreditRiskModeling_012002.pdf January 2002. Accessed 10 Sept 2014
Chien BC, Lin JY, Yang WP (2006) A classification tree based on discriminant functions. J Inf Sci Eng 22(3):573–594
Coffman JY (1986) The proper role of tree analysis in forecasting the risk behavior of borrowers, management decision systems. MDS Reports, Atlanta
Dietterich T (2000) An experimental comparison of three methods for constructing ensembles of decision trees: bagging, boosting and randomization. Mach Learn 40(2):139–157
Durand D (1941) Risk elements in consumer installment financing. Studies in consumer installment financing: Study 8, National Bureau of Economic Research
Feldesman MR (2002) Classification trees as an alternative to linear discriminant analysis. Am J Phys Anthropol 119(3):257–275
Fisher R (1936) The use of multiple measurements in taxonomic problems. Ann Hum Genet 7 (2):179–188
Freund Y, Schapire RE (1998) Discussion of the paper "Arcing Classifiers" by Leo Breiman. Ann Stat 26(3):824–832
Freund Y, Schapire R (1999) A short introduction to boosting. J Jpn Soc Artif Intell 14 (5):771–780
Hsieh NC, Hung LP (2010) A data driven ensemble classifier for credit scoring analysis. Expert Syst Appl 37(1):534–545
Jobson J (1992) Applied multivariate data analysis. Springer Texts in Statistics, New York
Johnson RA, Wichern DW (2007) Applied multivariate statistical analysis. 6th edn, Prentice hall Englewood Cliffs
Khandani AE, Adlar JK, Lo AW (2010) Consumer credit-risk models via machine-learning algorithms. J Bank Finance 34:2767–2787
Klecka WR (1980) Discriminant analysis. Quantitative applications in the social sciences. Sage Publications, Beverly Hills
Kuzey C, Uyar A, Delen D (2014) The impact of multinationality on firm value: a comparative analysis of machine learning techniques. Decis Support Syst 59:127–142
Lai KL, Yu L, Shouyang W, Zhou L (2006) Credit risk analysis using a reliability-based neural network ensemble model. Lecture notes in computer science, Artificial neural networks—ICANN
Lai KL, He K, Yen J (2007) Modeling VaR in crude oil market: a multi scale nonlinear ensemble approach incorporating wavelet analysis and ANN. Lecture notes in computer science, computational science—ICCS
Langley P (1995) Elements of machine learning. Morgan Kaufmann Series in Machine Learning. 1st edn, Morgan Kaufmann, Burlington
Leigh W, Purvis R, Ragusa JM (2002) Forecasting the NYSE composite index with technical analysis, pattern recognizer, neural networks, and genetic algorithm: a case study in romantic decision support. Decis Support Syst 32(4):361–377
Maclin R, Opitz D (1997) An empirical evaluation of bagging and boosting. In: Proceedings of the 14th national conference on artificial intelligence. Cambridge, MA, pp 546–551
Maimon O, Rokach L (2004) Ensemble of decision trees for mining manufacturing data sets. Mach Eng 4:l–2
Mokeddem D, Belbachir H (2009) A survey of distributed classification based ensemble data mining methods. J Appl Sci 9(20):3739–3745
Opitz D, Maclin R (1999) Popular ensemble methods: an empirical study. J Artif Intell Res 11:169–198
Paleologo G, Elisseef A, Antonini G (2010) Subagging for credit scoring models. Eur J Oper Res 201(2):490–499

Pampel FC (2000) Logistic regression: a primer. Quantitative applications in the social sciences. Sage Publications, Beverly Hills
Press JS, Wilson S (1978) Choosing between logistic regression and discriminant analysis. J Am Stat Assoc 73(364):699–705
Quinlan R (1987) Simplifying decision trees. Int J Man-Mach Stud 27:221–234
Quinlan R (1992) C4.5: programs for machine learning. Morgan Kaufmann, Los Altos
Rokach L (2005) Ensemble methods for classifiers. Data mining and knowledge. discovery handbook. Springer, New York
Rokach L (2009) Taxonomy for characterizing ensemble methods in classification tasks: a review and annotated bibliography. Comput Stat Data Anal 53(12):4046–4072
Schooner HM, Talor MW (2010) The new capital adequacy framework: Basel II and credit risk. Global Bank Regulation, pp 147–164
Skurichina M, Duin RPW (2002) Bagging, boosting and the random subspace method for linear classifiers. Pattern Anal Appl 5:121–135
Tan AC, Gilbert D, Deville Y (2003) Multi-class protein fold classification using a new ensemble machine learning approach. Genome Inf 14:206–217
Thomas LC, Edelman DB, Crook JN (2002) Credit scoring and its applications. Society for Industrial and Applied Mathematics, Philadelphia
Tukey JW (1977) Exploratory data analysis. Addison-Wesley, Reading
Tumer K, Ghosh J (2001) Robust order statistics based ensembles for distributed data mining. In Kargupta H, Chan P (eds) Advances in distributed and parallel knowledge discovery. AAAIMIT Press, Cambridge, pp 185–210
Ugalde HMR, Carmona JC, Alvarado VM, Reyes-Reyes J (2013) Neural network design and model reduction approach for black box nonlinear system identification with reduced number of parameters. Neurocomputing 101:170–180
Xie H, Han S, Shu X, Yang X, Qu X, Zheng S (2009) Solving credit scoring problem with ensemble learning: a case study. In: Proceedings of the 2nd international symposium on knowledge acquisition and modeling. Wuhan, China, pp 51–54

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Part II
Decision Models in Production and Processes Management

A Review on the Dynamic Decision Models for Manufacturing and Supply Chain

Juliana Keiko Sagawa and Marcelo Seido Nagano

Abstract Manufacturing sites are primarily dynamic, that is, production plans and schedules are usually affected by disturbances and environmental changes. On the other hand, the decision analysis models for engineering management must aim to represent reality with accuracy. Thus, the study of the dynamic models in the engineering management field is paramount. In this chapter, dynamic decision models for manufacturing and supply chain are discussed. First, an overall review of the deterministic dynamic models based on control theory and state representation is presented. After that, a set of models specifically applied to scheduling and production control is discussed in detail. A comparative analysis of these models is also presented, followed by some directions for future research.

Keywords Dynamic decision models · Control theory · Dynamic modelling · Manufacturing · Supply chain

1 Introduction

A model is a depiction of reality. Bertrand and Fransoo (2002) add that it "is always an abstraction from reality in the sense that not the complete reality is included" (p. 243). Thus, although every model is not a complete representation by definition, there is usually a trade-off between the accuracy of the model in representing the situation it is proposed to and its complexity. More accurate and detailed models

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tend to be more complex in terms of mathematical formulation and, consequently, their mathematical solution tend to be costlier. Thus, a balance between accuracy and complexity has to be found.

Real life is primarily dynamic. Time is an essential dimension over which human life and activities are structured. In many decision problems, however, it is adequate to collect a set of information over a period of time and then solve the problem in the static domain. This is the approach applied in many of the manufacturing and supply chain problems, and its effectiveness is not being questioned. Some researchers highlight this fact, asserting that the majority of the supply chain and production models are based on average performance or steady-state conditions (Suri and Desiraju 1997; Ortega and Lin 2004; Sarimveis et al. 2008). Nevertheless, "static models are insufficient when dealing with the dynamic characteristics of the supply chain system, which are due to demand fluctuations, lead time delays, sales forecasting, etc." (Sarimveis et al. 2008). Also, local manufacturing sites are subjected to many disturbances, such as urgent jobs, absenteeism, changes in demand patterns, machine breakdowns, lack of raw materials, inconsistencies in the human decision-making process and others.

From the considered context emerges the importance of the decision models that depict the dynamics of the manufacturing sites and supply chains. These models allow a more accurate representation of the production reality considering the time dimension and the unexpected events belonging to this reality. The tools from dynamic modelling methodologies and control theory enable the development and simulation of these models. With these tools, it is possible to improve the accuracy of the models by considering the dynamics of real situations while at the same time coping with the complexity, since these tools provide adequate mathematical formulations and solutions for the models. Therefore, the mentioned balance between accuracy and complexity may be reached.

This chapter is devoted to present several decision models that consider the dynamics of the manufacturing and supply chain systems. First, a broad review of models for different applications in the manufacturing and supply chain area is presented. Afterwards, in a subsequent section, emphasis is given for detailing the models applied to production control and scheduling of manufacturing sites. The focus on these models is justified by the results of the literature scanning performed. The results showed that the dynamics of the supply chain have been receiving more attention from the researchers than the dynamics of manufacturing sites, concerning short-term production control and scheduling. By analysing these models in more detail, open opportunities of research in a neglected branch are uncovered. In the penultimate section, a comparison between the dynamic models for scheduling and production control is presented, followed by the final remarks and directions for future research.

2 Dynamic Decision Models for Supply Chain and Manufacturing

The earliest models of manufacturing systems based on dynamic modelling and control theory date from 1950. Simon (1952) applied control theory to a production–inventory problem; the objective was to control the rate of production for a single product in terms of servomechanism theory. In this model, alternative decision rules were evaluated using cost criterion. His efforts were followed by Vassian's (1955) contribution. He extended the application of servomechanism theory to discrete-time models and proposed an order policy to minimize the inventory balance variance.

Åström and Kumar (2014) present a broad perspective on the development of the control science in several areas, how it emerged and developed in the engineering, telecommunication and physical, chemical and biological fields, among others, including a small section concerning manufacturing applications. Most of the applications in manufacturing arose in what they call "The Golden Age" (Åström and Kumar 2014). A rapid growth of control applications in all fields occurred in the period of 1960–2000, and there was also a very dynamic development of theory and subspecialities.

Another breakthrough came with Forrester (1958, 1961), which proposed the representation of a manufacturing system by means of a set of resources flowing through various states according to rates. The methodology, first called industrial dynamics, was later renamed system dynamics and originated a relevant branch of research with applications in many areas. In parallel with that, applications of dynamic programming to inventory problems were being developed, such as the work of Scarf (1960).

One point of interest for the control history in manufacturing is also the use of state space representation to production–inventory modelling, as proposed by Christensen and Brogan (1971) and Porter and Bradshaw (1974). Actually, the mathematical representation of the models developed according to industrial dynamics formulation resembles the state space representation, as highlighted by Ortega and Lin (2004). The state space representation is the matrix form of differential equations of the state variables. One matrix equation expresses the derivatives of the state variables, and another matrix equation represents the outputs of the system. As well known in the control field, this representation allows modelling systems with multiple controlled variables, while the classical control theory approach using transfer functions allows the control of one single variable.

Different criteria were proposed to classify the dynamic models applied to manufacturing and supply chain. Ortega and Lin (2004) proposed a classification based on the type of application and on the two approaches highlighted by Axsäter (1985). According to the latter, there are two approaches to simplify dynamic models and deal with nonlinear configurations and uncertainties. The first one refers to the assumption of the certainty equivalence principle; in this case, models with uncertainties are approximated by deterministic models based on averages.

The second option is the use of a hierarchical approach. Planning at a higher aggregate level usually leads to fewer (aggregate) variables to deal with. Based on that, Ortega and Lin (2004) classify the models into two groups. The first one is labelled "horizontal extensions" and comprises the models focused on the supply chain dynamics. These deterministic models are extensions of the production–-inventory systems developed for manufacturing a single product in a single stage. The second group is formed by models that were developed according to a "hierarchical approach". It encompasses multi-echelon models where the product structure tree or the bill of materials (BOM) is used as an input matrix for the production–inventory system. As known, the BOM is a hierarchical representation of the assemblies, subassemblies, components and parts that form a product. These models are considered "vertical extensions" of the first production–inventory systems (Ortega, Lin 2004) and were also named by Sarimveis et al. (2008) as "multi-level, multi-stage" (MLMS) production–inventory systems.

Another classification scheme, proposed by Sarimveis et al. (2008), is based on the fundamentals and the methodology underlying the models. Therefore, five categories are proposed by the authors, comprising the models based on classical control theory, dynamic programming and optimal control, model predictive control, robust control and approximate dynamic programming. According to this criterion, the models reviewed by Ortega and Lin (2004) would be in the first category.

In this text, we propose a classification structure that is primarily based on the type of application of the models, however, extending the two categories presented by Ortega and Lin (2004). The earliest models described so far were grouped under the category of "pioneer models", since they provided the basis for the further developments in the field. Moreover, another category was added to highlight the models devoted to study the dynamics of manufacturing sites, focused on operation scheduling and shop floor control. Tables 1–4 present some dynamic decision models for manufacturing and supply chain, following the mentioned classification scheme.

In terms of the underlying methodology and tools, the models presented in Tables 1–4 are deterministic and based on classical control theory methodology (block diagrams, transfer functions, etc.) as well as state representation and bond graphs, which is a more specific methodology for dynamic modelling. In the specific scope of this review, we did not consider the models based on control methodologies such as dynamic programming and optimal control, model predictive control and robust control. For these models, the review of Sarimveis et al. (2008) is recommended as further reading.

After the earliest models proposed in the decades of 1960 and 1970, Towill (1982) developed a production–inventory system in a block diagram form, composed of two basic subsystems: a feedforward subsystem that is associated with demand forecast and carries information from the external environment and a feedback subsystem that carries internal information related to the results of previous decisions. This system was called inventory and order-based production control system (IOBPCS) and considered a single product or represented a set of

Table 1 Pioneer dynamic models of production–inventory systems

Authors	Type of model/ application	Applied methodologies and tools	Contributions
Simon (1952)	Pioneer models (fundamental basis)	Servomechanism continuous-time theory, Laplace transform	Applied control theory to a production–inventory problem by controlling the rate of production for a single product in terms of servomechanism theory; alternative decision rules evaluated using cost criterion
Vassian (1955)		Classical control theory, Z transform	Extended the application of servomechanism theory to discrete-time models; proposed an order policy to minimize the inventory balance variance
Forrester (1958, 1961)		Industrial dynamics/system dynamics	Developed causal loop diagrams which represent the system under study by means of various resources which flow through various states according to rates; the mathematical model is based on rate and level equations; studied the demand amplification effect (Forrester effect or bullwhip effect) using an industrial dynamics model of a three-stage supply chain (factory, distributor and retailer)
Christensen and Brogan (1971), Porter and Bradshaw (1974)		State space representation	One of the firsts to apply state space representation to production–inventory modelling

aggregate products. As it can be observed in Table 2, the IOBPCS model was modified and extended by a group of researchers, originating a whole family of models. According to Sarimveis et al. (2008), the IOBPCS family is based on some or all of the five components:

- the lead time, which incorporates production delays in manufacturing sites. In the model, the lead time represents the period of time from the moment the order is placed to the moment the goods become available at the inventory;
- the target stock setting, that is, the definition of a reference value for the stock level. In the IOBPCS and APIOBPCS models, this target is a fixed value, while

Table 2 Single-product production–inventory models and extensions to supply chain

Authors	Type of model/application	Applied methodologies and tools	Contributions
Burns and Sivazlian (1978)	Single-product production–inventory models and extensions to supply chain ("horizontal extensions")	Classical control theory, signal flow graph diagram, frequency response analysis	Continued the study on the Forrester effect (bullwhip effect), representing each stage of the supply chain as a signal flow graph diagram; proposed the use of a "recovery operator" to reduce the bullwhip effect
Towill (1982)		Classical control theory, block diagrams, transfer functions, Laplace transform	Developed a normalized transfer function to relate the inventory level and the consumption rate; developed an inventory–production model named inventory and order-based production control system (IOBPCS) considering three parameters: production delay time, time to adjust inventory and demand averaging time
Edghill and Towill (1990)		Classical control theory, block diagrams, frequency response analysis	Compared two control systems, one with a fixed desired inventory level and another with variable desired inventory level; the latter, named VIOBPCS model, is an extension of the IOBPCS model
Wikner et al. (1991)		Classical control theory, block diagrams, transfer functions	Proposed and compared five approaches to improve supply chain dynamics with a control theory-based model
Wikner et al. (1992)		Classical control theory, block diagrams, transfer functions, Laplace and Z transforms	Represented production lead times and replenishment policies by expression in the frequency domain; calculated the Laplace and Z transforms for some commonly used forecasting techniques, such as moving averages and first-order exponential smoothing; applied a PID controller to the system
John et al. (1994)		Classical control theory, block diagrams, transfer functions	Extended the IOBPCS model, proposing the APIOBPCS model, which considers a constant desired inventory level and utilizes all three control policies (demand, inventory and pipeline policies); in other words, a work-in-process (WIP) feedback loop is added, so that the order rate is also influenced by the WIP levels

(continued)

Table 2 (continued)

Authors	Type of model/application	Applied methodologies and tools	Contributions
Agrell and Wikner (1996)		Classical control theory, block diagrams, transfer functions	Studied the IOBPCS model using a multi-criteria decision-making approach; response speed and response smoothness were the two objectives to be optimized
Towill et al. (1997)		Classical control theory, block diagrams, transfer functions, nonlinear and time-varying elements	Considered sources of uncertainty in lead time estimation; proposed an additional nonlinear and time-varying feedback loop to the model to provide updated estimates of current lead time, which in turn updates the desired level of work in process
Evans et al. (1998)		Classical control theory, steady-state design principles	Modelled and simulated the dynamic behaviour of a logistical control system, aiming to maximize customer service levels while minimizing finished goods stock levels; compared different control alternatives
White (1999)		Classical control theory, block diagrams, transfer functions	Showed that simple inventory management techniques are equivalent to proportional control; showed that PID controllers could reduce stock levels by 80 %
Disney et al. (2000)		Classical control theory, genetic algorithms	Searched for near-optimal values for the parameters used in a generic model of production and distribution control
Disney and Towill (2002)		Classical control theory, causal loop diagrams, block diagrams, Z transform	Showed that poor parameter selection caused instability in a vendor-managed inventory (VMI) supply chain; proposed general stability criteria for this kind of supply chain

(continued)

Table 2 (continued)

Authors	Type of model/application	Applied methodologies and tools	Contributions
Dejonckheere et al. (2002, 2003)		Classical control theory, block diagrams, transfer functions, frequency response analysis	Analytically evaluated the bullwhip effect (Forrester effect) when the exponential smoothing is used to forecast demand; evaluated the impact of the order-up-to replenishment rules on the bullwhip effect using frequency response analysis; extended the APIOBPCS model to consider variable inventory desired levels, obtaining the APVIOBPCS model
Zhou et al. (2006)		Classical control theory, block diagrams, transfer functions	Extended the APIOBPCS model, presenting a hybrid system containing both manufacturing and remanufacturing; implemented a Kanban policy in the remanufacturing loop and studied effect of including this loop in the dynamics of the system
Lalwani et al. (2006)		State space representation	Presented discrete-time state space representations (matrices A, B, C, D) for several models in the IOBPCS family; performed stability, controllability and observability tests for the APVIOBPCS model
Wang et al. (2008)		Classical control theory, block diagrams, Laplace transform	Studied the APIOBPCS model subjected to ramp demand and showed that there will be inventory drift in this case; proposed the use of a PI controller in the inventory feedback loop to eliminate the inventory drift and the use of a PD controller in the order rate policy to smooth the inventory level
Zhou et al. (2010)		Classical control theory, block diagrams, transfer functions	Studied the APIOBPCS model in the situation where the echelon decision-maker may be handling a wide range of SKUs in a non-altruistic environment where the information of the market trends may either be withheld or unavailable; showed that APIOBPCS may be well matched to such situations

in the VIOPBCS and APVIOBPCS models, it is a multiple of current average sales rates;
- the demand policy, which corresponds to the forecasting method used to average the current market demand. As previously mentioned, the demand forecast is inputted as feedforward information to the system;
- the inventory policy, which determines the rate at which the inventory error is corrected by adjusting the order rate. The inventory error or inventory deficit corresponds to the difference between the desired stock level and the actual stock level. The inventory policy is closely related to the lead time, since a modification in the order rate at a given time will produce a delayed modification in the inventory level, which significantly affects the dynamics of the system;
- the pipeline policy, which controls the rate at which the work-in-process (WIP) error is corrected. Analogously to the inventory error, the WIP error is the difference between the desired and the actual WIP levels. The IOBPCS and VIOBPCS models do not present the feedback loop related to the pipeline policy; this loop was included in the APIOBPCS and APVIOBPCS models.

As previously mentioned, a different class of dynamic decision models comprises the multi-echelon models (or MLMS models) where the various items that compose an end product or the various stages of production are represented in a matrix form. Input–output analysis and Laplace or Z transforms are the methodologies often applied. Most of the models of this class are devoted to lot sizing and timing decisions, i.e. determining the amount that must be produced of a given item and the time at which the production of the item must start to optimize costs.

Initially, the objective function usually defined in the models was based on the minimization of the set-up, inventory holding and backlog costs. Later on, the objective became to maximize the annuity stream, which corresponds to maximize the net present value (NPV) of all payments associated with the processes concerned (i.e. the revenues of selling products when demanded and the costs incurred in production and inventory holding). In this approach, Laplace transforms were applied to evaluate the resulting cash flows when adopting the NPV criterion in the continuous domain.

The development of the continuous models presented by Grubbström and Molinder (1994, 1996) starts from the inventory balance and backlog equations. The product structure or BOM is represented by a matrix H that is multiplied by a delay factor to represent the lead time of manufacturing or purchasing a given item. The resulting generalized input matrix is a relevant parameter of the inventory balance expression. In order to obtain the solution of the optimization problem, the inventory and backlog equations are replaced into the objective function, which considers the set-up, inventory holding and backlog costs. The maximization is performed by equalling the partial derivatives to zero and solving the correspondent equations.

The multi-echelon models proposed by Grubbström and Ovrin (1992) and Grubbström and Molinder (1994) were extended in different ways. The contributions,

Table 3 Multi-echelon production–inventory models

Authors	Type of model/application	Applied methodologies and tools	Contributions
Axsäter (1976)	Multi-echelon production–inventory models ("vertical extensions" or "multi-level multi-stage" models)	Classical control theory, input–output analysis	Used the bill of materials (BOM) as an input matrix for a dynamic model that described a production–inventory system of a complex product
Grubbström and Lundquist (1977)		Classical control theory, input–output analysis	Extended Axsäter's (1976) model, examining the relationships between input–output analysis, material requirements planning (MRP) and production functions
Popplewell and Bonney (1987)		Classical control theory, input–output analysis, Z transform	Investigated how multiple products and multiple levels of production control could be represented by discrete linear control models; formulated a generic model and investigated its stability and its response to random disturbances
Grubbström and Ovrin (1992), Grubbström and Molinder (1994)		Classical control theory, input–output analysis, Z transform, Laplace transform	Proposed a decision model to define batch sizes and production starting times in a production system with multiple levels; included the production lead times in the model by introducing a delay factor in the matrix of the BOM; the model developed in 1992 is discrete, while the one proposed in 1994 is continuous
Grubbström and Molinder (1996)		Input–output analysis, Laplace transform, probability distributions	Extended Grubbström and Molinder's (1994) model by adopting the Poisson distribution to represent external demand for the end product
Bogataj and Horvat (1996)		Input–output analysis, Laplace transform, probability distributions, NPV	Extended Grubbström and Molinder's (1994) model by adopting the uniform distribution to represent external demand for the end product; use the maximization of net present value (NPV) as the objective function for the decision problem

(continued)

Table 3 (continued)

Authors	Type of model/application	Applied methodologies and tools	Contributions
Grubbström and Tang (1999)		Input–output analysis, Laplace transform, probability distributions, NPV	Included the definition of safety stocks to Grubbström and Molinder's (1994) model; the system is subjected to stochastic demand, with the interval between events following the gamma distribution
Grubbström and Tang (2000)		Input–output analysis, Laplace transform, probability distributions, NPV	Added to the previous models the possibility of rescheduling the production (i.e. redefining lot sizes and production starting dates) when the internal or external circumstances change
Grubbström and Wang (2003)		Input–output analysis, Laplace transform, statistical distributions, NPV	Added capacity constraints to the previous model (Grubbström and Molinders 1994), while also considering stochastic external demand
Hennet (2003)		Input–output analysis, state space representation, model predictive control	Modelled a multi-stage multi-item production plant where the production, supply and inventory plan is optimized under two different sources of information: short-term plan relies on firm orders received from customers and the long-term plan is based on predicted demands represented by random sequences
Zhou and Grubbström (2004)		Input–output analysis, Laplace transform, statistical distributions, NPV	Considered the same structure of the initial model (Grubbström and Molinder's 1994) and investigated the effect of the commonality, which is the use of the same type of component in different locations of product structure trees
Grubbström (2005) and Grubbström et al. (2010)		Input–output analysis, Laplace transform, statistical distributions, NPV	Investigated the condition for the optimality of a given production plan generated by multi-echelon lot sizing decision model, for the single-product case (2005) and for the general multi-item case (2010); this condition allows formulating the problem using binary decision variables; proposed the triple algorithm to solve the problem

(continued)

Table 3 (continued)

Authors	Type of model/application	Applied methodologies and tools	Contributions
Hennet (2009)		Input–output analysis, state space representation, model predictive control	Modelled a network of autonomous enterprises with distributed decisional structure as a multi-stage manufacturing model, where product structure BOM dictates the organization of the network; evaluate the effect of adopting local base stock policies applied to the inventory positions

as shown in Table 3, include the addition of safety stocks or capacity constraints, the use of the annuity stream as objective function, the consideration of stochastic external demands following different probability distributions and the study of the effects of commonality, among others.

It is interesting to note that in this case, the dynamic modelling and control tools, such as the Laplace transform, were not used to directly model the dynamics of the problem itself, but to optimize production decisions over a finite horizon, that is, they were applied to solve an optimization problem.

Besides the family of Grubbström's models, different multi-echelon approaches were proposed. Popplewell and Bonney (1987) considered a model where the dynamics of each level and stage are represented by a z transfer function and the inputs and outputs to each element are time series signals, which are also represented by z transforms. Davis and Thompson (1993) introduced the concept of a generic controller applied to each hierarchical level of production planning (aggregate, intermediate and detailed planning). The controller had four functions: assessment, optimization, execution and monitoring. The authors employed an integrated and stochastic decision-making approach within each implemented generic controller to address the uncertainties that are inherent to the production planning problem.

The study of multi-echelon inventory problems was also addressed by Axsäter (1990). Over the years, the basic model proposed by this author has also been extended. A two-echelon distribution inventory system with stochastic demand was modelled (Axsäter 2001), comprising a central warehouse and a number of retailers. The approximation of a high-demand system into a low-demand system is proposed to improve the solution time. Axsäter (2003) modelled the same two-echelon distribution inventory system, but using normal approximations both for the retailer demand and for the demand at the warehouse as a technique to approximate optimization of the reorder points. Another extension to the original model was developed to handle the situation where there is direct customer demand at the warehouse (Axsäter et al. 2007). In all these mentioned models, the system is controlled by continuous review installation stock (R, Q) policies with given batch quantities. In this sense, they could be classified in the same category of the IOBPCS models or in the category of multi-echelon models. However, they were not included in the review presented in Table 2 or Table 3 since they adopt a statistical and optimization approach, not focusing on the control theory approach.

Hennet (2009) proposed a model that could be considered as both a "horizontal" and a "vertical" extension of the production–inventory systems or could be better classified as a MLMS model. In this work, a network of autonomous enterprises is modelled as a multi-stage manufacturing model, and the product structure BOM dictates the organization of the network. Thus, producers of primary products play the role of suppliers, while producers of intermediate products play both the roles of suppliers and producers; similarly, producers of end products are both producers and retailers. It is assumed that the information available at each stage is mainly local, and it is also supposed that each stage adopts a base stock policy applied to the inventory positions. As main results, he found that under some traditional assumptions such as fixed lead times and common order periodicity, the local base stock policies are equivalent to an integrated policy.

Table 4 shows the last class of models reviewed in this chapter, specifically applied to scheduling and production control in manufacturing sites. These models will be discussed in the next sections.

3 Dynamic Decision Models for Operation Scheduling and Shop Floor Control

Some models focused on the scheduling and production control of manufacturing sites, such as the one presented by Wiendahl and Breithaupt (2000), are classified in some reviews (Sarimveis et al. 2008) as supply chain models. However, it is interesting to highlight these models and classify them in a different category for the following reasons:

- they use different variables and different modelling logics compared to the production–inventory systems of IOBPCS family or to the multi-echelon (multi-level multi-stage models);
- the IOBPCS and the multi-echelon models present several successful extensions and contributions of many researchers; contributions for the dynamic shop floor control and scheduling models were less numerous and, thus, are open opportunities of research;
- some of these models for scheduling and shop floor control overcome one limitation of the IOBPCS and the multi-echelon models, which is the fact of dealing with only a single product. The models developed by Prabhu and Duffie (1999) and Wiendahl and Breithaupt (2000) are examples of that, since they cope with the production of multiple products or multiple jobs.

The dynamic decision models for scheduling and production control of manufacturing sites will be discussed with more detail in the next subsections, followed by a comparative analysis.

3.1 *The Automatic Production Control System (Model 1)*

The first dynamic model for shop floor control analysed in this chapter is the automatic production control (APC) system proposed by Wiendahl and Breithaupt (1999, 2000). In this system, the shop floor is modelled according to an analogy with a continuous-flow system. Also, the funnel model (Wiendahl 1995) and the theory of the logistic operating curves (Nyhuis 1994; Nyhuis and Wiendahl 2006) provide the theoretical basis for the mathematical manipulations. The main advantage of a continuous model is the existence of more control theory tools for

Table 4 Scheduling and production control dynamic models

Authors	Type of model/application	Applied methodologies and tools	Contributions
Dembélé and Lhote (1993)	Scheduling and production control models (short-term detailed planning for manufacturing sites)	Bond graphs and conceptual extensions	Represent some manufacturing entities inspired in the bond graph theory; the power variables are the number of individual products in the batches and their frequency; the power is defined by the rate of flow and the energy by the number of convoyed products
Besombes and Marcon (1993)		Bond graphs and conceptual extensions	Proposed a techno-economic representation of a production system considering the flow of products and the cost variations in production; the flow variable represents the number of products demanded per unit time, and the effort variable represents an unitary cost of product demand
Prabhu and Duffie (1999)		Concept of the proportional integral (PI) controller	Proposed the distributed arrival time controller (DATC), a scheduling model where an integral controller is used to determine the arrival times of parts; the model works as a search engine that replaces the heuristics used in the traditional scheduling models
Wiendahl and Breithaupt (1999, 2000)		Funnel theory, logistic operating curves, capacity envelope, approximation to flow systems	Developed the automatic production control (APC) system, a flow-oriented stochastic model based on the funnel theory and the theory of logistic operating curves; the model has two controllers, one for the backlog and one for the work in process, and was applied to a job shop using the concept of transition probabilities
Ferney (2000)		Bond graphs, state space representation, approximation of discrete systems by continuous systems	Proposed bond graph representations for basic manufacturing entities, such as machines, intermediate stocks, sources of material, junctions and stocks of final products; simulated a theoretical manufacturing system with few machines

(continued)

Table 4 (continued)

Authors	Type of model/application	Applied methodologies and tools	Contributions
Haffaf and Kamel (2001)		Bond graph concepts, concepts of information systems	Proposed an approach where information is viewed as a form of energy, and the dual power variables (flow and effort) correspond data and treatments
Sader and Sorensen (2003)		Analogies to the properties of electrical components	Modelled a manufacturing system based on analogies between the manufacturing entities and electrical components, such as capacitors and resistors; simulated a theoretical system with few machines
Benmansour et al. (2004)		Bond graph concepts	Proposed 3 categories to classify the bond graph approaches for modelling manufacturing systems: physical, techno-economical and informational approach
Cho and Prabhu (2007)		Concept of the proportional integral (PI) controller	Proposed an integration of DATC with a distributed machine capacity controller (DMCC) at the CNC level; this controller receives feedback on the machine conditions from the lower level
Cho and Erkoc (2009)		Concept of the proportional integral (PI) controller	Studied the behaviour of the DATC when the jobs have the same due date; proposed the use of a double integral controller (DIAC)
Cho and Lazaro (2010)		Concept of the proportional integral derivative (PID) controller	Proposed the use of a proportional integral derivative (PID) controller based on the same framework of DATC
Li et al. (2011)		Concept of feedback loop	Proposed a computer-aided system where a dispatching heuristic is integrated to a closed-loop feedback control scheme; the feedback loop brings information from the shop floor about the need of rescheduling (re-executing the heuristics)

the continuous-time domain than for the discrete domain. According to the analogy between the manufacturing system and a flow system, the work in process (WIP) of a work centre on time t can be expressed as the difference between the input flow and the output flow, summed to the initial WIP. More specifically, the momentary work in process of work centre k depends on its initial inventory, its cumulated external input, the actual cumulative output of the upstream work centres flowing to it and its own actual cumulative output until time t. This relation is shown in Eq. 1.

$$\begin{aligned} \mathrm{mwip}_{\mathrm{order},k}(t) = {} & \mathrm{mwip}_{\mathrm{order},k}(0) + \mathrm{extin}_{\mathrm{order},k}(t) \\ & + \sum_{j=1}^{k} [\mathrm{out}_{\mathrm{order,max,j}}(t) - \mathrm{out}_{\mathrm{order,loss},j}(t)] p_{j,k} \\ & - [\mathrm{out}_{\mathrm{order,max,k}}(t) - \mathrm{out}_{\mathrm{order,loss},k}(t)], \end{aligned} \tag{1}$$

where $\mathrm{mwip}_{\mathrm{order},\ k}$ (t) = mean work in process of centre k at time t, $\mathrm{mwip}_{\mathrm{order},\ k}$ (0) = initial mean work in process of centre k, $\mathrm{extin}_{\mathrm{order},k}$ (t) = cumulative external input of centre k until time t, $\mathrm{out}_{\mathrm{order,\ max}j}$ (t) = cumulative potential outflow of upstream centre j until time t, $\mathrm{out}_{\mathrm{order,\ loss},\ j}$ (t) = cumulative potential lost of outflow due to empty upstream centre j until time t, $\mathrm{out}_{\mathrm{order,\ max},\ k}$ (t) = cumulative potential outflow of centre k until time t, $\mathrm{out}_{\mathrm{order,\ loss},\ k}$ (t) = cumulative potential loss of outflow due to empty centre k until time t and $p_{j,k}$ = fraction of total output from centre j flowing directly to centre k. All these variables (except $p_{j,k}$, which is dimensionless) are expressed in number of orders.

The parameters of initial work in process, external input and potential cumulative output of each work centre can be easily determined; the relation between losses in utilization ($\mathrm{out}_{\mathrm{loss},k}$) and the momentary WIP level, however, is not easy to define. Wiendahl and Breithaupt (1999, 2000) solved this problem by applying the funnel model and the theory of logistic operating curves.

The funnel model resembles Little's law (Little 1961) and defines the WIP of a system as the multiplication of its performance (in terms of production rate or throughput rate) and its mean range (or lead time). The concept of mean range, on its turn, is related to the mean runout time of the work centre, i.e. the time taken to process the work content. The funnel model differs from Little's law in two aspects: first, it is based on work content (i.e. a continuous amount) rather than on discrete orders; second, it considers the average output rate, i.e. the mean performance of the system, while the Little's law involves the average arrival rate of orders. According to Wiendahl and Breithaupt (2000), "the incoming orders, measured in hours of work content, form a stock of pending lots, which have to flow through de funnel outlet. The diameter of the outlet can be described as the capacity of the work system, which is adjustable within limits" and determines the actual performance of the system.

The theory of the logistic operating curves (Nyhuis 1994; Nyhuis and Wiendahl 2006), which is based on the funnel model, states that if a given work centre has a buffer of pending orders at all times, then the output of this centre is independent of the mean WIP. In this case, the performance of the system is equal to its capacity. In fact, there is an initial portion of the curve where the output performance increases as the WIP increases. However, after a critical value of WIP is reached, the output saturates, i.e. it becomes constant. Losses in production will only occur if the WIP is reduced beyond the critical value, causing interruptions in the material flow. The range, on the other hand, increases or decreases in direct proportion to the WIP and is bounded by a lower value that corresponds to the processing time of a single unit or of a minimum content of work. Beyond this point, the range cannot be further reduced. The critical value of WIP represents the WIP level necessary to run the system, considering that the arriving orders do not have to wait and the material flow is not interrupted.

With the equations of the logistic operating curves, it is possible to determine the actual output of the work centres, considering the losses. Thus, the application of Eq. 1 to a specific operating point of the performance curve yields the expression presented in Eq. 2.

$$\begin{aligned} \mathrm{mwip}_{\mathrm{order},k}(t) = {} & \mathrm{mwip}_{\mathrm{order},k}(0) \\ & + \int_0^t \left(\mathrm{extin}_{\mathrm{order},k}(t) + \sum_{j=1}^{k} \mathrm{per}_j(\mathrm{mwip}_j(t)) \frac{1}{\mathrm{mot}_j} p_{j,k} \right) \mathrm{mot}_j \mathrm{d}t \\ & - \int_0^t \mathrm{per}_k(\mathrm{mwip}_k(t)), \end{aligned} \tag{2}$$

where $\mathrm{per}_j(\mathrm{mwip}_j(t))$ is the output performance of a centre j for a given level of mean work in process. The performance is measured in terms of throughput rate, and its value is taken from the logistic curve. Actually, the term $\mathrm{per}_j(\mathrm{mwip}_j(t))$ represents a specific operating point of the work centre j in relation to its characteristic logistic curve of performance.

In order to adapt (1) to the continuous-time domain and use control theory elements, the dimensions of the variables must be converted from number of orders into work content (e.g. hours). This conversion is done by means of the mean order time of the work centres (mot), which appears in (2).

Based on the presented equations concerning the material flow in a work centre, Wiendahl and Breithaupt (1999, 2000) propose a flow-oriented stochastic job shop model using the concept of transition probabilities. These probabilities are calculated by normalizing a material flow matrix (MFM), which, on its turn, is obtained by collecting real data from the job shop. As known, this matrix shows the amounts of material or the number of orders that flow from a work centre to another. So, when normalized, it expresses the percentage of work content that flows to each work centre of a job shop.

The proposed model comprises two controllers: a backlog controller and a WIP controller. The backlog of a system may be defined as the difference between the planned sum of work and the actual output. Thus, in this case, the planned performance is the reference variable, whereas the capacity is used as a correcting variable. The objective is to allocate the adequate capacity to process the system load. The difference between the actual and the planned performance signals in the system is integrated over a time interval, resulting in the above-mentioned backlog. The role of the WIP controller, on its turn, is "to set the system to an operating point on the operating characteristic curve that was defined within the scope of production planning" (Wiendahl and Breithaupt 2000). The planned WIP is taken as the reference value, and the controller adjusts the input rate of the production system based on the WIP error, i.e. the difference between the actual WIP and the planned WIP.

As previously mentioned, the output variables performance, WIP and range are related by means of the funnel formula. Hence, only two of these variables may be simultaneously controlled. The backlog controller monitors the output performance of the system. Therefore, either a range or a WIP controller could be implemented. The WIP controller was preferred by the aforementioned authors for two reasons. First, according to them, the measurement of this variable is easier and more precise. Second, the values that it can assume are not limited as it happens for the range, which is limited at the bottom by the sum of the transportation and operation time.

Although different amounts of capacity may be allocated to a system, few systems are so flexible that this allocation can be instantaneous. Usually, a reaction time or a minimum installation time is required. In order to consider these times, the capacity installation and deinstallation is represented in the model by envelope curves.

It is possible to observe how the continuous-flow model functions with the aid of Fig. 1. The first step to run this model is to determine at which point on the characteristic curve the system should operate, that is, to determine the planned

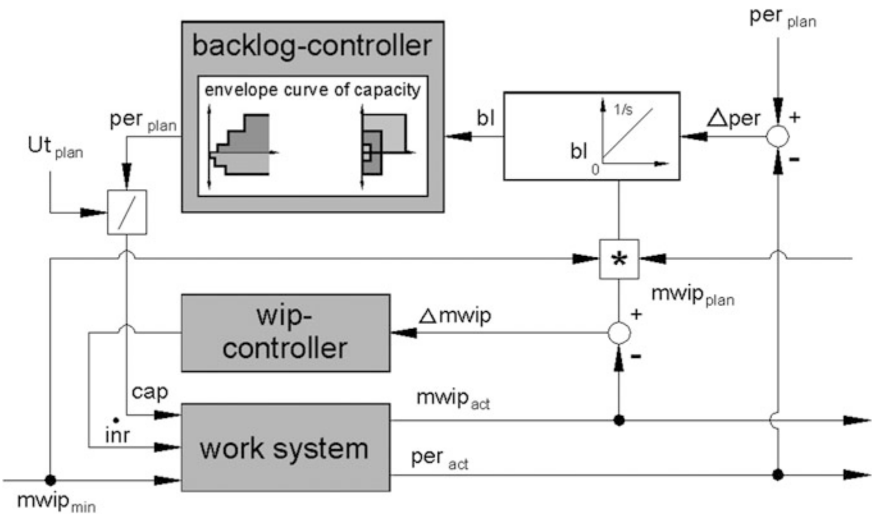

Fig. 1 Automatic production control system (Wiendahl and Breithaupt 2000)

performance. This means also to set a value for the system utilization. From the planned output and the planned utilization, the necessary capacity is calculated. The integration of the deviations between the planned performance and the actual performance over a time interval yields the backlog of the system. The backlog controller then calculates the planned performance for the next period, which will lead to the corrected capacity of the system. In the other branch, the relative planned WIP ($mwip_{rel,plan}$) is multiplied by the mean WIP minimum, resulting in the planned mean WIP. The actual mean WIP of the system is also compared to the target, i.e. the planed mean WIP. The WIP controller corrects the input rate of the system based on these deviations (Wiendahl and Breithaupt 1999, 2000).

Summarizing, the WIP controller executes the control while the target for the system utilization is not reached, i.e. when the work centres are operating below the planned utilization and when the actual WIP deviates from the planned WIP. When the utilization target is achieved and backlog arises, the backlog controller assumes the control task. The authors compare the two controllers to the conventional production control methods: capacity is usually increased when backlog increases in a production system; if the range keeps growing, the queue in front of the work system can be reduced by reducing the input rate of the system.

The proposed system was evaluated by means of computational simulations. An urgent order is introduced when the system is balanced, and the reaction of the system with and without control is observed. The mean WIP and the backlog over time are monitored in both cases. The balance is restored much faster in the controlled system, i.e. the WIP and the backlog levels come back to the initial level much faster than in the uncontrolled system. Also, for the uncontrolled system, when a higher utilization was set, the system spent much more time to reach balance again after the introduction of one single unplanned order. This result was also expected and is in accordance with the literature.

When the unplanned order arrives to the controlled system, the WIP controller reduces the input rate to decrease WIP to the planned level. Then, the backlog controller increases the capacity to the value that is necessary to decrease backlog to zero during the following period, respecting the reaction time for the capacity adjustment and the minimum time for the capacity installation. At the same time, the WIP controller starts to increase the input rate again, providing enough work to the system. In this model, the work that exceeds momentary actual capacity is not released until there is sufficient capacity available to process it (Wiendahl and Breithaupt 1997, 2000). "Capacity and work come together at the same time keeping ranges at the planned level and compensating disturbances between load and capacity. The quality of this process in a system with this control strategy installed is independent from the initial operating state of the production system" (Wiendahl and Breithaupt 2000).

3.2 A Dynamic Single-Product Manufacturing System Modelled with Bond Graphs (Model 2)

The bond graph methodology, presented by Karnopp and Rosenberg (1968), enables a pictorial representation of the dynamics of different kinds of physical systems. The basic elements used for modelling are inspired in ideal electrical (or mechanical) components, and the main principle of the methodology is the power transmission between components. The constitutive equations of the basic elements are written in terms of the power variables of flow (*f*) and effort (or stress, *e*) and in terms of the energy variables of momentum (*p*) and displacement (*q*). Compatibility equations that express the conservation of flow and effort are also used. Based on that, the state space model of a system can be derived from its pictorial representation using the bond graphs.

Although the methodology was originally devoted to model physical systems, such as electrical, mechanical and thermal systems, applications in the manufacturing field were also proposed. Dembélé and Lhote (1993) proposed an extension of the original methodology and created new elements to represent manufacturing entities. Besombes and Marcon (1993) interpreted the generalized variables in the context of manufacturing, considering both a physical and an economical view. According to that, the flow variable was defined as the number of products demanded per unit time, while the effort variable referred to the unitary cost of product demand.

In Besombes and Marcon's (1993) model, the resistor is related to the production direct unit cost to satisfy the demand. Hence, the constitutive equation of this element in terms of effort and flow variables is associated with the notion that the unit cost of processing a demand is a function of the flow of production. The capacitor is used to represent a stock of products.

Ferney (2000) was the first to propose a bond graph representation for a manufacturing system that could be accurately translated into state space representation and could be simulated. This was possible because the author's definitions of the manufacturing entities were not based on an extension of the bond graph methodology, but, on the contrary, they preserved the methodology formalism necessary for the adequate mathematical modelling.

Some of the analogies stated by Ferney (2000) between the manufacturing entities and the electrical components are similar to the ones established by Besombes and Marcon (1993). The machines were modelled as resistors and the stocks as capacitors. Each machine is fed by a stock of raw or preprocessed material, and it is connected to this stock by a coupling interface. This interface contains a source of effort, which is one of the bond graph basic elements, as well as the resistor and the capacitor. These three elements together—stock, coupling interface and machine—form what Ferney (2000) calls a "station", which is the main manufacturing entity of the proposed model. Other manufacturing entities are as follows: the sources of flow, which represent the sources of raw material to be processed by the system; the wells, corresponding to stocks of end products; and the junctions and transformers, which are used to drive the flow into the different stations of the manufacturing system, either spreading it over the system (divergent junctions and transformers) or aggregating it (convergent junctions).

In the discussed model, the generalized flow variable (f) of the bond graph methodology expresses the material flow over a given section of the manufacturing system, while the displacement q expresses the production volume, which corresponds to the integral of the production flow. The stress or effort variable (e) does not have an exact physical correspondence in the manufacturing system; however, it is very relevant to represent the coupling phenomenon between a machine and its precedent stock, in the case when its production capacity is impeded by the entity located upstream for missing available material.

The proposed model is suitable for the representation of the production system of a single product with a given average demand. The processing frequencies of the machines and the sources of flow, represented by U, are the controlled variables of the system. The control objective is to adjust the level of the output flow to attend the demand of the given product, while, at the same time, keeping the WIP at the desired levels. Before simulating the system with control, it is necessary to solve the state equations for the steady-state condition. This solution yields, for each machine, the average processing frequency that attends the average demand of the product in the absence of any disturbance.

Ferney (2000) applied the proposed model to a hypothetical manufacturing system composed by four stations with the following topology: two stations in parallel at the beginning of system, a convergent junction and two subsequent stations in series. The state representation of this manufacturing system was derived from the constitutive equations of each element, i.e. resistor, capacitor and junction. The system was simulated, considering that there was no material in stock at the initial moment. Other initial conditions set were as follows: an output flow of 4 material units per second at the last station, which corresponds to the demand rate of the end product, and reference stock levels of 15, 10, 20 and 22 material units for the stations 1–4, respectively. In addition, it was known that the output flow of station 2 was twice the output flow of station 1 in parallel, that is, station 2 had twice the processing capacity of station 1. Based on these boundary conditions, the steady-state solution of the state model was found. During the simulation, the controller adjusted the processing frequencies of the machines above and below these steady-state frequencies found. It was allowed to increase them by 20 % maximum in relation to the steady-state frequencies. Also, a maximum increment of 20 % in the stock level was permitted in case of uncertainties.

In order to test the system's ability to respond to unexpected events, the breakdown of the machine of station 3 was simulated, 45 s after the system started. The machine stayed broken for 5 s. During this period, the amount of material accumulated in the stock of station 4 enables it to continue production normally. An authorized overshoot in the stock preceding machine 3 is observed, as expected. In order to avoid an excessive accumulation of WIP at station 3, the controller decreases the processing frequencies of machines 1 and 2, as well as of the source of flow. After approximately 120 s, all the stocks are back to the reference levels and the balance is restored. Therefore, the results showed the system's ability to automatically respond to the imposed disturbance.

Sader and Sorensen (2003) also established analogies with electrical systems to model manufacturing systems, but not using bond graphs. According to the authors, these analogies aimed to simplify the modelling process and produce a visual representation of the system being modelled. However, the governing equations were developed without exactly referring to the equations of the analogous electrical system. In the proposed model, the material flow (or throughput) is equivalent to the current in an electrical system, while the WIP existing at any point in the manufacturing system is analogous to the charge on a capacitor. This approach is very similar to the one presented in Ferney (2000), but the machine, in this case, is represented by an ideal transistor rather than by an ideal resistor. The manufacturing station, thus, is obtained by coupling the transistor in parallel to the capacitor.

3.3 The Distributed Arrival Time Controller: A Scheduling Heuristic (Model 3)

Prabhu and Duffie (1999) proposed the distributed arrival time controller (DATC), a scheduling model where an integral controller is used to determine the arrival times of the parts (or jobs). In the model, the just-in-time logic is employed as the optimization criterion for scheduling; therefore, both earliness and tardiness of the jobs from the due dates are penalized. More specifically, the model works as follows: first, an arbitrary initial arrival time for all the jobs being scheduled is set; next, a shop floor simulation module calculates the expected completion times of the parts based on the arrival times defined in the previous step and the processing times of the parts; then, a feedback loop carries out the information about these completion times to the system; the completion times are compared to the fixed due dates of the jobs, generating an error signal for each part; finally, the controller integrates the error signals and, based on the results, adjusts the arrival times of the parts. The process is repeated until the errors are minimized.

In other words, the arrival time of a given part i is iteratively adjusted so that it may be completed as close as possible from its due date. Each part has an embedded controller, which is classified as integral since the arrival times of the parts are corrected based on the accumulated errors, i.e. based on the integral of the error signals. The completion times are calculated by the simulation module according to a first-come-first-served (FCFS) dispatching policy. Equation 3 expresses the arrival time of ith part in discrete-time domain.

$$a_i(t) = k_i \sum_{m=0}^{t-1} [d_i(m) - c_i(m)] + a_i(0) = k_i \sum_{m=0}^{t-1} z_i(m) + a_i(0), \quad (3)$$

where $a_i(t)$, $p_i(t)$, $c_i(t)$, $d_i(t)$ and $z_i(t)$ refer to arrival time, processing time, completion time, due date and deviation between completion time and due date of *i*th part, respectively. The parameter k_i is the control gain for *i*th part.

The objective function of the scheduling problem is to minimize the mean-squared deviations of completion times from due dates (MSD), as follows:

$$\mathrm{MSD} = \sum\nolimits_i (d_i - c_i)^2/n. \tag{4}$$

According to Cho and Erkoc (2009), the characteristics of the integral controller of DATC enable it to be used as a search engine, replacing the conventional heuristics used in the scheduling models. The computation of deviations and adjustment of arrival times, however, take place with limited global information since the integral controllers are distributed on the part entities and each controller is independent of the other ones, as can be seen in Eq. 1.

An extension of the DATC was developed by Cho and Prabhu (2007). They propose the integration of the DATC with a distributed machine capacity controller (DMCC) at the CNC level. This controller uses the output of a higher-level scheduling system (in this case the DATC) and receives feedback on the machine conditions from the lower level. This feedback is obtained in real time from physical sensors. According to the authors, the DMCC will try to increase its capacity to meet the production demand, while satisfying constraints imposed by the machine conditions, aiming to generate realistic schedules. The model was evaluated by means of computational experiments and presented an improved performance concerning the utilization of machine capacity.

The characteristics of DATC in regard to convergence and chattering of arrival times were investigated by Cho and Erkoc (2009), for the case where the parts have the same due dates. They have found that the response of the model depends on the relationship between processing times and due dates. If the due dates are infeasible, that is, if they are too close to each other and cannot be simultaneously met due to insufficient resource capacity, then the trajectory of arrival times converges to a steady-state value, regardless of the initial values of arrival times. On the other hand, the trajectory converges to distinct values of $d_i{-}p_\mathrm{i}$ when due dates are feasible. Cho and Erkoc (2009) applied DATC to static single-machine scheduling problems with known optima, in order to evaluate its performance. The biggest values for the average percentage deviation from the optimum solution were around 5 %.

Aiming to improve the performance and predictability of DATC, Cho and Erkoc (2009) proposed the double integral arrival time controller (DIAC). They also examined the characteristics and behaviour of this controller and compared its performance with the performance of DATC by means of computational experiments. They observed that the DIAC outperformed DATC.

Cho and Lazaro (2010) followed the same logic of DATC and proposed a model for scheduling based on the mathematical expression of a proportional integral and derivative (PID) controller. The controller adjusts the trajectory of the arrival times of the jobs in a single-machine configuration and generates schedules according to the just-in-time criterion, i.e. completing jobs as close as possible from their due dates. The proportional, integral and derivative gains of the controller were estimated using problem sets with known optimal schedules, aiming to generate near-optimal solutions in terms of due date deviations and system stability.

3.4 Adaptive Production Scheduling Using the Lever Heuristic (Model 4)

A model for production scheduling based on the integration of a heuristic and a closed-loop feedback control scheme is presented by Li et al. (2011). The authors propose the average processing time and lever heuristic (APT-LVR), which is an extension of Johnson's algorithm and relies on the analogy with the moment of forces applied on a beam. In this heuristics, a flow line with m machines is modelled as a lever, along which there is a counter that works as a fulcrum. Each machine j represents a punctual force with magnitude of d_{ij}, where d_{ij} is an array with the differences between the processing times of the jobs on machine j and the average of all processing times (APT). The forces are apart from each other by one unit of distance, and the counter is used as an auxiliary variable to divide the machines into two groups. Each group is considered a virtual machine. The fulcrum (counter) is moved along the beam, and the sum of the moments in each side of it is calculated. These sums correspond to an array associated with each virtual machine. Johnson's algorithm is thus applied to these two virtual machines to generate a scheduling sequence. The sequence with best performance is chosen.

This APT-LVR is integrated with a closed-loop feedback control scheme. An initial schedule is proposed and released. After that, feedback information is collected from the shop floor, and the jobs are rescheduled based on simulation and reapplication of the heuristics to the updated boundary conditions of the problem. The simulation module employed by the mentioned authors is labelled THOCPN-CS and was developed using Petri nets.

The necessary steps to run the computer-aided scheduling and control system are as follows:

1. Manually assign possible manufacturing resources (e.g. operators/machines) to each stage and hence form a task-resource matrix (TRM).
2. Schedule the jobs by the APT-LVR heuristic.
3. Simulate the execution of the jobs using the simulation module, and identify the bottleneck stages. Human schedulers may reallocate operators/machines in stages accordingly, to smooth production flow.
4. Reschedule the jobs by the APT-LVR heuristic.
5. Repeat steps 3 and 4 in the offline production scheduling phase until a satisfactory production schedule is obtained.
6. Deliver the production schedule to the shop floor and switch the control loop from the simulation model to the shop floor.

7. If any disturbance occurs on the shop floor, switch the control loop back to the simulation model, and go back to step 3 if operator/machine reallocation is necessary, or go back to step 4.

The proposed heuristic was applied to benchmark data for performance assessment. The authors also carried out a case study with a manufacturer of windows and doors. In one day, there were 1,396 jobs that should be processed on a five-stage flow shop. According to Li et al. (2011), productivity improved 1.49 %, which is equivalent to 20 additional products processed per day.

4 Comparative Analysis of the Dynamic Models for Operations Scheduling and Shop Floor Control

From the presented discussions about the dynamic models for scheduling and production control, it is possible to note that models 1 and 2 are similar in regard to the time domain and application, since both models are continuous and devoted to shop floor control. Using the same criteria, models 3 and 4 could be also grouped together by similarity. These latter are applied to scheduling problems and deal with detailed and discrete production orders, while model 1 works with weighted averages calculated from discrete orders and model 2 works with material rates and processing frequencies, considering a more aggregate perspective. It is interesting to highlight that model 1 was developed for a job shop, i.e. it is suitable to more complex production configurations than the remaining models. Thus, the use of average values may be advantageous to simplify the solution of the problem, since job shop scheduling problems are NP-complete. Although the similarities observed between some of the models, the modelling methodologies and the variables used are very different. Table 5 presents an outline of the comparative analysis.

It should be noticed that the models 1 and 2 are better aligned to the dynamic modelling and control theory principles. The controllers of these models automatically adjust the control variables when the system is subjected to an input disturbance, aiming to minimize the effect of this disturbance and bring the system back to balance. The disturbance corresponds to the arrival of an urgent job, in the case of model 1, and a machine breakdown, in the case of model 2. The variable of time (t) in model 1 corresponds to real shop calendar days; in model 2, it corresponds to a simulated time, but which is equivalent to real time if real parameters and initial conditions are set. Thus, it is possible to obtain an accurate estimate of how much time the systems would need to stabilize and which capacity adjustments would be necessary.

In the model 3, on the other hand, the variable of time actually corresponds to the iterations executed to reach the solution. Indeed, although the integration of this model to feedback information from the shop floor was proposed (Cho and

Table 5 Comparison of the discussed models

	Model 1	Model 2	Model 3	Model 4
	Wiendahl and Breithaupt (2000)	Ferney (2000)	Cho and Erkoc (2009)	Li et al. (2011)
Domain	Continuous	Continuous	Discrete	Discrete
Application	Shop floor control	Shop floor control	Scheduling	Scheduling
Nature of the problems	Dynamic, automatic	Dynamic, automatic	Static	Dynamic, not automatic
Production configuration	Job shop	Not applicable (single product)	Single machine	Flow shop
Number of products/jobs	Multiple	Single	Multiple	Multiple
Main variables and parameters	Work content, WIP, range, backlog, utilization, performance	WIP, inventory reference levels, processing frequency of the machines	Processing times, due dates, controller gains, lateness	Processing times, makespan
Theoretical background for modelling	Analogy with fluid systems, funnel model, logistic curves	Analogy with electrical systems, bond graph technique	Expressions of PI and PID controllers (not used in the dynamic sense)	Extension of Johnson's algorithm

Prabhu 2007), it is more similar to an iterative heuristic than to a dynamic model in the strict sense adopted in the dynamic modelling and control fields. The feedback loop that exists in this model does not bring feedback information from a dynamic system, i.e. it does not bring updated information about the dynamics of a shop floor, for instance. Rather, this loop is part of the algorithm for scheduling optimization. Although some disturbances may be presented to this model, such as the inclusion of an extra job to be scheduled, it essentially deals with a conventional problem, where there is a fixed number of parts to be scheduled, and after a given number of iterations, the best schedule is found. It should be emphasized that this analysis considers just the principles of dynamic modelling and control system and not other features of the model. Model 3 is shown to be effective in the context of its application, and this fact is not being called into question.

In the model 4, the feedback loop actually carries information about the shop floor status. Nevertheless, it seems that the control action is done by the user, which reapplies the proposed heuristics to a different set of initial conditions, rather than being automatically executed. This could be a point of improvement in the model. Anyway, this practical feedback of the scheduling execution status is of much interest for managers even if it is executed by people.

In terms of mathematical and application complexity, the model 1 has more variables and parameters and requires a repeated measurement of these variables in order to gather updated information about the execution of the schedule in the shop floor. In other words, it seems to request higher data acquisition and preprocessing efforts than the other models.

5 Final Remarks

In this chapter, several dynamic decision models for manufacturing and supply chain were presented. The overall review was focused on deterministic models based on classical control theory, state space representation and related methodologies. The models were classified into four categories: pioneer models, single-product production–inventory models and extensions to supply chain, multi-echelon production–inventory models and scheduling and production control models. The models from the last category were discussed in more detail and compared among each other. This comparative analysis highlighted some advantages and disadvantages of each model, being also useful to help practitioners when choosing the most suitable model for specific contexts.

The review revealed open opportunities for the development of dynamic decision models, especially for scheduling and production control. This body of knowledge is still incipient when compared to the set of control applications developed for production–inventory systems. Moreover, most of the approaches for scheduling problems are static or based on probability distributions and queuing theory. Therefore, this filed would certainly benefit from the development of models based on dynamic modelling and control theory. Also, some dynamic scheduling models that are applied to a single machine, for instance, should be extended to fit more complex configurations such as flow shops or job shops.

An important part of the dynamic modelling consists of estimating the values for the parameters of the model and the gains of the controller. For electrical or mechanical applications, systematic procedures were structured for synthesizing these gains or determining these parameters, but in the manufacturing area, it seems that these procedures are not well established yet. Hence, the proposition of methodologies to estimate these values for different models may be a relevant topic for improvement.

Sarimveis et al. (2008) also highlight the main limitations of the dynamic models developed for supply chain. Many models assume that lead times are fixed or known with relative accuracy; inventory levels are not bounded (neither bounded below by zero nor bounded above by limited storage capacities); a single product or a single set of aggregate products are manufactured in a single stage; there is no concurrent competition among different products for the use of common machinery and storage facilities; supply chain stages are connected in a row, ignoring other interactions in different levels; raw material, labour costs and inventory costs are fixed. It is known that these assumptions are not valid in many practical situations; on the other hand, overcoming these limitations is not trivial. Thus, the development of dynamic models that overcome part of these limitations is an issue that deserves effort. In addition, a paramount contribution to all the dynamic models for manufacturing and supply chain would be the application of these models in real systems, as a way to consider more realistic parameters and assumptions. In this case, it is also possible to better evaluate the system performance by comparing simulated results with actual outputs of the system. The consideration of more realistic assumptions in the models also implies the choice of adequate modelling and control tools to cope with the increased mathematical complexity of the models. In this way, it is possible to deal with the accuracy–complexity trade-off mentioned in the introduction of the chapter.

Finally, another direction for future research is the integration between production scheduling and shop floor control, i.e. the development of models that automatically make rescheduling decisions based on real-time feedbacks of the shop floor conditions. This integration is being somewhat explored in the chemical industry, where plant-level supervisory systems of the chemical processes may provide information for the automatic rescheduling of the production. There is still room for the extension of this research to all manufacturing areas.

References

Agrell PJ, Wikner J (1996) An MCDM framework for dynamic systems. Int J Prod Econ 45:279–292

Åström KJ, Kumar PR (2014) Control: a perspective. Automatica 50(1):3–43

Axsäter S (1976) Coordinating control of production-inventory systems. Int J Prod Res 14 (6):669–688

Axsäter S (1985) Control theory concepts in production and inventory control. Int J Syst Sci 16 (2):161–169

Axsäter S (1990) Simple solution procedures for a class of two-echelon inventory problems. Oper Res 38:64–69

Axsäter S (2001) Scaling down multi-echelon inventory problems. Int J Prod Econ 71 (1–3):255–261. doi:10.1016/S0925-5273(00)00123-7

Axsäter S (2003) Approximate optimization of a two-level distribution inventory system. Int J Prod Econ 81–82:545–553. doi:10.1016/S0925-5273(02)00270-0

Axsäter S, Olsson F, Tydesjo P (2007) Heuristics for handling direct upstream demand in two-echelon distribution inventory systems. Int J Prod Econ 108(1–2):266–270. doi:10.1016/j.ijpe.2006.12.014

Benmansour S, benabdelhafid A, Boudebous D, Boukachour J (2004) Bond graph for robust modelling of manufacturing systems. In: Proceedings of international conference on computational cybernetics, IEEE ICCC '04, Vienna, Aug 30–Sep 01 2004. IEEE, New Jersey, pp 291–295

Bertrand JWM, Fransoo JC (2002) Operations management research methodologies using quantitative modeling. Int J Oper Prod Manag 22(2):241–264

Besombes B, Marcon E (1993) Bond-graphs for modelling of manufacturing systems. In: Proceedings of IEEE international conference on systems, man and cybernetics, Le Touquet. IEEE, New Jersey, pp 256–261

Bogataj L, Horvat L (1996) Stochastic considerations of Grubbström-Molinder model of MRP, input-output and multi-echelon inventory systems. Int J Prod Econ 45(1):329–336

Burns JF, Sivazlian BD (1978) Dynamic analysis of multi-echelon supply systems. Comput Ind Eng 2:181–193

Cho S, Erkoc M (2009) Design of predictable production scheduling model using control theoretic approach. Int J Prod Res 47(11):2975–2993

Cho S, Lazaro A (2010) Control theoretic model using PID controller for just-in-time production scheduling. Int J Adv Manuf Technol 51(5–8):699–709

Cho S, Prabhu VV (2007) Distributed adaptive control of production scheduling and machine capacity. J Manuf Syst 26:65–74

Christensen JL, Brogan WL (1971) Modeling and optimal control of production processes. Int J Syst Sci 1:247–255

Davis WJ, Thompson SD (1993) Production planning and control hierarchy using a generic controller. IIE Trans 25:26–45

Dejonckheere J, Disney SM, Lambrecht MR, Towill DR (2002) Transfer function analysis of forecasting induced bullwhip in supply chains. Int J Prod Econ 78(2):133–144

Dejonckheere J, Disney SM, Lambrecht MR, Towill DR (2003) Measuring and avoiding the bullwhip effect: a control theoretic approach. Eur J Oper Res 147(3):567–590

Dembélé S, Lhote F (1993) Proposition of manufacturing systems modelling by bond-graphs. In: Proceedings of international conference on systems, man and cybernetics, 'Systems Engineering in the Service of Humans', Le Touquet, 17–20 Oct 1993. IEEE New Jersey pp 262–267

Disney SM, Towill DR (2002) A discrete transfer function model to determine the dynamic stability of a vendor managed inventory supply chain. Int J Prod Res 40(1):179–204

Disney SM, Naim MM, Towill DR (2000) Genetic algorithm optimization of a class of inventory control systems. Int J Prod Econ 68(3):259–278

Edghill J, Towill DR (1990) Assessing manufacturing system performance: frequency response revisited. Eng Costs Prod Econ 19:319–326

Evans GN, Naim MM, Towill DR (1998) Application of a simulation methodology to the redesign of a logistical control system. Int J Prod Econ 56–57(1):157–168

Ferney M (2000) Modelling and Controlling product manufacturing systems using bond-graphs and state equations: continuous systems and discrete systems which can be represented by continuous models. Prod Plan Control 11(1):7–19

Forrester JW (1958) Industrial dynamics: a major breakthrough for decision makers. Harvard Bus Rev 36:37–66

Forrester JW (1961) Industrial dynamics. MIT Press, Cambridge

Grubbström RW (2005) Algorithms for optimal dynamic lotsizing in discrete and continuous time. Int J Agile Manuf 8(2):85–96

Grubbström RW, Lundquist J (1977) The Axsäter integrated production–inventory system interpreted in terms of the theory of relatively closed systems. J Cybern 7:49–67

Grubbström RW, Molinder A (1994) Further theoretical considerations on the relationship between MRP, input–output analysis and multi-echelon inventory system. Int J Prod Econ 35 (1):299–311

Grubbström RW, Molinder A (1996) Safety production plans in MRP-systems using transform methodology. Int J Prod Econ 46–47(1):297–309

Grubbström RW, Ovrin P (1992) Intertemporal generalization of the relationship between material requirements planning and input–output analysis. Int J Prod Econ 26(1–3):311–318

Grubbström RW, Tang O (1999) Further developments on safety stocks in an MRP system applying laplace transforms and input–output methodology. Int J Prod Econ 60–61:381–387

Grubbström RW, Tang O (2000) An overview of input–output analysis applied to production-inventory systems. Econ Syst Rev 12(1):3–25

Grubbström RW, Wang Z (2003) A stochastic model of multi-level/multi-stage capacity-constrained production–inventory systems. Int J Prod Eco 81–82:483–494

Grubbström RW, Bogataj M, Bogataj L (2010) Optimal lotsizing within MRP Theory. Annu Rev Control 34(1):89–100

Haffaf H, Kamel RM (2001) Bond-graph for Information Systems. Int J Gen Syst 30(4):441–462

Hennet J-C (2003) Bi-modal scheme for multi-stage production and inventory control. Automatica 39:793–805
Hennet J-C (2009) A Globally optimal local inventory control policy for multistage supply chains. Int J Prod Res Spec Issue 47(2):435–453 (Cutting edge of the French community in production research)
John S, Naim MM, Towill DR (1994) Dynamic analysis of a WIP compensated decision support system. Int J Manuf Syst Des 1(4):283–297
Karnopp DC, Rosenberg RC (1968) Analysis and simulation of multiport systems. M.I.T. Press, Massachusetts
Lalwani CS, Disney SM, Towill DR (2006) Controllable, observable and state space representations of a generalized order-up-to policy. Int J Prod Econ 101:172–184
Li W, Luo X, Xue D, Tu Y (2011) A heuristic for adaptive production scheduling and control in flow shop production. Int J Prod Res 49(11):3151–3170
Little JDC (1961) A proof for the queuing formula L = λW. Oper Res 9:383–387
Nyhuis P (1994) Logistic operating curves—a comprehensive method of rating logistic potentials, EURO XIII/OR36. University of Strathclyde Glasgow, 19–22 July 1994
Nyhuis P, Wiendahl H-P (2006) Logistic production operating curves – basic model of the theory of logistic operating curves. CIRP Annals—Manuf Technol 55(1):441–444
Ortega M, Lin L (2004) Control theory applications to the production-inventory problem: a review. Int J Prod Res 42(11):2303–2322
Popplewell K, Bonney MC (1987) The application of discrete linear control theory to the analysis and simulation of multi-product, multi-level production control systems. Int J Prod Res 25:45–56
Porter B, Bradshaw A (1974) Modal control of production–inventory systems using piecewise-constant control policies. Int J Syst Sci 5:733–742
Prabhu VV, Duffie NA (1999) Nonlinear dynamics in distributed arrival time control of heterarchical manufacturing systems. IEEE Trans Control Syst Technol 1(6):724–730
Sader BH, Sorensen CD (2003) Deterministic and stochastic dynamic modeling of continuous manufacturing systems using analogies to electrical systems. In: Chick S, Sánchez PJ, Ferrin D, Morrice DJ (eds) Winter simulation conference; 7–10 Dec 2003. IEEE, New Jersey, pp 1134–1142
Sarimveis H, Patrinos P, Tarantilis C, Kiranoudis CT (2008) Dynamic modeling and control of supply chain systems: a review. Comput Oper Res 35(11):3530–3561
Scarf H (1960) The optimality of (S, s) policies in the dynamic inventory problem. In: Arrow K, Karlin S, Suppes P (eds) Mathematical methods in the social sciences, Stanford University Press, Stanford, pp 196–202
Simon HA (1952) On the application of servomechanism theory in the study of production control. Econometrica 20:247–268
Suri R, Desiraju R (1997) Performance analysis of flexible manufacturing systems with a single discrete material-handling device. Int J Flex Manuf Syst 9(3):223–249
Towill DR (1982) Dynamic analysis of an inventory and order based production control system. Int J Prod Res 20(6):671–687
Towill DR, Evans GN, Cheema P (1997) Analysis and design of an adaptive minimum reasonable inventory control system. Prod Plan Control 8:545–557
Vassian JH (1955) Application of discrete variable servo theory to inventory control. Oper Res 3 (3):272–282
Wang X, Liu Z, Zheng C, Wu J (2008) Analysis and design of a production and inventory control system for ramp demand. In: Proceedings of WiCOM '08—4th international conference on wireless communications, networking and mobile computing, Dalian, IEEE, New Jersey, pp 1–5
White AS (1999) Management of inventory using control theory. Int J Technol Manage 17:847–860
Wiendahl H-P (1995) Load-orientated manufacturing control. Springer, New York

Wiendahl H-P, Breithaupt J-W (1997) Production planning and control on the basis of control theory. In: Okino N, Tamura H, Fujii S (eds) Advances in production management systems—perspectives and future challenges. Chapman & Hall, London, pp 351–362
Wiendahl H-P, Breithaupt J-W (1999) Modelling and controlling the dynamics of production systems. Production Planning and Control. 10(4):389–401
Wiendahl H-P, Breithaupt J-W (2000) Automatic production control applying control theory. Int J Prod Econ 63(1):33–46
Wikner J, Towill DR, Naim MM (1991) Smoothing supply chain dynamics. Int J Prod Econ 22:231–248
Wikner J, Naim MM, Towill DR (1992) The system simplification approach in understanding the dynamic behaviour of a manufacturing supply chain. J Syst Eng 2:167–178
Zhou L, Grubbström RW (2004) Analysis of the effect of commonality in multi-level inventory systems applying MRP theory. Int J Prod Econ 90:251–263
Zhou L, Disney S, Towill DR (2010) A pragmatic approach to the design of bullwhip controllers. Int J Prod Econ 128(2):556–568
Zhou L, Naim MM, Tang O, Towill DR (2006) Dynamic performance of a hybrid inventory system with a Kanban policy in remanufacturing process. Omega 34:585–598

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A Multicriteria Decision Model for Classifying Management Processes

Ana Carolina Scanavachi Moreira Campos and Adiel Teixeira de Almeida

Abstract In process-oriented organizations, process owner is accountable for monitoring, controlling and improving the processes for which he/she is responsible and for ensuring that everything is running smoothly. However, he/she does not have enough time to devote equally to all processes, and as different ones require different attention levels, he/she should give priority to those processes that require the highest levels of attention. On that basis, this chapter proposes a management model which supports manager in classifying his/her business processes into categories of managerial procedures for the purposes of planning in the short term. This classification, based on a multiple criteria evaluation, enables activities that are associated with each business process to be effectively managed.

Keywords Business process management · Classification of business processes · Decision model · Multicriteria decision analysis · Planning activities in the short term · Process orientation · Process owners

1 Introduction

Nowadays, intense competition among organizations aims at gaining a greater market share and this plus global expansion has led to organizations becoming more concerned with improving the quality of their products and, at the same time,

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with reducing costs. Several researchers have reported that a way to achieve such objectives is to adopt a process view of business (Reijers 2006). Consequently, an organization that adopts the process view of business is employing Business Process Management (BPM) concepts (Kohlbacher and Gruenwald 2011; Campos et al. 2011).

Process orientation (PO) implies emphasizing the business process instead of focusing on the functional organizational structure. In other words, process-focused organizations are concerned with ensuring that all their business operations aim to promote customer satisfaction, whereas function-oriented organizations have their internal structure divided into several departments in which each focuses only on the outcome from its departmental point of view (Kumar et al. 2010).

The benefits associated with adopting business PO practices as described in the literature include improving business performance, reducing tensions and conflicts across departments/functional areas, increasing interfunctional connectedness, developing group cooperation and team spirit, eliminating duplicated activities and non-core activities, cost savings and increasing customer satisfaction (McCormack 2001; Reijers 2006; Škrinjar et al. 2008; Kumar et al. 2010).

One of the major features of process-oriented organizations is that there are process owners. According to Hammer and Stanton (1999), process owner is responsible for an end-to-end process. That is to say, he/she is senior manager responsible for ensuring that all tasks defined within the process are carried out as planned. Moreover, he/she is responsible for designing and continuously improving processes, measuring their performance and ensuring that all processes are running smoothly and effectively.

Therefore, manager plays an essential role in effective process management. Thus, in order to bring competitive advantage to the organization, the manager needs to monitor and control the processes for which his/her is responsible and continuously improve them. However, time is a problem for manager and hence he/she cannot monitor and control all his/her processes closely. As a result, since different processes require different levels of attention, he/she should prioritize those processes that require the highest levels of attention.

In this context, this chapter sets out a management model based on multicriteria decision analysis (MCDA), particularly ELECTRE TRI-B method. The model helps the manager to classify his/her business processes into categories of managerial procedures for the purposes of planning in the short term the activities associated with each business process. This classification, based on a multiple criteria evaluation, enables his/her activities associated with each business process to be managed effectively. This model can be used by managers in all types of organizations, since they can adjust the model according to their organization's targets and strategies and their own leadership style. Note that the model proposed in this chapter focuses on the aggregation of multiple objectives (criteria) of a single manager, since the model aims to support the manager to manage his/her processes and effectively plan his/her activities during the working week associated with each business process. Adapting of the model for group decision problems can be addressed in future studies.

The organization of this chapter is as follows. Section 2 describes some concepts of MCDA and the ELECTRE TRI-B method, used in the model proposed in this work, and gives a summary of the papers found in the literature that use MCDA in the BPM area. The management planning model is described in Sects. 3 and 4 introduces an example that is used for illustration purposes. The final section contains some conclusions and suggests directions for future research.

2 Literature Review: Multicriteria Decision Analysis and Business Process Management

Decision-making involves the selection of a course of action from among a set of possible alternatives in order to achieve a desired solution for a given problem. In this context, MCDA aims to support, clarify and conduct the decision-making process where several points of view must be taken into account including the decision-maker's value judgments and preferences (Figueira et al. 2005).

MCDA models have been applied to help people make decisions in many different fields, such as those of the environment, finance, and health care. In the BPM area, there are also some examples of using this approach in the literature. Mansar et al. (2009) proposed a decision-making tool using the Analytic Hierarchy Process (AHP) multicriteria method that ranks the best practices for Business Process Redesign (BPR) in order to improve efficiency in the redesign of a business process. The list of best practices was provided by the tool in line with the redesign team's preferences. A method based on the AHP approach for choosing business process management software (BPMS) was drawn up by Stemberger et al. (2010). Campos and Almeida (2014) propose a framework for selecting a modelling language for BPM in accordance with the purposes of modelling. Shimizu and Sahara (2000) designed an approach that uses the AHP method and IDEF0 (Integration Definition for Function Modelling) for supporting decision in BPM. By using it, practitioners can evaluate and choose the best one from among all alternatives for improving the process.

A model for choosing a business process for BPM based on the AHP, Fuzzy AHP and BSC (Balanced Scorecard) was described by Cho and Lee (2011). This model uses the BSC in order to define criteria for evaluating processes, AHP and Fuzzy AHP (fuzzy theory combined with the AHP method) to generate the weight of such criteria and to choose the appropriate process for BPM. Felix and Bing (2001) used the design of flexible manufacturing systems (FMSs) models for business process reengineering (BPR). The AHP method was used to support selecting the best design feasible for the company. Yen (2009) proposed an approach based on the AHP method to combine various measures of business process outcomes derived from the business process goal and preferences of stakeholders into only one measure of the business process.

The MCDA process consists of two main phases: structuring and evaluation. The structuring phase of the decision problem is an important activity in the decision-making process (Raiffa 2002), and therefore, the time and effort spent on this phase should be sufficient to ensure this is done thoroughly. The process of problem structuring aims to organize the elements of a decision problem into a coherent structure that is useful when initiating the decision process. This structure serves as a basis for learning, research and discussion about the problem. A badly structured problem can lead to the wrong problem being addressed, thus causing inadequate solutions to be generated (Belton and Stewart 2002). For more information about the process of problem structuring for MCDA, see Keeney (1992), Belton and Stewart (2002) and Roy (1996).

To move from problem structuring to the evaluation phase, it is necessary to build the multicriteria model. According to Belton and Stewart (2002), the building of the model should be seen as a "dynamic process, informed by and informing the problem structuring process, and interacting with the process of evaluation". The main tasks involved in building the multicriteria model include creating alternatives to be considered, establishing the criteria for assessing the consequences of each alternative and eliciting the decision-maker's preference structure (Belton and Stewart 2002).

Sometimes, the task of defining the alternatives is simple, but in other situations, this may be not so easy and might well be part of a research study (Belton and Stewart 2002). When identifying the alternatives is not something that can be done immediately (the decision-maker does not have knowledge of the alternatives), the alternatives can be generated by looking for them from new perspectives, or by using tools and technique, such as brainstorming, or by using heuristics (Pedrycz et al. 2010). The criteria should be defined based on the objectives and goals to be achieved, since they are used to compare the alternatives and to assess how well each alternative meets the goals (Lu et al. 2007). During the structuring phase of the problem, a number of objectives will have emerged naturally and one way of converting these objectives into criteria is by means of the "value-focused thinking" approach developed by Keeney (1992). Keeney (1992) separated these objectives into means-ends objectives and fundamental objectives and established their relationships. Thus, the criteria are established from fundamental objectives. According to Roy (1996), a family of criteria is coherent, if it is complete (exhaustive), non-redundant and concise. See Keeney (1992, 1996), Roy (1996), Belton and Stewart (2002) for more details on the process of generating alternatives and establishing criteria.

In order to help the decision-maker in the decision-making process, the presence of a decision analyst is recommended. The analyst can aid the decision-maker as to initializing and structuring the problem, building the multicriteria model, eliciting his/her preference structure and helping him/her to explore possible solutions (Roy 1996).

The evaluation phase consists of applying the decision rules (formal methods) and sensitivity analysis in order to produce a recommendation for a decision. The idea that the formal methods hold in common is to settle on a framework for evaluating the consequences of making a choice. However, different methods require diverse kinds of value information and follow different algorithms for aggregating the performance of each alternative across all the criteria. Hence, there are different methods proposed in the MCDA literature: methods that add criteria in a unique function of synthesis, such as multi-attribute utility theory (MAUT); outranking methods, including ELECTRE and PROMETHEE; and interactive methods (Belton and Stewart 2002).

In the process of selecting a multicriteria method for dealing with a particular problem, consideration should be given to the context and the features of the problem, the kinds of information available and their degree of precision and the decision-maker's preference structure. Moreover, it is important to think over what kind of solution to the problem is required. From this perspective, there is a need to consider whether the objective of the analysis is to choose the best alternative, or to sort or to rank or to describe the alternatives considered in the problem (Roy 1996).

The context of the problem studied in this chapter is a sorting problem. Given the set of business processes, there is a need to classify these processes into categories of managerial procedures for the purposes of planning in the short term the activities associated with each business process. Thus, to tackle this type of problematic, the authors consider it appropriate to use the ELECTRE TRI-B multicriteria method due to its having some helpful features. The first is related to the fact that it is an outranking method, so incomparable situation can be considered in the evaluation process. In ELECTRE TRI-B, incomparability appears when an alternative has an excellent performance in some criteria and a poor one in others (Zopounidis and Doumpos 2002). The idea of incomparability brings relevant information to the decision-making process, since the ELECTRE TRI-B method will indicate, by means of incomparable situations, the business processes that have these kinds of characteristics in their evaluation. Thus, these business processes can be analysed carefully (Hurson and Ricci 1998). Secondly, ELECTRE TRI-B is a non-compensatory method. Consequently, the weights of criteria do not have the meaning of substitution rates, and thus, improving the performance of an alternative on any one criterion does not produce improvement in global performance, and therefore, the alternative does not change the category (Bouyssou and Marchant 2007a). As a result, the business process(es) allocated to the best category will be those that have the best average performance(s) when all the criteria are considered simultaneously. Moreover, this method is able to deal with both quantitative and qualitative evaluations and has the ability to handle heterogeneous scales in order to produce the classification of business processes (Figueira et al. 2010). In addition, as the assignment of a business process to a category will be made by comparing its performance against pre-established performance standards, the ELECTRE TRI-B method is applied in the model proposed in this chapter instead of ELECTRE TRI-C (which compares one alternative to another from the set). The ELECTRE TRI-B method is explained below.

3 ELECTRE TRI-B Method

The ELECTRE TRI-B outranking method addresses the problem of sorting. This method aims at allocating a set of alternatives (a_i) to one of several predefined ordered categories (C_k) taking into account the evaluation of the alternatives based on multiple criteria ($g_j(a_i)$). First, the method builds outranking relations S between each alternative and reference profiles (Ir_k) which limit the categories. Afterwards, these relations are explored by the method in order to allocate each alternative to a particular category. The value of reference profiles is chosen by the decision-maker (Figueira et al. 2005).

An alternative outranks a reference profile (a_iSIr_k) if a_i is at least as good Ir_k. The assessment of the outranking degree of an alternative a_i over a reference profile is described by the credibility index $\sigma(a_i,Ir_k)$. This index ranges from 0 to 1 and is calculated on the basis of the partial concordance indices c_j, the global concordance index C and the discordance index d_j [see Merad et al. (2004) for a more detailed description].

In order to calculate the credibility indices, the decision-maker needs to define several parameters for each criterion. This includes the weights that represent the relative importance of the criteria and the veto threshold which is related to the idea of blocking the outranking relation S. In other words, alternative a_i cannot outrank reference profile Ir_k on one specified criterion if the performance of Ir_k surpasses that of a_i by an amount greater than the veto threshold. The weights are used for computing the global concordance index, and the veto thresholds are used to calculate the discordance index (Lourenço and Costa 2004). In addition, two other thresholds should be established by the decision-maker: the indifference q_j and the preference threshold p_j. They are used to express the imprecision or uncertainty in the evaluation of the criteria (Merad et al. 2004).

The definition of these parameters can be made by the decision-maker with the help of a decision analyst. This definition can be made through direct interrogation by the decision analyst who interacts with the decision-maker in order to construct the decision-maker's preference model (Zopounidis and Doumpos 2002). However, as this direct elicitation of parameters is not an easy task for the decision-maker and requires him/her to make a high cognitive effort, many different studies have been dedicated exclusively to preference elicitation procedures (Zopounidis and Doumpos 2002). For example, Mousseau and Slowinski (1998) based on the preference disaggregation paradigm proposed an approach to compute the value of all the ELECTRE TRI parameters simultaneously from assignment examples. They also developed ELECTRE TRI Assistant, a new module included in the ELECTRE TRI software version 2.0, which implements this approach. However, this methodology requires difficult nonlinear programs to be solved. In order to simplify the mathematical computations and make it easy to solve the inference programs, many authors propose elicitation procedures in which one subset of the parameter is inferred, while the others are fixed. This simplification leads to there being a linear program to solve instead of a nonlinear one. With a view to eliciting weights, the software SRF was developed by Figueira and Roy (2002). This software runs the revised version of Simos' procedure which they proposed. Mousseau et al. (2001) presented a procedure for inferring the weights of the ELECTRE TRI method from assignment examples. Their research suggests that 2 m, where m is the quantity of criteria, is an adequate number of assignment examples from which to infer weights. A model to estimate the importance coefficients (criteria weights) was also the subject of research by Fernandez et al. (2008). To infer discordance-related parameters of ELECTRE TRI, Dias and Mousseau (2006) put forward a procedure to compute the value of the veto thresholds on the basis of outranking examples. Ngo The and Mousseau (2002) proposed an inference model which infers the reference profiles from assignment examples. Although all these inference methods provide the value of the parameter, this value should not be considered its correct and final value. Instead, the decision-maker should continuously revise the information he provides in order to learn from the results of the inference methods and deepen his/her understanding of his/her preference in an interactive learning process (Dias and Mousseau 2006).

The outranking relation between an alternative and the reference profiles (a_iSIr_k) is built by comparing a credibility index $\sigma(a_i,Ir_k)$ with a specific cutting level λ. The cutting level represents the minimum value for $\sigma(a_i,Ir_k)$ so that a_i outranks Ir_k (a_iSIr_k). Thus, if (Mousseau and Slowinski 1998):

- $\sigma(a_i, Ir_k) \geq \lambda$ and $\sigma(Ir_k, a_i) < \lambda$, then a_iSIr_k;
- $\sigma(Ir_k, a_i) \geq \lambda$ and $\sigma(a_i, Ir_k) < \lambda$, then Ir_kSa_i;
- $\sigma(a_i, Ir_k) \geq \lambda$ and $\sigma(Ir_k, a_i) \geq \lambda$, then a_i and Ir_k are indifferent;
- $\sigma(a_i, Ir_k) < \lambda$ and $\sigma(Ir_k, a_i) < \lambda$, then a_i and Ir_k are incomparable.

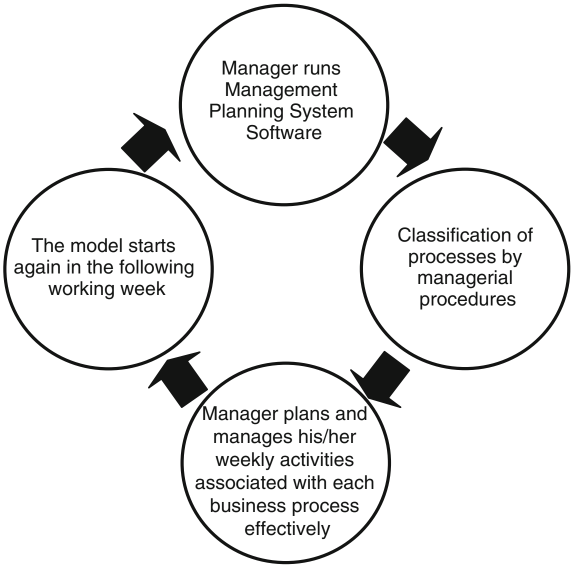
The cutting level λ should be in the range of 0.5–1 and is fixed by the decision-maker. Merad et al. (2004) recommend that the value of cutting level λ is greater than the highest weight in order to avoid the most weighted criterion being the only one used to define the allocation category.

The assignment of an alternative to one of the categories is undertaken by exploring these outranking relations. The ELECTRE TRI-B method has two assignment algorithms, deemed pessimistic and optimistic. The results of classification by these two algorithms may be different due to the presence of the incomparability relations between alternatives and reference profiles (Zopounidis and Doumpos 2002). The pessimistic algorithm is more demanding than the optimistic one and therefore, the decision-maker should use it when it is desirable to employ a conservative policy or when there is a limitation of available resources (Siskos et al. 2007).

4 Management Planning Model

The management planning system (MPS) is a model that enables a manager to plan and manage his/her weekly activities associated with each business process more effectively based on processes for which he/she is responsible, and on an evaluation

Fig. 1 Structure of management planning system model



of the performance of such processes and MCDA. Specifically, this model supports a manager in analysing both business process data and performance information and classifies the business processes into categories of managerial procedures for the purposes of planning in the short term in order to help the manager find for the best strategy for managing each process since he/she does not have enough time to devote himself/herself equally to all his/her processes and different processes require different attention levels. Therefore, a manager can better organize his/her time in order to devote himself/herself to the processes that require the highest levels of attention. As the MPS model can be adjusted by the manager, it can be used in different kinds of organizations, such as government units and factories.

The structure of the MPS model is illustrated in Fig. 1 and is as follows: At the beginning of the working week, the MPS software is run by the manager. The tool generates the classification of processes under the manager's responsibility into categories of managerial procedures. If he/she knows the classification of processes, the manager can plan and manage his/her activities during the working week in order to manage his/her activities associated with each business process effectively. The model should be run again in the following working week.

Processes can be classified into as many categories as the manager wishes, depending on his/her management style and strategy. A distinct style of management should be applied to every category. In order to classify the processes into categories of managerial procedures, MCDA methods can be used, in particular the pessimistic algorithm of the ELECTRE TRI-B method. The reasons for using the ELECTRE TRI-B method in the model proposed in this article were previously discussed in Sect. 2. The pessimistic algorithm was chosen because classifying business processes into categories of managerial procedures for the purposes of the manager planning and managing his/her weekly activities associated with each business process requires the manager to be cautious, since he/she will dedicate himself/herself only to the processes that require the highest levels of attention. Moreover, time is a limited resource for managers (Siskos et al. 2007). In this way, by means of the pessimistic algorithm, a business process can be allocated into a category when its evaluation on each criterion is at least as good as the lowest reference profile that has been defined, on the criterion, to be in this category (Condor et al. 2011).

The manager can adopt, for example, three categories in order to classify the processes into categories of managerial procedures since this classification is simple and may facilitate the management of processes. Thus, processes that present a grave problem, those the performance of which are low and therefore, far below that planned, are classified as High Attention; a process the performance of which is just below that planned is classified as Attention; and processes that are working as planned or present minor problems as Low Attention.

In accordance with this classification, the manager should first concentrate on the processes that were assigned to the High Attention category, i.e., the manager needs to pay most attention to the processes allocated to this category, must intervene sharply in these processes and has to take immediate corrective action. Daily meetings with the immediate supervisor of the process in order to require a fast and effective solution to the problem or even for the manager to solve the problem on his/her own are examples of direct interventions. However, the type of intervention to be made for each category depends on the everyday practices of individual managers and executives and their skills in management and leadership and it also depends on the organization's policy.

The manager also needs to give attention to processes that are in the Attention category, although not as much as to those of the High Attention category and should make moderate interventions in such processes. An example of this type of intervention is, for example, communicating with the immediate supervisor of the process, by telephone, to ask for solutions.

Processes allocated to the Low Attention category do not need to receive attention from the manager since they are those that are working as stipulated or present small problems. So, for these processes, the manager can keep an eye on the indicators, but interventions are not required.

In order to adjust the MPS software, the manager should undertake the following tasks:

(a) Identify all the processes and activities within the organization for which he/she is responsible.
(b) Determine the criteria to be considered in order to assess the processes. These criteria should be clear enough to enable him/her to evaluate the performance of the processes. The definition of criteria depends on the organization's targets, his/her management strategies and understanding of the processes.

(c) Define criteria weights that are obtained from his/her judgments. In this situation, they denote specifically the degree of importance of each process outcome.
(d) Establish the value of reference profiles that defines each category according to his/her preferences and strategies.
(e) Determine values for preference (p) and indifference (q) thresholds for each criterion in order to take the imprecision or uncertainty of the evaluations of the process outcomes into account.
(f) Define the veto threshold (v) for each criterion.
(g) Establish the cutting level (λ) according to his/her objective and preferences.

Whenever the manager considers it necessary, he/she can modify the set of processes and criteria defined in tasks A and B and can make modifications to the parameters established in tasks C, D, E, F and G. A decision analyst can assist the manager to perform these tasks, since the analyst can help the decision-maker to structure the problem and elicit his/her preference structure (Roy 1996).

5 Applying the Model: An Example

The use of the model is demonstrated by way of an example. Note that this example is based on real data from a glassware factory.

A glassware factory produces five kinds of glass containers, including glass containers for the food and pharmaceutical industry, bottles for carbonated beverages (such as spring water, beer and soda) and for distilled beverages and glassware for the table (such as wine and water glasses, plates, jars and pots). Each kind of glass container is independently manufactured in a different production line.

As the manager of this glassware factory is responsible for these five production lines and does not have enough time to devote himself equally to all five lines, he needs to manage his activities associated with each business process in an effective way. Thus, at the beginning of his working week, the manager runs the MPS software that he adjusted with the help of a decision analyst using the sequence of tasks described in Sect. 3 (Table 1):

(a) Processes: The task of identifying the business processes for which he is responsible was simple, since the processes have already been modelled and documented and at his disposal. For this numerical application, the five production lines (carbonated beverage bottles, distilled beverage bottles, food containers, pharmaceutical containers and glassware for the table) were considered. It was assumed that these processes are independent, since each production line works independently of each other, although they receive molten glass that comes from a single furnace. If the processes were interdependent, they should be combined into a single process (a single alternative) to be evaluated by the model. In situations where the manager does not have clear knowledge of these processes, one way of identifying them is by means

Table 1 Adjustment of the management planning system software

		Criteria					
		PTM	LR	L	CC	IR	CD
	Direction of preference	Increasing	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing
	Weight	5	3	1	2	3	3
Production line	Carbonated beverage bottle	93	2	2	1	1	0.4
	Distilled beverage bottle	92	1.8	2	2	0.7	0.5
	Food container	95	0.7	1.5	2	1	0.1
	Pharmaceutical container	94	5	3	1	1	0.3
	Glassware for the table	89	1	1.5	3	0.5	1
	Ir_1	93	1	1.7	1.5	0.3	0.2
	Ir_2	91	2	2.5	2.5	0.8	0,7

of process mapping. Process mapping is an important step in BPM. It is a visual approach to document and detail the current process and so helps the manger enhance his knowledge about the processes and activities within the organization. Currently, there are many different business process mapping tools to conduct process mapping, such as ARIS Express, TIBCO Business Studio and Questetra BPM.

(b) Criteria: the criteria were established from the objective. Thus, in order to classify the processes into categories of managerial procedures, metrics were considered which enables a comparison to be made of the processes and their performance to be assessed. The manger believes that the indicators that already exist in the company are sufficient to make the assessment and prioritize production lines, and therefore, he did not consider the creation of new indicators necessary. Therefore, the criteria used in the MPS are pack-to-melt ratio (PTM), line-rejected ratio (LR), loss ratio (L), customer complaints (CC), internal reject rate (IR) and critical defect ratio (CD). The definitions of each criterion are as follows:

- Pack-to-melt ratio (%)—measures the weight of packed glass in relation to the amount of glass melted;
- Line-rejected ratio (%)—is defined as the number of rejects by automatic inspection machine out of the number of products analysed;
- Loss after rework ratio (%)—is the number of products that is discarded after 100 % inspection out of the number of products analysed;
- Customer complaint (ppm)—notification from the customer of the lack of quality of a product;
- Internal reject rate (%)—is the number of total rejects out of the total number of products produced;
- Critical defect ratio (%)—is the number of products that have a critical defect out of the total number of products produced;

(a) Criteria weights: A weight should be established for each criterion and this value should increase with the importance of the criterion (Roy 1996). Thus, a five-point weighting scale of 1–5 was used (1 for lowest weight and 5 for highest weight) in order to indicate the importance of each criterion. The criteria weights were obtained from the manager's judgments. When defining of weights is a difficult task for the manager, he can use some weights elicitation procedures drawn from the literature (Figueira and Roy 2002; Mousseau et al. 2001; Fernandez et al. 2008).

(b) Reference profiles: As the manager wishes to classify the production lines into 3 categories (High Attention, Attention and Low Attention), two reference profiles (Ir_1 and Ir_2) were established for each criterion and are presented in Table 1. The value of these reference profiles represents standards to be compared with values of process performance in order to categorize the production lines. The reference profile Ir_1 establishes the minimum performance a production line must possess so as to be in the Low Attention Category, and the reference profile Ir_2 defines the minimum performance a production line must possess so as to be in the Attention Category. Otherwise, the production line is allocated to the High Attention Category. Defining these values was not a difficult task for the manager due to his professional background.

(e, f, g) After the analyst had explained the meaning of the ELECTRE TRI-B parameters, the thresholds (preference, indifference and veto) and the cutting level were defined. This was done by means of the decision analyst directly interrogating the manager, and out of their interaction, the manager's preferences were elicited (Zopounidis and Doumpos 2002). In addition, as described in Sect. 2, there are some procedures for inferring the parameters of the ELECTRE TRI-B method in the MCDA literature that can be used to help the manager infer the values of these parameters. For this application, the preference (p) and indifference (q) thresholds were defined as being equal to zero and the veto threshold was not considered. The cutting level (λ) was specified at 0.70, which meets the recommendation given by Merad et al. (2004) (the value of cutting level λ should be greater than the highest weight in order to avoid the most weighted criterion being the only one to define the allocation category).

The tool generates the classification of processes which are under the manager's responsibility. The production lines of pharmaceutical container and glassware for the table were allocated to the category of High Attention. The production lines of bottles of carbonated beverages and distilled beverages were allocated to the category of Attention and the production line of food container to that of Low Attention.

Given this result, the manager can plan and manage his weekly activities associated with each business process more effectively. In accordance with this classification, the manager should first concentrate on the production line of pharmaceutical container and glassware for the table. Thus, he has to spend more time during the week working with these production lines. However, he also has to dedicate some time of the working week to the production lines of bottles of carbonated beverages and distilled beverages, since these lines were classified as Attention, although not for as much time as the lines of the High Attention category.

The model proves very useful, especially nowadays when the manager does not have much time to spend processing and organizing information. In this case, having a tool that presents the information in an organized and user-friendly way, but at the same time which is able to express, all the information needed with regard to the performance of the organizational process is of great value.

Other benefits offered by this software are as follows. The MPS shows clearly and directly the current status for each process, enabling the effective management of activities associated with each business process. The model also enables the manager to take corrective, quick action to improve processes, since the system clearly shows which processes present a grave problem (those the performance of which is far below that planned). So a manager will spend his/her time with what really needs to be tackled. To do so, a manager does not need to spend much time gathering this information; he/she just needs to run the model once the software has been adjusted and an employee has supplied the performance data. This prevents the manager from needing to look at several indicators for the different processes that are under his/her responsibility.

Another advantage of the MPS is that it can be automated since the data can be extracted in real time from any existing database. In addition, the model is also very flexible because the manager can change the customization settings whenever he/she deems it necessary. Moreover, although the suggestion is to run the model once a week, the manager can run it whenever he/she considers it necessary.

One difficulty of this model is that the initial configuration of the data is not an easy task. Hence, obtaining help from a decision analyst is suggested so as to assist the manager to define the data and, in particular, to define parameters. This phase also may be delayed depending on the manager's professional knowledge and his/her understanding of his/her processes and process performance.

This work set out to develop a tool that a manager can handle with ease, one which neither takes up much of his/her time nor requires detailed knowledge of the MCDA and the ELECTRE TRI-B method and one which the manager can use in the real world. However, in order to obtain these features, the model considers only the pessimist algorithm (the rationale for the choice of this algorithm was given in Sect. 3). As a result, some information is lost, because if the software also displayed the result of the optimistic algorithm, it would be possible to see the cases where the incomparability situation occurred and so the processes allocated to different categories by both algorithms could be analysed with attention. Another disadvantage of the software is that sensitivity analysis cannot be conducted.

6 Conclusion and Further Research

Decision-making is an important task of management. Manager is required to make decisions constantly in order to solve problems. Efficient and effective decisions in managing processes bring competitive advantage to the organization and lead to its being successful.

This work proposed a management model based on MCDA the objective of which is to support the manager in analysing both the business process data and performance information in order to help the manager look for the best strategy for managing each process. By doing so, manager can plan and manage his/her weekly activities associated with each business process, in an effective manner. Thus, for example, he/she can devote himself/herself to the processes that require the highest levels of attention, since he/she does not have enough time to devote himself/herself to all processes equally.

In order that a manager can do so, the tool provides him/her with the classification of processes under his/her responsibility in categories of managerial procedures during planning for the short term. The model uses the ELECTRE TRI-B multi-criteria method to classify the processes due to its having features, such as its being a non-compensatory sorting method that can deal with both quantitative and qualitative evaluations and its having the ability to handle heterogeneous scales.

In addition, this method considers incomparable situations in the evaluation process. However, this characteristic was not so well explored by the MPS software since it did not allow for the intention of developing a tool that can be easily used by managers in the real world.

The advantages and disadvantages of MPS software were discussed. This chapter also includes a review of the literature that reports on the papers that apply MCDA in the BPM area.

Developing the MPS software and assessing it in real-life situations are proposals for future research studies. Furthermore, an adaptation of the MPS software for group decision problems can be addressed in future work.

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References

Belton V, Stewart TJ (2002) Multiple criteria decision analysis. Kluwer Academic Publishers, Boston

Bouyssou D, Marchant T (2007) An axiomatic approach to noncompensatory sorting methods in MCDM, I: The case of two categories. Eur J Oper Res 178:217–224

Campos ACSM, de Almeida AT (2014) Multicriteria framework for selecting a process modelling language. Enterp Inf Syst 1–16

Campos ACSM, Daher S, de Almeida AT (2011) New patents on business process management information systems and decision support. Recent Pat Comput Sci 4:91–97

Cho C, Lee S (2011) A study on process evaluation and selection model for business process management. Expert Syst Appl 38:6339–6350

Condor RD, Scarelli A, Valentini R (2011) Multicriteria decision aid to support multilateral environmental agreements in assessing international forestry projects. Int Environ Agreem Politics Law Econ 11:117–137

Dias LC, Mousseau V (2006) Inferring Electre's veto-related parameters from outranking examples. Eur J Oper Res 170:172–191

Felix TS, Bing J (2001) The application of flexible manufacturing technologies in business process reengineering. Int J Flex Manuf Syst 13:131–144

Fernandez E, Navarro J, Duarte A (2008) Multicriteria sorting using a valued preference closeness relation. Eur J Oper Res 185:673–686

Figueira J, Roy B (2002) Determining the weights of criteria in the ELECTRE type methods with a revised Simos' procedure. Eur J Oper Res 139:317–326

Figueira J, Greco S, Ehrgott M (eds) (2005) Multiple criteria decision analysis: state of the art surveys. Springer, Boston

Figueira J, Greco S, Roy B, Słowinski R (2010) ELECTRE methods: main features and recent developments. In: Zopounidis C, Pardalos P (eds) Handbook of multicriteria analysis. Springer, New York

Hammer M, Stanton S (1999) How process enterprises really work. Harvard Bus Rev 44:108–118

Hurson Ch, Ricci N (1998) Multicriteria decision making and portfolio management with arbitrage pricing theory. In: Zopounidis C (ed) Operational tools in the management of financial risks. Kluwer, Dordrecht, pp 31–55

Keeney RL (1992) Value-focused thinking: a path to creative decision making. Harvard University Press, Cambridge

Keeney RL (1996) Value-focused thinking: identifying decision opportunities and creating alternatives. Eur J Oper Res 92:537–549

Kohlbacher M, Gruenwald S (2011) Process orientation: conceptualization and measurement. Bus Process Manag J 17:267–283

Kumar V, Movahedi B, Lavassani KM, Kumar U (2010) Unleashing process orientation: a comparative study of enterprise system implementation in Canadian and US firms. Bus Process Manag J 16:315–332

Lourenço RP, Costa JP (2004) Using ELECTRE TRI outranking method to sort MOMILP nondominated solutions. Eur J Op Res 153:271–289

Lu YYL, Wu CH, Kuo TC (2007) Environmental principles applicable to green supplier evaluation by using multi-objective decision analysis. Int J Prod Res 45:4317–4331

Mansar SL, Reijers HA, Ounnar F (2009) Development of a decision-making strategy to improve the efficiency of BPR. Expert Syst Appl 36:3248–3262

McCormack K (2001) Business process orientation: do you have it? Qual Prog 34:51–58

Merad MM, Verdel T, Roy B, Kouniali S (2004) Use of multi-criteria decision-aids for risk zoning and management of a large area subjected to mining-induced hazards. Tunn Undergr Space Technol 19:125–138

Mousseau V, Slowinski R (1998) Inferring an ELECTRE TRI model from assignment examples. J Glob Optim 12:157–174

Mousseau V, Figueira J, Naux JP (2001) Using assignment examples to infer weights for ELECTRE TRI method: some experimental results. Eur J Oper Res 130:263–275

Pedrycz W, Ekel P, Parreiras R (2010) Models and algorithms of fuzzy multicriteria decision-making and their applications. Wiley, Chichester

Raiffa H (2002) Decision analysis: a personal account of how it got started and evolved. Oper Res 50:179–185

Reijers HA (2006) Implementing BPM systems: the role of process orientation. Bus Process Manag J 12:389–409

Roy B (1996) Multicriteria methodology for decision aiding. Kluwer Academic Publishers, Netherlands

Shimizu Y, Sahara Y (2000) A supporting system for evaluation and review of business process through activity-based approach. Comput Chem Eng 24:997–1003

Siskos Y, Grigoroudis E, Krassadaki E, Matsatsinis N (2007) A multicriteria accreditation system for information technology skills and qualifications. Eur J Oper Res 182:867–885

Škrinjar R, Bosilj-Vukšic V, Indihar-Štemberger M (2008) The impact of business process orientation on financial and non-financial performance. Bus Process Manag J 14:738–754

Stemberger MI, Bosilj-Vuksic V, Jaklic J (2010) Business process management software selection —two case studies. Ekonomska Istrazivanja-Econ Res 22:84–99

The AN, Mousseau V (2002) Using assignment examples to infer category limits for the ELECTRE TRI method. J Multi-crit Decis Anal 11:29–43

Yen VC (2009) An integrated model for business process measurement. Bus Process Manag J 15:865–875

Zopounidis C, Doumpos M (2002) Multicriteria classification and sorting methods: a literature review. Eur J Oper Res 138:229–246

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Part III
Selection of Suppliers and Partnerships Management

A Multi-criteria Decision Support System for Supplier Selection

Vanessa B.S. Silva and Fernando Schramm

Abstract The success of a company depends directly on the performance of its suppliers. In this sense, all aspects that contribute to the competitiveness of a good or service must be considered during the selection of suppliers; these aspects include price, quality, lead time, etc. Therefore, the management of the supply chain should ensure a structured procedure for selecting its suppliers, in which a multi-criteria analysis approach is effectively considered during the selection. This chapter presents a multi-criteria decision support system for selecting suppliers; the system is divided into three main parts: (i) a structural phase, in which the parameters of the model are defined; (ii) the application of the multi-criteria method, in which the multi-criteria method PROMETHEE II is applied to construct a ranking of suppliers according to the parameters defined in the previous step; and (iii) the analysis of the results, in which a sensitivity analysis is performed to verify the robustness of the results. Also, in this chapter, this system was applied to a problem in the civil construction industry and shows that the proposed decision support system is a powerful tool to be used by any organization to support their supplier selection processes. The system assures an evaluation of suppliers based on a set of aspects that are important with regard to the purchasing of a good; also, the decision support system encourages impartiality during the selection and improves the transparency of the process, which indicates that the system is appropriate to support the selection process that occurs in public organizations.

Keywords Multi-criteria decision analysis (MCDA) · Decision support system (DSS) · PROMETHEE II · Supplier selection

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1 Introduction

The quality of suppliers is one of the aspects that contributes to the competitiveness and performance of an organization. To be successful, the organization should include a proper evaluation and selection of their suppliers in their strategic planning.

The identification of criteria for selecting and evaluating suppliers has been the focus of many studies in the field of purchasing since the 1960s, beginning with the work of Dickson (1966). The author identified in the specialized literature at least 50 criteria that can be considered in supplier selection decisions. This study also evaluated the importance of some of these criteria according to the opinion of members of the National Association of Purchasing Managers, which includes agents and managers from the United States and Canada. Dickson's work was the starting point for the study conducted by Weber et al. (1991), which evaluated the importance of 23 criteria identified by the first author according to the number of times each criterion appears on studies about supplier selection that were published in the literature between 1967 and 1990. Degraeve et al. (2000) and De Boer et al. (2001) extended this review until 2000. In 2010, Ho et al. (2010) investigated the multi-criteria approaches used in supplier evaluation and selection through a literature review on specialized journals that were published from 2000 to 2008; the authors identified 14 relevant criteria; however, most of them had already been presented by Dickson in 1966. Based on the number of times that these criteria appear in the literature, the authors proposed the following ordering of importance for these criteria: (1) quality, (2) delivery, (3) price/cost, (4) manufacturing capability, (5) service, (6) management, (7) technology, (8) research and development, (9) finance, (10) flexibility, (11) reputation, (12) relationship, (13) risk, and (14) safety and environment. The above studies show that a multi-criteria approach is mandatory in decisions regarding supplier selection and evaluation; moreover, in contemporary supply management, quality followed by delivery is more important than price; therefore, a decision based only on the lowest price is certainly a badly informed decision.

The increasing importance of purchasing management for competitiveness and performance improvement of organizations is forcing managers to adopt a new attitude regarding supplier selection decisions, which includes the use of formal approaches for supporting these decision-making processes, such as the Multi-criteria Decision Analysis (MCDA) (Vincke 1992; Roy 1996). MCDA is a technique to structure and analyze complex decisions, involving multiple criteria, some of which conflict with each other (i.e., a technique for solving multi-criteria problems). The use of this technique for supporting supplier selection problems is increasing, as shown by the number of recent publications in purchasing specialized literature: Nagurney et al. (2005), Alencar and Almeida (2008), Kull and Talluri (2008), Ting and Cho (2008), Cruz (2008, 2009), Ordoobadi (2009), Tuzkaya et al. (2009), Kirytopoulos et al. (2010), Awasthi et al. (2010), Yücel and Güneri (2011), Schramm and Morais (2012), Alinezad et al. (2013), Arikan (2013), Dursun and Karsak (2013), and Karsak and Dursun (2014).

Many methods have been developed to support the choosing, sorting, and ranking of alternatives in decisions involving multi-criteria problems. These methods can be classified according to the meaning of the constants in the function that aggregates the intra-criterion information. When these constants lead to trade-offs among criteria, methods are compensatory, which produces a disadvantage in some criteria to be compensated for by a large advantage in another criterion. When these constants indicate relative importance coefficients, methods are non-compensatory and thus avoid trade-offs among criteria (Silva et al. 2010).

This chapter presents a decision support system (DSS) for supplier selection based on the use of a non-compensatory method of the family Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) (Brans and Vincke 1985), which provides a ranking of alternatives from best to worst, according to their overall performance in relation to the criteria discussed in Ho et al. (2010). One of the advantages of PROMETHEE over other non-compensatory methods is related to the fact that the decision makers find it easy to understand the concepts and parameters inherent in the method, which makes the preference modeling simpler and, consequently, increases the effectiveness of applying the methods developed (Silva et al. 2010).

This chapter is organized into five sections: Sect. 2 presents the fundamentals of MCDA, with emphasis on the study of the multi-criteria family of methods PROMETHEE, Sect. 3 presents the proposed approach for suppliers' selection, Sect. 4 presents a numerical application, and the conclusions of the study are presented in Sect. 5.

2 MCDA

Vincke (1992) defines a multi-criteria decision problem as a situation in which a defined set of actions, called A, and a family of criteria, called F, must be reduced to a subset by a decision maker, who wishes to determine a subset that is considered to be the best with respect to F (i.e., a choice problem); to divide A into subsets according to some norms (i.e., a sorting problem); or to rank the actions of A from best to worst (i.e., a ranking problem). Roy (1996) adds description problematic intended for the description of actions and their consequences in a formalized and systematic way; however, Belton and Stuart (2002) consider this problematic as a learning approach to gain greater understanding of what may or may not be achievable. There are also portfolio selection problems that incorporate constraints to the multi-criteria decision problems (Vetschera and Almeida 2012).

Roy (1996) classifies the methods for supporting multi-criteria decision problems into three approaches: (i) unique synthesis criterion, (ii) outranking synthesis, and (iii) interactive local judgment, which alternate calculation steps, giving successive compromise solutions and dialogue steps, which yield extra sources of information with the decision maker's preferences. The unique synthesis criterion approach consists of aggregating the different points of view into a unique function that will be optimized. The outranking synthesis approach consists of building a relation called an outranking relation, which represents the decision maker's preferences, after which, this relation is exploited to help the decision maker to solve his/her problems. The outranking methods seem to be the most successful because of their adaptability to real problems and the fact that decision makers comprehend these methods more easily (Al-Rashdan et al. 1999).

PROMETHEE is a family of outranking methods developed by Brans and Vincke (1985). Two possibilities are considered to solve a ranking problem: PROMETHEE I, which provides a partial preorder, and PROMETHEE II, which provides a total preorder on the set of possible actions.

The starting point of these methods is an evaluation matrix of alternatives based on an appropriate set of criteria. Then, a preference function P_j is assigned for each criterion j. According to the authors, six types of functions span most of the cases occurring in practical applications. Figure 1 presents these functions, where p and q represent the preference and indifference threshold, respectively.

This function describes how the decision maker's preference changes with the difference in performance level for two alternatives in a specific criterion, $g_j(a) - g_j(b)$. The preference function $P_j(a, b)$ provides the intensity of the preference for one alternative a over another b considering a specific criterion j; its values will be between 0 and 1, where the value 1 means the case of strict preference of a over b.

The preference intensity must be calculated for all criteria and for each pair of alternatives. The next step is to determine a preference index $P(a, b)$ for each pair of alternatives over all criteria using the preference intensity and the weights given to the criteria that represent only their respective relative importance. The preference index provides the preference for one alternative over another considering all

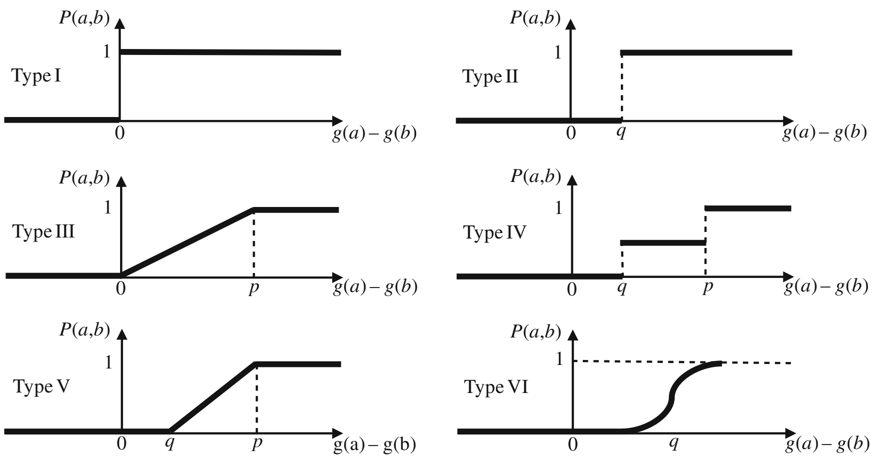

Fig. 1 Types of criteria

criteria; a value of 1 indicates the highest preference. It is defined as a weighted average of preferences of the individual criteria:

$$P(a,b) = \frac{1}{W}\sum_{j=1}^{n} w_j P_j(a,b) \tag{1}$$

$$W = \sum_{j=1}^{n} w_j \tag{2}$$

where w_j is the weight of criterion j.

Two indices are calculated using the preference index: the positive outranking flow, $Q^{+}(a)$, and the negative outranking flow, $Q^{-}(a)$. The positive outranking flow expresses the extent to which an alternative outranks all others; a larger positive outranking flow indicates a better alternative. The negative outranking flow expresses the extent to which an alternative is outranked by all others; a smaller negative outranking indicates a better alternative. These parameters are used to explore the relation among alternatives. They are defined by the following expressions, respectively:

$$Q^{+}(a) = \sum_{a \neq b} \frac{P(a,b)}{n-1} \tag{3}$$

$$Q^{-}(a) = \sum_{a \neq b} \frac{P(b,a)}{n-1} \tag{4}$$

where n is the number of alternatives.

In PROMETHEE II, a complete preorder (i.e., complete ranking without ties) of alternatives is obtained from the net flow that was calculated for each alternative. The net flow is obtained from the difference between the positive and negative flow:

$$Q(a) = Q^{+}(a) - Q^{-}(a) \tag{5}$$

Alternative a outranks alternative b if $Q(a) > Q(b)$; they are indifferent if $Q(a) = Q(b)$.

3 DSS for Suppliers Selection

The proposed DSS will support any employee within the organization who is responsible at some level for buying or approving the acquisition of a good. In the next lines, the terms “buyer” and “supplier” will be used to represent the organizations that are buying and selling something, respectively; therefore, the evaluation of a supplier regards the evaluation of an organization as a whole. The DSS is divided into three phases: (i) the structural phase, (ii) the application of the multi-criteria method, and (iii) the analysis of the result. Each phase is described below.

The structural phase is intended to create a data structure, if it does not yet exist, with all of the data necessary for the application of the DSS for supplier selection; this requires a high level of interaction between decision analyst, who can be an individual or a software agent, and the decision maker (DM).

The data structure will contain all of the goods that can be purchased by the buyer, their respective suppliers, and the name of the agent who is responsible for the purchasing (i.e., the DM). This data structure also contains the suppliers' selection criteria that are based on the study of Ho et al. (2010) and their respective descriptions. It is important to ensure that the DM understands the meaning of these criteria and how they will be evaluated on their respective scales. Table 1 presents the description of the criteria that are divided into two groups: (i) objective criteria and (ii) subjective criteria. The suppliers will provide their own performance in relation to the criteria of the first group, and the buyer will evaluate the suppliers in relation to the criteria of the second group, allowing an evaluation that takes into account other aspects of the suppliers beyond the ones that are directly related with the purchasing itself; for example, the relationship between the buyer, the supplier, and the reputation of the supplier in the market.

The initiatives for evaluation of C1 (Table 2) were identified in the study of Ho et al. (2010). The initiatives of C8 (Table 3) were identified in the study of Handfield et al. (2002).

The DMs must assign the weights of the proposed criteria according to the good, whose purchasing they are responsible for. They must assign a value between 0 and 10 to each criterion that represents their relative importance. If a criterion is not relevant to a specific good, its weight should be set to zero. The values are then normalized and inserted into the data structure.

Another responsibility of DMs at this phase is to assign one of the preference functions suggested by Brans and Vincke (1985) to each criterion (Fig. 1). This function estimates how the decision maker's preference changes with the difference in performance level for the two alternatives within a specific criterion. However, for those criteria that are evaluated through a subjective scale, it must be considered that if the performance of one alternative is slightly higher than the performance of another, then the former is entirely preferable; then, for the criteria C11 and C12, the usual criterion function (Type I) will be assigned.

Once these above data are organized into the data structure, the results will be fed into a purchase order request with the performance of available suppliers in relation to all criteria. Obviously, if new goods and/or suppliers are being considered in a given purchase, the data structure must be updated.

After a purchase order request, all registered suppliers of the requested good are invited to provide their performance in the criteria of the first group (Table 1); these evaluations will feed into the data structure, and the suppliers who did not send offers will not participate in the selection process. The DM will then evaluate the suppliers who sent proposals in relation to the criteria of the second group.

Table 1 Set of criteria

Criteria		ID	Evaluation dimension	Objective
1st group	Quality	C1	Initiatives implemented by the supplier to improve the quality of its products/services and/or processes. Metric: number of the initiatives (Table 2) that is implemented on the supplier	Max
		C2	Warranty that the goods comply with the minimal required specification. Metric: percentage of goods meeting required specification	Max
	Service	C3	Lead time between the order and its delivery. Metric: number of days	Min
		C4	Time to repair or replace in case of faulty goods, without any cost to the buyer. Metric: number of months	Max
	Price/Cost	C5	Unit price of the good. Metric: monetary value	Min
		C6	Cost of delivery of the order. Metric: monetary value	Min
		C7	Payment terms. Metric: number of days.	Max
	Sustainability	C8	Initiatives implemented by the supplier to promote the sustainable development of the region where it is installed. Metric: number of the initiatives (Table 3) that is implemented on the supplier	Max
2nd group	Research and development (R&D)	C9	Value that was invested by the supplier in its R&D department during the last 12 months. Metric: monetary value	Max
	Finance	C10	Solvency, i.e., the supplier ability to pay its obligation to creditors and other third parties in the long term. Metric: the ratio between assets and liabilities	Max
	Reputation	C11	Reputation of the supplier in the market. Metric: linguistic scale (very high-VH, high-H, medium-M, low-L, and very low-VL)	Max
	Relationship	C12	Relationship between the supplier and the buyer. Metric: linguistic scale (very good-VG, good-G, regular-R, bad-B, and very bad-VB)	Max

The data structure will be used as the input to the application of the multi-criteria method PROMETHEE II, whose description is presented on Sect. 2. The output of this method is a ranking of the registered suppliers, who are participating in the selection process, according to their overall performance in relation to all criteria. The PROMETHEE II method can easily be implemented in programing languages, and the result could be provided readily.

The third phase of the DSS is intended to analyze this result. If the DM does not agree with the result, the analyst should perform a sensitivity analysis by altering

Table 2 Considered initiatives for the evaluation of C1

Items	Definition
01	Continuous improvement program
02	Six sigma program
03	Total quality management program
04	Corrective and preventive action system
05	Inspection process
06	Control of process
07	ISO quality system
08	Non-conforming material control system
09	Quality award
10	Quality certification
11	Quality manual
12	Quality management practices and systems

Table 3 Considered initiatives for the evaluation of C8

Items	Definition
01	ISO 14000 certified
02	Third-party certification (eco labeling)
03	Product labeling
04	Take-back or reverse logistics program
05	Programs to foster employee awareness
06	Participation in Environmental Protection Agency
07	Waste management program
08	Environmentally friendly product packaging

the weights of some criteria and verifying the impact of this on the final result until a solution that is in accordance with the preference of DM is achieved.

After determining the final ranking of suppliers, the set of weights that provided those results is presented to the DM, who is asked to update the structure with this new set of data, which changes the relative importance of the criteria for a specific good. Any updating on the data structure at this phase or during the first phase registers the person who is responsible; also, if he/she does not desire an update of the data structure, a document is generated indicating the set of weights that was considered for that specific selection process.

Therefore, the third phase could return the process to the structural phase or to the application of the method (Fig. 2).

The next section shows a numerical application of the method described to illustrate how the DSS works.

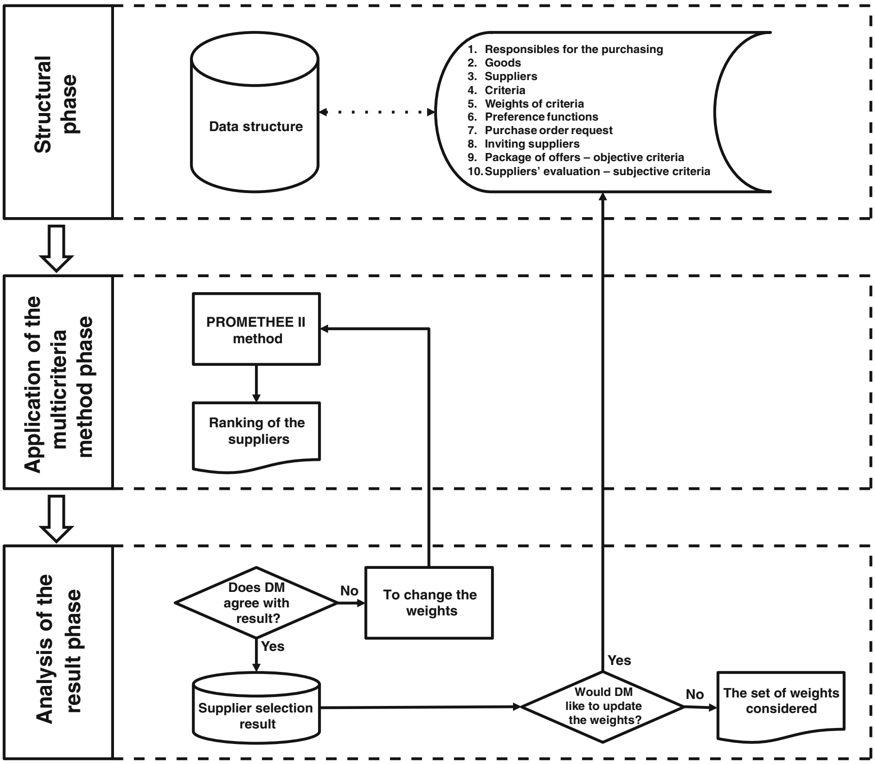

Fig. 2 DSS flowchart

4 Numerical Application

To illustrate the application of the DSS, it was applied to support a supplier selection in a civil construction company. The information regarding the evaluation of suppliers is obtained from a previous selection that occurred in the company without the support of the DSS; for this reason, some activities of the DSS were suppressed, such as the formal inviting of the suppliers.

The DM is a purchasing manager of a vertical building located at Recife in Pernambuco, Brazil. For the requested good (i.e., a multi-use mortar), there are five suppliers, who are identified here as S1, S2, S3, S4, and S5. All criteria are considered important by the DM; however, he assigned a weight of zero to some because the information necessary to evaluate the suppliers in relation to these criteria are not available for this application; nevertheless, this fact does not influence the illustration of how the DSS works. According to the DM, in C1, C2, C3, C5, and C6, if the performance of one alternative is slightly higher than the performance of another, then the former is entirely preferable; therefore, a Type I

Table 4 Data structure

DM: purchasing manager													
Good: multi-use mortar													
Criteria	ID	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
	Weights	0.37	0.10	0.07	0.00	0.24	0.15	0.00	0.00	0.00	0.00	0.05	0.02
	Function	I	I	I	–	I	I	–	–	–	–	I	I
Suppliers evaluation	S1	3	92.8	5	0	10.9	1.10	0	0	0	0	VH	VG
	S2	2	87.7	7	0	7.7	1.85	0	0	0	0	VL	VB
	S3	3	91.3	18	0	8.6	1.17	0	0	0	0	L	B
	S4	1	92.1	10	0	7.2	1.43	0	0	0	0	M	R
	S5	3	91.8	8	0	8.9	1.50	0	0	0	0	H	G

Table 5 Ranking of suppliers

Ranking	Suppliers	Q(.)
1st	S1	1.34
2nd	S3	0.42
3rd	S4	−0.09
4th	S5	−0.27
5th	S2	−1.4

preference function was assigned to these criteria. The structure of the data that was constructed for this application is presented in Table 4.

At the second phase of the DSS, the PROMETHEE II method was applied and a ranking of suppliers was obtained (Table 5).

To verify the robustness of the result, a sensitivity analysis regarding the weights of the criteria was performed during the third phase. The first supplier in the ranking is S1, who had the worst performance in criterion C5, which evaluates the suppliers in relation to the unit price of their offers. Thus, the DM wanted to know whether increasing the weight of C5 would imply the selection of another supplier instead of S1. To verify this, the analyst increased the relative importance of C5 while decreased the weights of the other two more important criteria (e.g., C1 and C6); with this change, the order of importance of the criteria became C5 > C1 > C6 > C2 > C3 > C11 > C12. It was verified that even with an increase of almost 50 % in the weight of C5 (from 0.24 to 0.34), S1 remained in the first position of the ranking, while S3 and S4 switched positions. Therefore, the analysis indicates that the obtained result is robust.

5 Conclusions

The proposed DSS is composed by a data structure that organizes the information necessary for any supplier selection process (i.e., goods, employees who responsible for the purchasing of each good, list of suppliers, etc.) as well as some of the associated activities (i.e., purchasing order request, inviting suppliers, receiving suppliers' package of offers, evaluation of suppliers, etc.).

The DSS allows purchasing managers to evaluate their suppliers according to a set of criteria, which were identified in extensive studies regarding supplier selection problems that were published in specialized literature since the 1960s. This allows decision makers to assign different weights to the criteria; the relative importance of the criteria can vary according to each selection process, making it possible to also eliminate some criteria by assigning a weigh of zero to them. In this sense, the proposed DSS can be adopted to support supplier selection processes that occur in any type of organization, including public ones.

The second phase of the DSS applies the PROMETHEE II multi-criteria method to the data organized into the data structure. This method provides a ranking of suppliers based on their overall performance in relation to all of the criteria that is being considered in the selection process. One of the advantages of PROMETHEE II is related to the fact that its concepts and parameters can be easily understood by any decision maker. This method can also easily be implemented in a computer language.

In the third phase, the DSS allows decision makers to review the results of the selection or verify its robustness by changing the relative importance of the criteria in a sensitivity analysis.

Therefore, the proposed DSS is a powerful tool that can be used by any organization to support supplier selection processes. It assures an evaluation of suppliers based on a set of criteria that are important to be considered in a purchasing of a good; also, the DSS encourages impartiality during the selection process and improves the transparency of the process, which is appropriate particularly in public organizations. The DSS can even be created as an automated agent when implemented as a computer program.

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References

Alencar LH, Almeida AT (2008) Multicriteria decision group model for the selection of suppliers. Pesquisa Operacional 28(2):321–337

Alinezad A, Seif A, Esfandiari N (2013) Supplier evaluation and selection with QFD and FAHP in a pharmaceutical company. Int J Adv Manuf Technol 68(1–4):355–364

Al-Rashdan D, Al-Kloub B, Dean A, Al-Shermmeri T (1999) Environmental impact assessment and ranking the environmental projects in Jordan. Eur J Oper Res 118(1):30–45

Arikan F (2013) A fuzzy solution approach for multi objective supplier selection. Expert Syst Appl 40(3):947–952

Awasthi A, Chauhan SS, Goyal SK (2010) A fuzzy multicriteria approach for evaluating environmental performance of suppliers. Int J Prod Econ 126(2):370–378

Belton V, Stewart TJ (2002) Multiple criteria decision analysis: an integrated approach. Kluwer Academic Publishers, Boston

Brans JP, Vincke P (1985) A preference ranking organization method (the PROMETHEE method for multiple criteria decision-making). Manage Sci 31:647–656
Cruz JM (2008) Dynamics of supply chain networks with corporate social responsibility through integrated environmental decision-making. Eur J Oper Res 184(3):1005–1031
Cruz JM (2009) The impact of corporate social responsibility in supply chain management: Multi-criteria decision-making approach. Decis Support Syst 48(1):224–236
De Boer L, Labro E, Morlacchi P (2001) A review of methods supporting supplier selection. Eur J Purchasing Supply Manage 7(2):75–89
Degraeve Z, Labro E, Roodhooft F (2000) An evaluation of supplier selection methods from a total cost of ownership perspective. Eur J Oper Res 125(1):34–59
Dickson GW (1966) An analysis of vendor selection systems and decisions. J Purchasing 2 (1):5–17
Dursun M, Karsak EE (2013) A QFD-based fuzzy MCDM approach for supplier selection. Appl Math Model 37(8):5864–5875
Handfield R, Walton SV, Sroufe R, Melnyk SA (2002) Applying environmental criteria to supplier assessment: a study in the application of the analytical hierarchy process. Eur J Oper Res 141:70–87
Ho W, Xu X, Dey PK (2010) Multi-criteria decision making approaches for supplier evaluation and selection: a literature review. Eur J Oper Res 202(1):16–24
Karsak EE, Dursun M (2014) An integrated supplier selection methodology incorporating QFD and DEA with imprecise data. Expert Syst Appl 41(16):6995–7004
Kirytopoulos K, Leopoulos V, Mavrotas G, Voulgaridou D (2010) Multiple sourcing strategies and order allocation: an ANP-AUGMECON meta-model. Supply Chain Manage Int J 15 (4):263–276
Kull TJ, Talluri S (2008) A supply risk reduction model using integrated multicriteria decision making. IEEE Trans Eng Manage 55(3):409–419
Nagurney A, Cruz J, Dong J, Zhang D (2005) Supply chain networks, electronic commerce, and supply side and demand side risk. Eur J Oper Res 164(1):120–142
Ordoobadi SM (2009) Development of a supplier selection model using fuzzy logic. Supply Chain Manage: Int J 14(4):314–327
Roy B (1996) Multi-criteria methodology for decision aiding. Kluwer Academic Publishers, Netherlands
Schramm F, Morais DC (2012) Decision support model for selecting and evaluating suppliers in the construction industry. Pesquisa Operacional 32(3):643–662
Silva VBS, Morais DC, Almeida AT (2010) A multicriteria group decision model to support watershed committees in Brazil. Water Resour Manage 24(14):4075–4091
Ting S-C, Cho DI (2008) An integrated approach for supplier selection and purchasing decisions. Supply Chain Manage Int J 13(2):116–127
Tuzkaya G, Ozgen A, Ozgen D, Tuzkaya UR (2009) Environmental performance evaluation of suppliers: a hybrid fuzzy multi-criteria decision approach. Int J Environ Sci Technol 6 (3):477–490
Vetschera R, Almeida AT (2012) A PROMETHEE-based approach to portfolio selection problems. Comput Oper Res 39(5):1010–1020
Vincke P (1992) Multi-criteria decision aid. Wiley, Bruxelles
Weber CA, Current JR, Benton WC (1991) Vendor selection criteria and methods. Eur J Oper Res 50(1):2–18
Yücel A, Güneri AF (2011) A weighted additive fuzzy programming approach for multi-criteria supplier selection. Expert Syst Appl 38:6281–6286

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The Management of the Negotiation Process in Interorganizational Partnerships from the Trust Perspective

Telma Lúcia de Andrade Lima and Danielle Costa Morais

Abstract In an increasingly complex, dynamic and highly competitive environment, there has been a proliferation of interorganizational relationships with an emphasis on cooperative relationships. For companies to define or redefine the terms of interdependence in established transactions, negotiations are required, and trust has been considered crucial for enabling joint gains in the development and implementation of the agreement. Negotiators who trust each other transfer their thoughts more comfortably and more readily accept the ideas of the other party because trust not only reduces transaction costs but also has a mutually causal relationship with information sharing, which further creates value in the exchange ratio. The present study analyses trust in the negotiation processes of interorganizational partnerships. The three areas of study, interorganizational relationships, trust and negotiation, are interlinked; therefore, a conceptual model for analysing the dimensions of trust in an integrative negotiation is proposed. The analysis covers the three stages of a negotiation process between two organizations: pre-negotiation, negotiation and post-negotiation. From the results of this study, it is concluded that identifying and developing actions to strengthen the trust dimensions in the processes of relationship negotiations between organizations is important for cooperatively developing and encouraging mutual benefits for the companies involved.

Keywords Interorganizational partnerships · Negotiation · Trust

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1 Introduction

In contrast with the organizational decision to act alone and with interorganizational relationships (IORs) in which goals are not shared, and continuity in the relationship is not intended, at present, organizations increasingly interact cooperatively, seeking long-term partnerships and lasting relationships.

Encouraged by the dynamics of these relationships, their motivations and their success factors, many studies have been conducted in the last three decades (Powell 1990; Ring and Van de Ven 1992, 1994; Zaheer et al.1998; Barringer and Harrison 2000; Das and Rahman 2010).

According to Powell (1990), cooperative organizational arrangements, such as partnerships and strategic alliances, provide rapid access to and secure resources and knowledge that are outside the boundaries of the organization. Additionally, economies of scale in joint productions form, and these ventures include the sharing of risk. In this sense, Das and Teng (1998) note that cooperation agreements between companies are alliances that aim to achieve the strategic objectives of the partners.

Although such organizational arrangements entail considerable possibilities and benefits, they are also notoriously unstable, and high failure rates have been observed (Barringer and Harrison 2000; Das and Rahman 2001; Deitz et al. 2010). Opportunism, defined as self-interest seeking with malice (Williamson 1985), has been considered one of the factors responsible for frequent unplanned endings of these agreements (Das and Rahman 2010).

In this context, trust—the positive expectation of the fulfilment of obligations, even with the possibility of opportunism (Zaheer et al.1998)—has been considered one of the most important concepts and has frequently been noted in connection with cooperative relationships between enterprises (Grandori and Soda 1995). The existence of trust between partners in the formation and maintenance of alliances can reduce opportunistic behaviour and the need for hierarchical controls (Powell 1990; Ring and Van de Ven 1992; Gulati 1998), which tends to increase organizational flexibility and the ability to adapt to new needs.

Trust is considered crucial for the creation, development and coordination of relationships between organizations (Mayer et al. 1995; Zaheer et al. 1998; Klerk 2012) and a key element for high-level performance, sustained relations of alliance and facilitating conflict resolution (Ring and Van de Ven 1994; Nooteboom 1996). Furthermore, according to Maguire et al. (2007), a high level of trust between organizations can reduce formal governance and the need for contractual arrangements.

Nevertheless, companies involved in IORs become more dependent and vulnerable to the decisions and actions taken by the other party in the agreement, keeping them in a state of interdependence that may be a precursor to potential conflicts. Managing this interdependence requires negotiations (Das and Kumar 2011), and negotiations on the formation and development of relations between organizations are also necessary.

Negotiators who trust each other transfer their thoughts more comfortably and more easily accept the ideas of the other party because, according to Dyer and Chu (2003), trust not only reduces transaction costs but also has a mutually causal relationship with information sharing, which creates additional value in the exchange relationship. Furthermore, the mutual trust between negotiators can help to create a suitable climate, providing more opportunities to consider each other's needs and mutually effect concessions (Butler 1999).

Olekalns and Smith (2012) note that first impressions about the other party's trustworthiness are critical to the development of a negotiation. First impressions that the other party is trustworthy can stimulate the development of a virtuous cycle of increasing trust and cooperation. However, first impressions that the other party is untrustworthy can lead to the development of a vicious cycle of mistrust and competition. It is difficult to say whether trust induces cooperation or whether cooperation induces trust (Payan and Svensson 2007).

This chapter proposes a conceptual model that analyses trust in the negotiation processes of interorganizational partnerships based on the dimensions of trust, relating them to the strategies of integrative negotiation phases proposed by Kersten (2003): pre-negotiation, negotiation and post-negotiation. It offers general concepts concerning interorganizational relationships, trust and negotiation. In addition, this chapter presents the model proposed, considering the critical role that trust plays in the negotiation phases. Finally, the chapter describes the perceptions of Brazilian IT organizations concerning interorganizational partnerships and trust.

2 General Concepts: Interorganizational Relationships, Trust and Negotiation

2.1 Interorganizational Relationships

IORs are voluntary cooperative agreements between at least two organizations for achieving a competitive advantage by exchange and sharing resources and specific assets (Peng and Kellogg 2003).

The academic literature on IORs is extensive and fragmented, with a combination of multidisciplinary arguments (Barringer and Harrison 2000) mainly drawn from economics, sociology and organizational theory, reflecting the multifaceted nature of these relationships. Studies have focused mainly on new organizational formats and the combinations of motives, intentions and goals that lead organizations to effect such connections.

According to Powell (1990), cooperative organizational arrangements, such as partnerships and strategic alliances, provide rapid access to and secure the resources and knowledge that are outside the boundaries of the organization. They also create economies of scale in joint research and/or productions, as well as the sharing of risk in these ventures. In this sense, Teece (1992) argues organizations establish cooperative relationships to quickly obtain complementary resources in a cost-efficient and flexible fashion. Furthermore, they can reduce the threat of future rivalry from co-optation by potential competitors (Prahalad and Hamel 2005).

Doz and Hamel (2000) argue that there are three logics that lead to the formation of partnerships, namely: (1) the logic of strategic co-optation, which aims to make the situation of the members of the alliance more interesting and increase their competitive capabilities; (2) the logic of co-specialization, which focuses on creating opportunities using the complementary skills and resources of the companies; and (3) the logic of learning and internalizing, which promotes learning and the acquisition of skills.

Alongside the variety of reasons for the proliferation of new organizational arrangements, there is also a diversity of theoretical and methodological approaches to exploring and better understanding them. Barringer and Harrison (2000) derived a list of six paradigms that expound the motivations of organizations to form these relationships: transaction costs, resource dependency, strategic choice, stakeholder, learning and institutional.

The paradigm of transaction costs was introduced by Coase (1937) and subsequently consolidated by Williamson (1985, 1991, 1996) under the name of transaction cost economics (TCE). It has received considerable attention in the literature on cooperative relationships because it offers a justification theory to situations in which cooperation is preferable to vertical integration (Barringer and Harrison 2000). Companies involved in IORs may reduce the sum of transaction costs and production and may also reduce the resulting uncertainties of market-related problems. The central issue in TCE is the decision whether to internalize the production of equipment, supplies, etc., or to turn to the market to buy them. The joint evaluation of the production costs and transaction will guide this decision.

In the paradigm of resource dependence (Pfeffer and Salansik 1978), firms form interorganizational relationships to gain access to critical resources from external sources and to exert power or control over other companies (Barringer and Harrison 2000).

In the paradigm of strategic choice, IORs are justified based on the decisions that affect the strategic position and competitive advantage in relation to competitors and consumers. Examples include maximizing the ability to offer attractive products and services, increased efficiency and cost reduction (Barringer and Harrison 2000; Powell 1990). The authors argue that strategic choice is broad because all motivations presented here can be incorporated into it.

With regard to the stakeholder paradigm, Barringer and Harrison (2000) found that firms form alliances to align their interests with the interests of stakeholders as well as to reduce environmental uncertainties.

The paradigm of learning motivates organization to consider the relationships between them as an effective way to transfer knowledge, thereby increasing organizational skills and adding value to themselves (Barringer and Harrison 2000).

Finishing the analysis of Barringer and Harrison (2000) concerning the paradigms that substantiate IORs, we emphasize that the institutional paradigm legitimates the organizations to expand their visibility, reputation, image and the prestige of their partnership relations with other well-established companies.

Ring and Van de Ven (1994) noted, from the perspective of process, that IORs are social mechanisms constructed for collective action and are continually shaped and restructured by the actions and symbolic interpretations of the parties involved. The development and evolution of these relationships are conducted dynamically in a repetitive sequence of phases, namely, negotiation, commitment and execution. In negotiation, the expectations concerning the motivations, possible investments and perceived uncertainties of the business are developed together. At the stage of commitment, obligations and standards that will guide future relationships are determined. These agreements are then formalized as a written contract or take the form of a mutual psychological commitment. In the execution phase, the commitments and action rules are implemented. The phases are consecutively evaluated for efficiency and equity, and, depending on how the terms of the agreement are negotiated, executed and modified, the relationship will continue or be terminated.

3 Trust

Trust is considered a complex and multidimensional phenomenon (Cummings and Bromiley 1996) and has been explored by a variety of disciplines. Although varied concepts and assertions concerning trust are found in the literature, there is a consensus regarding its importance in social and organizational relationships and economic transactions as well as its multidimensionality (Mayer et al. 1995; Zaheer et al. 1998; Maguire et al. 2007).

Among researchers of organizational behaviour, it has been argued that trust is related to the expectation of the fulfilment of obligations, even with the possibility of opportunism (Zaheer et al. 1998), and it is necessary for cooperation and communication in productive relations (Tschannen-Moran and Hoy 2000). For researchers in business management, trust has been defined as a collective judgment of a group concerning attitudes such as honesty and the credibility of the other group (Bradach and Eccles 1989; Bromily and Cummings 1996).

Hosmer (1995) was motivated by the numerous approaches used in studies of trust, especially ethical philosophy and organizational theory, which link the individual and interpersonal aspects with economic transactions and organizational performance, and he sought to precisely define what trust. He presented trust as the expectation of ethically justifiable behaviour, that is, morally correct decisions and actions that recognize and protect the interests of the other party in a joint effort or economic exchange.

From a multidisciplinary analysis of the literature on trust, Rousseau et al. (1998) found that the expectations of others and the willingness to be vulnerable are elements present in all definitions of trust and defined it as a psychological state that includes the willingness to put yourself in a position of vulnerability based on positive expectations concerning the intentions or behaviour of another. The authors stressed that, despite the common meaning, the difference between interpersonal trust and interorganizational trust is plain because of the change in the object of analysis.

Within the context of negotiation, Ross and Lacroix (1996) indicate that for any negotiation to occur, it appears that there must be a minimal level of trust. According to the authors, trust is considered the willingness of a party to accept risk and increase its vulnerability to the other party, whose behaviour is beyond its control. The party that assumes risk is confident that the other party will not exploit its vulnerabilities.

Other definitions have been proposed, and, among the elements considered, we highlight the definitions of trust in terms of the belief or expectation of action shared by the parties, involving uncertainties, risks and vulnerabilities. Furthermore, the multidimensional approach to defining trust, drawn from the numerous perspectives from which the concept was explored, produced a multitude of subconstructs to meet the different meanings it has for people and organizations.

3.1 Trust and Its Dimensions

According to Das and Teng (2001), in a context of organizational strategic alliances, the concept of trust, operationalized through positive expectations regarding the other in a situation of risk, is based on two dimensions, goodwill, which is related to the belief in and the integrity of the partners, and performance, which is related to the skill and competence of the partner in the realization of all planned activities. To conceptualize trust as an expectation rather than conviction, the authors considered the uncertainty of future behaviour and the possibility of betrayal.

Zaheer et al. (1998) operationalized the concept of trust through expectations concerning the action of the actor, based on three components: predictability—the actor will behave predictably; credibility—the actor will fulfil its obligations; and justice—given the chance for opportunism to occur, the actor will act and negotiate fairly.

Mayer et al. (1995), based on one of the most cited models of trust in management, considered that, in addition to the propensity to trust, trust depends on a set of information variables, such as benevolence, integrity and ability. Benevolence is related to the positive perception of an action for the welfare of others; integrity is the perception that the object of trust adheres to a set of acceptable principles; capacity comprises the set of skills that characterize a given individual. In this sense, Butler (1999) considers the capacity as a qualifier for whether a particular actor can perform a specific task or action. For Schoorman et al. (2007), these elements explain trust not only from an individual but also from group and organizational perspectives.

Mishra (1996) described trust as a multidimensional construct, and he incorporated four dimensions into his definition: competence, openness, concern and reliability. The combination of these dimensions determines the overall degree of trust that one party has with respect to a given referent. Competence means that the other party has the skills, knowledge and capacity to do what is requested. Openness is related to honesty and candour. Concern entails one party's belief that its self-interests are balanced with the other party's interests. Finally, reliability refers to the consistency of behaviour between words and corresponding actions.

According to Bachmann (2001), trust is linked to the existence of uncertainty in the economic transaction because it is impossible to control every detail in most exchange relationships (Das and Teng 1998) as well as to identify in advance any changes, reactions and sanctions of the actors involved (Cunha and Melo 2006). For Williamson (1973), this means that contracts are formal mechanisms for incomplete control, creating the possibility for the parties to act opportunistically. Without this uncertainty, trust would be irrelevant.

Some authors argue that trust and control are interdependent variables and that they should not be completely eliminated in favour of each other because they do not conceive of any contexts governed solely by control without elements of trust, or vice versa. Das and Kumar (2011) recognize that, although contracts are essential to interorganizational arrangements, the relative importance that the partners give each other may be a result of the effectiveness of negotiations between parties.

4 Negotiation

Negotiation has been considered a ubiquitous social activity. It takes place in many situations and is influenced by ethical, cultural and social circumstances. Its diversity and complexity and the importance of decisions have led to various studies, producing a rich theory with a variety of settings (Almeida et al. 2012; Thompson et al. 2010; Bichler et al. 2003).

For some, negotiation aims to conquer people to obtain something you want, using information and power to influence the behaviour of a network of stress (Cohen 1980). For others, negotiation means to reach a joint decision when the parties have different preferences (Bazerman 2004) or it is a communication process used by a group to try to reach a mutually acceptable agreement on certain issues (Lomuscio et al. 2003).

To Raiffa (1982), there is an art and a science to negotiation. The art of negotiation resides in the interpersonal skills to convince and be convinced, the ability to employ strategies that frustrate the plans of the adversary and the wisdom to know when and how to use them. The science of negotiation involves a systematic analysis for troubleshooting.

In the vision of Fisher et al. (2005), negotiation is a means to obtain what we want from each other when there are conflicting and common interests and entails a two-way communication process to reach an agreement. What stands out in this definition is the process of bilateral communication; that is, both parties involved in the negotiation should be senders and receivers of information; otherwise, the process collapses into an imposition of wills.

Adopting a broader concept, Kersten (2001, 2003) defines negotiation as a process of decision-making that involves two or more parties to reach an agreement that satisfies the requirements of the participants in the face of conflicts of interest and limited information. Each participant has independent interests, but the participants are interdependent because they cannot achieve their goals unilaterally.

In the context of IORs, Das and Kumar (2011) define negotiation as a process of integration and reconciliation of interests between partners. The authors acknowledge that the permanent state of interdependence among firms in partnerships is a precursor to potential conflicts and that the management of this independence requires negotiations.

4.1 Types of Negotiation

In general, negotiations are classified into two types: distributive and integrative (Raiffa 1982), although researchers have different descriptions for them.

Distributive negotiations, also known as win–lose (Raiffa 1982) or positional bargaining (Fisher et al. 2005), are characterized by the distribution of the object of negotiation between the parties so that each party tries to take the largest "slice" possible, seeking the best results for themselves at the expense of the other party. According to Raiffa (1982), in a distributive negotiation, one single subject is under dispute and the parties have interests "almost" strictly opposite to each other: if one party wishes to win as much as it can win, then the more it wins, the more the other loses.

Raiffa (1982) analysed distributional bilateral negotiations based on the existence of a zone of agreement or bargain area (Thompson 2009), the region between the reserve values of the negotiators. The reserve values represent the maximum and minimum limits acceptable by the parties, according to the position that they occupy. For example, in a negotiation of purchase and sale, the seller's reserve value, or reserve price, will be the lowest value that he accepts for sale, and the reserve value of the buyer will be the largest amount paid for the purchase. If the parties reach an agreement, and assuming that there was no parallel negotiation, whether actual or potential, it is expected that the final value is agreed within the agreement area.

Integrative negotiations, known for allowing best commitments, win–win solutions, joint gains and value creation (Kersten 2001; Tajma and Fraser 2001), are those whose main feature is the integration of the resources of the parties involved to enlarge the object of negotiation and generate mutual gains for all parties. Raiffa (1982) considers that there are several issues in dispute and that the parties are not strictly competitive, that is, as much as one party wins, the other party does not necessarily lose, and both can earn more. The parties will cooperate to increase the total to be divided. In game theory, this is known as match-zero-sum.

In an integrative negotiation, efficiency is linked to finding the best possible solution (Raiffa 1982), in which both parties' interests are fully maximized. This solution is known as the Pareto optimal solution (Thompson et al. 2010). That is, any other outcome could not constitute a gain for one party without constituting a loss for the other.

The literature widely suggests that, when there are two or more issues with different priorities for each trader, the use of integrative negotiation tactics is more effective than the use of distributive negotiation tactics. The integration of interests, cooperation and sharing of information allows for the maximization of joint outcomes, even if the parties have to give in with respect to certain goals (Almeida et al. 2012; Fisher et al. 2005; Kersten 2003; Raiffa 1982). However, as emphasized by Almeida et al. (2012), cooperative action is not the same thing as naivety or the abandonment of goals and objectives, but instead it involves the use of creativity, flexibility and attitude to achieve your goals.

The balance between cooperation and competition is reflected in the types of negotiation strategies that will be chosen by the partners (Das and Kumar 2011). It is necessary to consider the different types of contexts to evaluate the type of negotiation to be developed (Watkins 1999). In negotiations that are conducted in contexts that imply lasting relationships, new rounds of negotiation, consensus for conflict resolution and joint gains, the integrative approach is presented as the most favourable.

4.2 The Negotiation Phases

In the literature, there is no consensus on the description of the stages of negotiation. However, traditionally it occurs in at least three phases: pre-negotiation, planning or preparation; negotiation; and post-negotiation (Agndal 2007; Nieuwmeijer 1992).

Kersten (2003) describes negotiation as a process that occurs in three phases: pre-negotiation, negotiation and post-negotiation. In the pre-negotiation phase, the goal is the study and understanding of the issues being negotiated. This stage involves analysing the negotiation problem, the context of the problem, and the access and use of knowledge about the participants. Alternatives and options for value creation are identified and each party makes its own plans for negotiation.

In the second phase, negotiation, the strategies and tactics developed in the previous phase are deployed. Exchanges of messages, offers and counter-offers to closing the agreement are made. A consensus on the issues is reached or the negotiation process is terminated.

In the last phase, post-negotiation, the negotiated points are reviewed, and the results are monitored to verify that the agreement is being fulfilled. One notes that the author identifies the negotiation process as constituting more than the reaching of an agreement, emphasizing preparation before the negotiation and monitoring of the agreement after it has been reached.

5 Analysis of the Negotiation Process in the Management of Interorganizational Partnerships from the Trust Perspective

In the context of IORs, trust is considered one of the most important concepts and is frequently noted in connection with the cooperative relationships between enterprises. Although it is a valuable asset, it is not reduced if it is used in these relationships. Indeed, Bachmann (2001) argues that trust can be regarded as a form of capital that appreciates in value with its use, benefiting both sides of the relationship. However, after a review and an analysis of the literature on trust, IORs and negotiation, it was possible to identify that trust does not develop on its own and that a series of deliberate actions that take into account the multidimensionality of trust are required for its construction and maintenance. In the context of negotiation, four dimensions of trust standout are as follows: openness, concern, credibility and competence.

The proposed model in this section, which is presented in Fig. 1, was developed for the analysis of the dimensions of trust in an integrative negotiation process

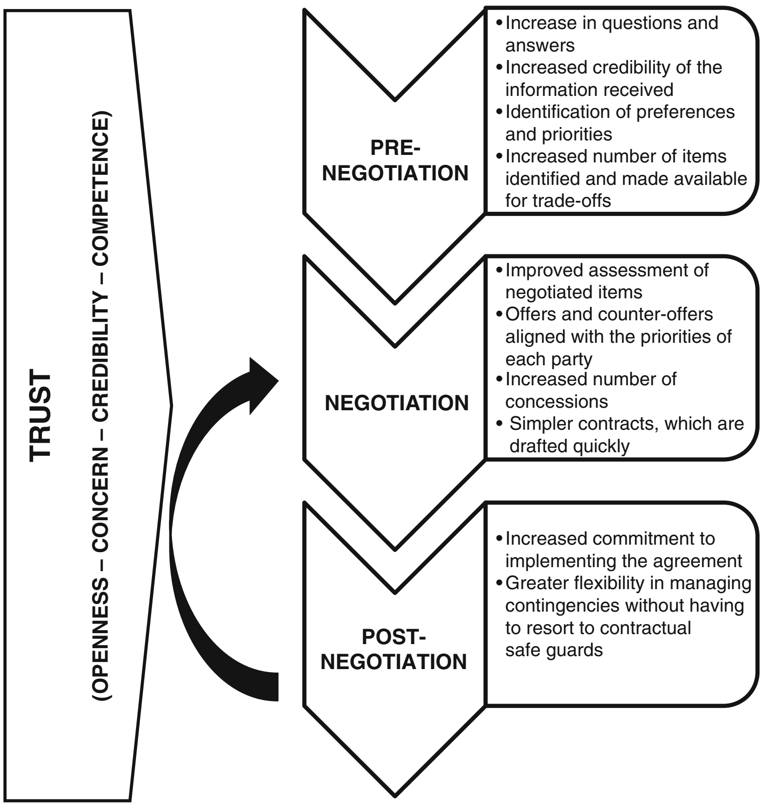

Fig. 1 Analysis of the dimensions of trust in an integrative negotiation process

during the formation or conducting of IORs. It is based on the incorporation of the attributes related to the trust negotiation phases proposed by Kersten (2003), pre-negotiation, negotiation and post-negotiation. The implications and results of the existence of the trust are considered for each of these phases.

5.1 Trust in the Pre-negotiation Phase

As is seen in Fig. 1, pre-negotiation is the first phase of the negotiation process. It is considered the preparation phase. For negotiators, preparation means understanding their own position and interests, the position and interests of the other party, the object of negotiation, the external factors that influence the process and work-arounds that can be used to create and distribute value to the next trading phase, allowing a favourable outcome for both sides (Almeida et al. 2012; Thompson 2009; Kersten 2003).

At this stage of negotiation, the dimension of openness contributes to the perception of trust and relates to communication. "Without communication there is no negotiation" (Fisher et al. 2005, p 50). The term openness indicates the mental disposition of the negotiator to share information and to accept the ideas of the other party (Tzafrir and Dolan 2004). The parties must be open not only to talking but also to listening to what is being said. Without proper communication, cooperative relationships tend to suffer (Das and Teng 1998).

Openness to sharing information is critical in the first two phases of the integrative negotiation process. The more information that is exchanged between parties, the more preferences and priorities will be identified and this information will be incorporated into decisions, enabling perceptions and decisions to converge for mutual gains (Aldair et al. 2004; Tzafrir et al. 2011; Thompson et al. 2010).

Das and Teng (1998) argue that, for various reasons, open communication enables the building of trust between partners, which helps to resolve minor disputes common in daily operations, producing a more harmonious working relationship. Open communication also allows companies to collect evidence of the credibility and integrity of character of the partners, and, as a foundation for continuous interaction, it allows the partners to identify and develop common values and norms, reinforcing the sense of trust between them.

Therefore, seeking and sharing information in the pre-negotiation phase are essential to the development of trust between parties (Butler 1999). Given that trading is not a unilateral process (Fisher et al. 2005), reciprocal actions in this direction may contribute to the rapid development of mutual trust and create value in the agreements established because the exchange of information and the willingness to solve problems are supported by the expectation that the other party will act reciprocally (Olekalns and Smith 2012). Lewicki (2006) notes that the more trust increases, the greater the likelihood that the negotiation will develop favourably, increasing the points of agreement and reducing the points of inflection.

However, the perception of trust in this information exchange process will be positive based on whether the information exchanged is honest and frank, even when the information is negative in character (Tzafrir et al. 2011). The initial perception of low trust due to the discrediting of the information received makes negotiators apprehensive and reluctant to question and share information, even inclines them to give dishonest information to avoid being exploited by the other party and reduces the credibility of the fulfilment of the agreement, thereby preventing the efficient construction of an integrative agreement (Lewicki 2006; Thompson et al. 2010).

The decision to share accurate and honest information is a result of the existing level of initial trust between the parties. Thompson (2009) identifies it with immediate trust, which needs to be built quickly and is based on a smaller amount of information. This initial trust depends on other dimensions that represent trust: concern, competence and credibility. However, these dimensions will only be expanded when there is an opening for communication and the mutual exchange of information.

During the pre-negotiation phase, the concern dimension can be evaluated based on positive information about the reputation of the companies, for example, good references on their treatment of partners and employees.

In turn, the competence dimension can be identified through information regarding the quality of the products and services offered by the company; the training of professionals who will be appointed to develop the activities of the partnership; and partnerships already established with other companies, research centres and universities.

The credibility dimension, in pre-negotiation, can be developed based on information on the compliance of the delivery of products or services provided by business partner to their customers and their other partner institutions or companies. Data on the ethical reputation of the partner company, its professionals and its other partner companies or institutions also influence this dimension of trust.

5.2 Trust in the Negotiation Phase

In the next phase of the proposed model, negotiation, the execution of what was planned in the previous phase begins. The dimensions of trust that stand out are concern, competence, openness and credibility.

The demonstration of concern for the interests and welfare of the other party provides a climate of trust, and negotiators can come to consider it in their reviews, offers and concessions. Their own interests are balanced with those of the other party (Tzafrir et al. 2011). The positive perception of an action taken for the welfare of others is indicative of benevolence and can contribute to the building of trust (Lewicki 2006).

Moreover, concern is also perceived in terms of justice and fairness. Negotiators who are concerned with the creation and maintenance of a fair relationship can induce a party not to feel cheated and taken advantage of, increasing the perception of trust. Thus, the use of common standards of justice and fairness, identified in the pre-negotiation, if employed in the evaluations made during the negotiations towards building a fair relationship, contributes to the increase in trust between parties.

The competence dimension focuses on the skills and abilities of the other party (Das and Teng 2001). In assessing whether the other party has the ability to do what is proposed, negotiators are led to trust, saving time and energy in efforts to draft the agreement (Lewicki 2006), which strongly contributes to value creation and the elaboration of simpler contracts without going into great details and the need for stipulated controls. This trust is considered not only easy to establish but also easy to break. For some, this trust may be regarded as a calculus based on the costs or benefits that the parties incur by keeping commitments (Thompson et al. 2010).

The competence dimension, in the negotiation, can be identified from positive data regarding the quality of the products or services offered; data on the existence of qualified professionals in the partner company; data on quality certifications for the products or processes used; data on partnerships with research institutes, universities and funding agencies or data on partnerships with other organizations. Although these aspects of the competence dimension have been cited with respect to the pre-negotiation phase, it is at this stage they will become clearer and hold greater evidence because of the development of the surveys carried out in the previous phase. Trust, here, is not the initial trust that was perceived during the planning of the partnership. Rather, it is an enlarged trust borne of the information that has been exchanged.

The dimensions of openness and credibility can also be checked in the negotiation phase through the reciprocal exchange of information and the assessment of commitments made to the partnership.

Negotiators demonstrate the fulfilment of commitments through their reputation and the information shared between the parties. They contribute to increased trust by promoting the formulation of offers and arguments for value creation and risk taking at this stage of the negotiation. Thompson (2009), based on the work of Glick and Croson (2001), notes that venture capitalists who invest together in various technology companies in Silicon Valley share information on the reputations of these companies, and, depending on the speed of business, companies with bad reputations do not even make it onto the agendas of these investors.

Han et al. (2012) found that negotiators with a highly moral identity develop integrative negotiations more effectively, achieving greater results, especially when they are involved with negotiators who hold similar moral values. For these authors, in a negotiation, moral identity governs the cognitive process that enables the effective use of integrative tactics, inducing the parties to explore more alternatives and effecting more concessions. Their findings, then, emphasize the need to have a good ethical reputation for building trust between parties. Trust violations based on ethical issues are difficult to repair (Olekalns and Smith 2012).

In addition to the benefits of integrative capacity described above, trust also reduces transaction costs by enabling the reduction of time and effort in achieving efficient agreements that are mutually acceptable (Zaheer et al. 1998). However, negotiators with a bad reputation disrupt the development of trust, delay and burden the partnership because of the possibility for opportunistic behaviour to occur before or after the agreement of partnership (Williamson citing Zaheer et al. 1998).

5.3 Trust in the Post-negotiation Phase

In the last phase of the model, post-negotiation, the negotiated points are reviewed, and the results are monitored to verify that what has been agreed upon is being fulfilled. An agreement between organizations is not limited to a signed contract but includes the decisions to be implemented throughout the life of the partnership (Tzafrir et al. 2011), which may exceed the time frame that was agreed upon for the execution of activities. The warranties of products or services jointly developed and regulatory frameworks related to patents or specific cost reductions, in which the companies are jointly and severally liable, must also be taken in account. Therefore, in interorganizational contexts, the post-trade phase extends throughout this cycle, according to the decisions that were made with respect to deadlines and the responsibilities to be performed.

When partners trust each other, they are in a better position to appreciate the benefits of contractual flexibility, enabling faster responses, more efficient and better adaptation to new environments (Das and Teng 1998) and reducing costs by avoiding legal remedies through the courts (Zaheer et al. 1998).

The credibility dimension of trust that stands out at this stage is related to the fulfilment of obligations (Zaheer et al. 1998). This refers to the expectations of consistency between what is said and what is done. Trust means that the promises will be fulfilled and that the actions will correspond to what was agreed upon. For Tzafrir and Dolan (2004), credibility is strengthened when promises are maintained and fulfilled. The positive results of achieving the goals established by the partners contribute to the maintenance of and increase in confidence in the partnership.

In the post-negotiation phase, even when a complex and sophisticated formal contract has been developed, some detail or contingency for which no clause was written can occur (Lewicki 2006). Thus, trust, represented by all of the dimensions that have been presented, will contribute to the implementation of the agreement because the parties will believe that the other party will act based on not only what was written but also on what was agreed upon.

If there is change in the environment or the occurrence of unanticipated events, partners may request that some issues are reviewed. New proposals may be made and new reviews, counter-offers, concessions, etc., may occur. According to the commitment of resources and the strategy used to maintain the partnership, joint solutions that do not affect the development of the partnership may be found; otherwise, contractual safeguards may be used.

6 An Exploratory Study of the Relations of Partnership, Negotiation and Trust in the Context of Brazilian IT Organizations

With the aim of better understanding and aligning the issues related to partnerships between organizations, specifically the motivations and outcomes of such partnerships and how the dimensions of the construct trust are perceived, an exploratory study of IT and communications organizations in Recife, the capital of Pernambuco, was conducted.

Pernambuco, a state in north-eastern Brazil, holds a place on the world stage because of its human capital, entrepreneurship and innovation, mainly through companies in the Porto Digital, a productive arrangement involving information technology, communications and the creative economy that is configured as an important promising market in the regional economy. In 2010, 200 companies located in the Porto Digital had a turnover of R$ 1bn (Porto Digital 2013).

Companies in the IT and communications sector were selected for this survey because of the high likelihood of these companies to form partnerships, because they aggregate technological and human resources that have different specialized skills and strategies to meet the entire business chain in which they work and because they represent a sector with a strong regional performance.

For the data collection, a questionnaire survey was mailed to 110 companies, mainly to member companies of Porto Digital. Of these, 39 were returned, representing a 34 % response rate. The questionnaire was developed using constructs related to cooperation and trust defined in previous empirical work and was divided into three sections. The first and second sections covered aspects related to the characteristics of the partnerships made, their motivations, activities undertaken, achievements, actions and the behaviours of the partners that occurred during the IOR. The third section sought to identify the respondents' perceptions of the issues related to partnership and trust in this study.

Regarding the representativeness of the companies that entered into IORs, we found that among the valid responses, 84 % of companies made some type of partnership with another organization. Regarding the types of agreements adopted by organizations, 32 % were in the form of joint productions, 18 % in distribution agreements and 22 % in research and development or consortium agreements. Other types accounted for 25 %.

The main motivation of companies to develop partnerships was the creation of value through the pooling of resources, positions and skills, followed by learning and the internalizing of new skills. This result confirms the logic of co-specialization of Doz and Hamel (2000), which focuses on creating opportunities for organizations from IORs with complementary skills and resources, as well as the paradigm of learning, which considers partnerships as an effective means for knowledge transfer, and the strategic logic of co-optation, which aims to make the situation more interesting for alliance members and increasing their competitive capabilities.

These findings allow us to interrelate the partnerships' goals with the goals of the negotiations, and, although the questions related to the gain function in the development and internalization of new skills are latent, it is observed that companies have identified the possible risks of this exposure as the loss of strategic information and resources. However, because of their trust in the partner, the companies decided to take the risks involved.

With regard to the risks involved in partnerships, companies had several concerns, highlighting the risk of non-compliance with the agreement. However, this risk enabled greater perception of the successful results of the partnerships, which allows for the perception of trust, related to the credibility dimension, between the parties.

However, when a comparative analysis of the assessed risks and opportunistic actions that developed during the partnership agreements was performed, it is observed that the risk of loss of resources and loss of strategic information, which together accounted for 29 % of assessed risks, can be considered as the most commonly perceived risk by some companies because they recognized that partners have appropriated funds for their own benefit.

The companies demonstrated trust in the partner because they showed moderate positive expectations that the partners would act as initially agreed upon and, even if given the chance, would not take actions that could negatively affect them. It was found that this positive expectation was extended to partners whose firms at least had knowledge of their competences and skills to develop activities.

Despite the formality of the relationship, the companies did not regard contractual safeguards as sufficient for establishing relationships with companies of doubtful competence. That is, negative evaluations of the dimensions of credibility impacted the formation of the partnership, and even the use of formal controls was no possible to reverse them, hence the importance of reputation in the partner selection process.

When considering new partnerships, high positive expectations in the actions of the partner companies were found, even with the companies that had not made partnerships. In addition to the positive expectation of the partner's action, in this analysis the respondents' evaluation of the elements of the construct of trust, i.e. ability, benevolence and integrity, corroborated the definition of trust used in this study as well as all of the integral elements of the multidimensionality of the concept.

This exploratory study allowed us to operationalize and verify how the dimensions of trust identified in the literature review are emphasized in the context of IORs of IT and communications companies.

In general, the IT and communications sector is favourable for the formation of partnerships because of the demand for specialized skills and technological resources as well as interdisciplinary projects that can be developed by combining skills and resources. Corroborating the logic of specialization of Doz and Hamel (2000) and resource dependence (Pfeffer and Salansik 1978), it was found that the main motivation behind forming partnerships for the organizations surveyed was value creation through the pooling of resources, positions and skills, followed by learning and the internalizing of new skills.

These findings enable us to interrelate the goals of the partnership with the objectives of the negotiations and, although the issues related to the gain function in the development and internalization of new skills are latent, it is observed that companies have identified the possible risks of this exposure as the loss of strategic information and resources. However, because of their trust in the partner, i.e. their positive expectations that the partner would act as initially agreed upon and that, even if given the chance, would not take actions that could adversely affect them, they decided to take the risks involved.

It is noteworthy that the risk of non-compliance with the agreement, which is most often presented in the respondents' reports of the risks involved, was what enabled higher perceptions of the successful results of the partnerships made.

7 Concluding Remarks

Several researchers concluded that the presence of trust in relationships is crucial to successful partnerships, producing effective results and leading to cooperative behaviour and better IORs. Identifying and building trust during the negotiation phase can modify the perception of possible risks and the identification of solutions beneficial to the parties involved as well as the perception of the competence and credibility of the partner.

These facts have influenced the way that the negotiation process unfolds because it is possible for parties to use trust as a way to resolve conflicts and to achieve mutual gains.

The analysis of the critical role that of trust plays in relation to the dimensions of openness, concern, credibility and competence in the negotiation phase has highlighted the importance of the perception of trust for the development of integrative strategies, emphasizing information sharing, resource efficiency and the flexibility and commitment necessary for the parties to implement the agreement. Thus, actions such as the dissemination and collection of information on a reciprocal basis; the presentation of good moral character and competence; concern and empathy between the parties and the recognition of the breach of trust with developing remedial actions are ways to build and maintain trust.

References

Agndal H (2007) Current trends in business negotiation research: an overview of articles published 1996–2005. SSE/EFI working paper series in business administration. No: 2007; 003

Aldair W, Brett J, Lempereur A, Okumura T, Shikhirev P, Tinsley C, Lytle A (2004) Culture and negotiation strategy. Negot J 20(1):87–111

Almeida A, Morais D, Costa A, Alencar L, Daher S (2012) Decisão em grupo e negociação: métodos e aplicações. Atlas, São Paulo

Bachmann R (2001) Trust, power and control in trans-organizational relations. Organ Studies 22:337–365

Barringer B, Harrison J (2000) Walking a tightrope: creating value through interorganizational relationships. J Manage 26(3):367–403

Bazerman M (2004) Processo Decisório: para cursos de administração e economia. Elsevier, Rio de Janeiro

Bichler M, Kersten G, Strecker S (2003) Towards a Structured Design of Electronic Negotiations. Group Decis Negot 12(4):311–335

Bradach L, Eccles G (1989) Price, authority, and trust: From ideal types to plural forms. Annu Rev Sociol 15:97–118

Butler K (1999) Trust expectations, information sharing, climate of trust, and negotiation effectiveness and efficiency. Group e Organ Manage 24(2):217–238

Cohen H (1980) Você pode negociar qualquer coisa. Record, Rio de Janeiro

Coase R (1937) The nature of the firm. Economica 4(16):386–405

Cummings L, Bromiley P (1996) The organizational trust inventory (OTI)—development and validation. In: Kramer R, Tyler T (eds) Trust in organizations: frontiers of theory and research. Sage, Thousand Oaks, pp 302–330

Cunha C, Melo M (2006) A confiança nos relacionamentos interorganizacionais: o campo da biotecnologia em análise. RAE—Eletrônica. 5(2)

Das K, Rahman N (2010) Determinants of partner opportunism in strategic alliances: a conceptual framework. J Bus Psychol 25:55–57

Das K, Rahman N (2001) Partner misbehaviour in strategic alliances: guidelines for effective deterrence. J General Manage 27(1):43–70

Das K, Kumar R (2011) Interpartner negotiations in alliances: a strategic framework. Manage Decis 49(8):1235–1256

Das K, Teng B (2001) Trust, control, and risk in strategic alliances: an integrated framework. Organ Studies 22(2):251–283

Das K, Teng B (1998) Between trust and control: developing confidence in partner cooperation in alliances. Acad Manage Rev 23(3):491–512

Deitz D, Tokman M, Richey R, Morgan R (2010) Joint venture stability and cooperation: direct, indirect and contingent effects of resource complementarity and trust. Ind Mark Manage 39:862–887

Doz L, Hamel G (2000) A vantagem das alianças: a arte de criar valor através das parcerias. Quality Mark, São Paulo, São Paulo

Dyer J, Chu W (2003) The role of trustworthiness in reducing transaction costs and improving performance: Empirical evidence from the United States, Japan, and Korea. Organ Sci 14:57–68

Fisher R, Ury W, Patton B (2005) Como chegar ao sim: negociação de acordos sem concessões, 2nd edn. Imago, Rio de Janeiro

Glick S, Croson R (2001) Reputations in negotiation. In: Hoch e S, Kunreuther H (eds) Wharton on decision making. Wiley, New York, pp 177–186

Grandori A, Soda G (1995) Inter-firm networks: antecedents, mechanisms and forms. Organ Stud 16:183–214

Gulati R (1998) Alliances and networks. Strategic Manage J 19(4):293–317

Kersten G (2003) The science and engineering of e-negotiation: an introduction. In: HICSS 2003. Proceedings of the 36th Hawaii international conference on system sciences, Los Alamitos, Hawaii. IEEE Computer Society, pp 27–36

Kersten G (2001) Modeling distributive and integrative negotiations—review and revised characterization. Group Decis Negot 10(6):493–514

Klerk S (2012) Establishing and developing business networks: the importance of trust. African J Bus Manage 6(18):5845–5856

Han I, Kwon S, Bae J, Park K (2012) When are integrative tactics more effective? The moderating effects of moral identity and the use of distributive tactics. Int J Conflict Manage 23(2):133–150

Hosmer T (1995) Trust: the connecting link between organizational theory and philosophical ethics. Acad Manage Rev 20:379–403

Lewicki R (2006) Trust and distrust. In: Schneider A, Honeyman C (eds) The Negotiator's Fieldbook. American Bar Association—Section of Dispute Resolution, Washington, pp 191–202

Lomuscio A, Wolldridge M, Jennings N (2003) A classification scheme for negotiation in electronic commerce. Int J Group Decis Negot 12(1):31–56

Maguire H, Paterson I, Al-Hakim L (2007) The soft side of supply chain management: the importance of trust. In: ANZAM 2007: managing our intellectual and social capital, Sydney

Mayer C, Davis H, Schoorman D (1995) An integrative model of organizational trust. Acad Manage Rev 20:709–734

Mishra A (1996) Organizational responses to crisis: the centrality of trust. In: Kramer R, Tyler T (eds) Trust in organizations: frontiers of theory and research. Sage, Thousand Oaks, pp 261–287

Nieuwmeijer L (1992) Negotiation: methodology and training. HSRC Press, Pretoria

Nooteboom B (1996) Trust, opportunism, and governance: a process and control model. Organ Studies 17:985–1010

Olekalns M, Smith P (2012) Negotiations and trust. In the Encyclopedia of peace psychology. Christie DJ (ed) Wiley, New York, http://works.bepress.com/mara_olekalns/19. Accessed Jun/2012

Payan J, Svensson G (2007) Cooperation, coordination, and specific assets in interorganizational relationships. J Mark Manage 23(7/8):797–812

Peng T, Kellogg J (2003) Partners, resources, and management mechanisms of interorganizational collaborative ties in non-profit organizations. J Am Acad Bus 3:291–298

Prahalad C, Hamel G (2005) Competindo pelo Futuro. Campus, Rio de Janeiro

Pfeffer J, Salancik R (1978) The external control of organizations: a resource dependence perspective. Harper e Row, New York

Porto Digital (2013) Porto Digital. http://www.portodigital.org Accessed Jan/2013

Powell W (1990) Neither market nor hierarchy: network forms of organization. Res Organ Behav 12:295–336

Raiffa H (1982) The art and science of negotiation. Harvard University Press, Cambridge

Ring P, Van de Ven A (1994) Developmental process of cooperative interorganizational relationships. Acad Manage Rev 19:90–118

Ring P, Van de Ven A (1992) Structuring cooperative relationships between Organizations. Strategic Manage J 13:483–498

Ross W, Lacroix J (1996) Multiple meanings of trust in negotiation theory and research: a literature review and integrative model. Int J Conflict Manage 7:314–360

Rousseau M, Sitkin B, Burt S, Camerer C (1998) Not so different after all: a cross-discipline view of trust. Acad Manage Rev 23(3):393–404

Schoorman F, Mayer C, Davis H (2007) An integrative model of organizational trust: past, present, and future. Acad Manage Rev 32(2):344–354

Tajima M, Fraser N (2001) Logrolling procedure for multi-issue negotiation. Group Dec Negot 10:217–235

Teece D (1992) Competition, cooperation, and innovation: organizational arrangements for regimes of rapid technological progress. J Econ Behav Organ 18(1):1–25

Thompson L (2009) O Negociador, 3rd edn. Prentice-Hall, São Paulo

Thompson L, Wang J, Gunia B (2010) Negotiation. Annu Rev Psychol 61:491–515

Tschannen-Moran M, Hoy A (2000) Multidisciplinary analysis of the nature, meaning, and measurement of trust. Rev Educational Res 70(4):547–593

Tzafrir S, Sanchez R, Unger, K (2011) Social motives and trust: implications for joint gains in negotiations. Group Decis Negot 1–24, doi:10.1007/s10726-011-9252-8

Tzafrir S, Dolan L (2004) Trust-me: a scale for measuring employee manager trust. Manage Res 2(2):115–132

Watkins M (1999) Negotiation in a complex world. Negot J 15(3):245–270

Williamson O (1996) The mechanisms of governance. Oxford University Press, New York

Williamson O (1991) Comparative economic organization: the analysis of discrete structural alternatives. Adm Sci Q 36(2):269–296

Williamson O (1985) The economic institutions of capitalism—firms, markets, relational contracting. Free Press, New York

Williamson O (1973) Markets and hierarchies: some elementary considerations. Am Econ Rev 63 (2):316–325

Zaheer A, Mcevile B, Perrone V (1998) Does trust matter? exploring the effects of interorganizational and interpersonal trust on performance. Organ Sci 9:141–159

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Decision Making Regarding Information Sharing in Partnerships with Suppliers

Patricia Guarnieri

Abstract Decision making related to select partners, considering the strategic nature of decisions related to information sharing in partnerships, is essential. This chapter proposes a general and systematic model related to decisions of partnerships management. The model is focused in the strategic decision of partner's choice for information sharing, under an MCDA perspective, which helps to avoid the bullwhip effect in supply chain management. Thus, it is shown that is possible the suppliers' categorization in levels of partnerships driving suitable suppliers to share information in appropriate ways. A numerical application is presented to illustrate the application of the model.

Keywords Bulwhipp effect · Decision making · Information sharing · Multiple criteria decision making · Partnerships

1 Introduction

The need to maintain relationships with suppliers has become a critical issue to business (Lambert 2008), which is a result of competitive pressures, the need to achieve cost efficiency and urgency of establishing relationships with key suppliers. These close relationships can provide buyers with the expertise needed to develop new products, new technologies and new processes, avoid the bullwhip effect, among others. Besides that, according the SCOR model (2006), the suppliers can be considered as an extension of the manufacturing process of the companies, so processes are dependent on reliable supply flows that respond rapidly to demand variability.

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In this context the activities of identify the best suppliers for a new product or service or to evaluate the performance of a former supplier, is very complex due to the metrics used include not only quantitative measures (as cost, delivery fees, defect rate, etc.) but also qualitative factors, such as stability of management, reliability, ability to design and process, management capability, financial condition, among other factors (Bozarth and Handfield 2008).

It should be emphasized that the objective of a supplier selection problem (SSP) is to identify suppliers with the highest potential for meeting a manufacturer's needs consistently and at an acceptable overall performance. Selecting suppliers from a large number of possible suppliers with various levels of capabilities and potential is a difficult task and it is configured as a multi criteria decision making aid (MCDA) problem, by nature.

In order to make possible the integration amongst supply chain's members, companies have been implemented a variety of information systems (IS) and technologies (IT), which are essential to facilitate information sharing (Lambert 2008). The synchronization of supply chain members through information sharing can eliminate the bullwhip effect, which is considered the distortion of information from one part of the supply chain to another, the distortion of consumption pattern from the ordering pattern at a firm (Ciancimino et al. 2012). Nevertheless, in order to share strategic information in supply chain management (SCM), it is necessary select appropriate partners. Thus, the activities of identifying the best suppliers for a new product or service, or even to evaluate the performance of an existing supplier are essential tasks in managing the supply chain. The supplier management makes possible that the collaborative process occurs in an efficient manner (Bozarth and Handfield 2008).

Some articles have been published mainly in the last decade about this matter: selection and performance evaluation of suppliers for purchasing of components/materials (Dulmin and Mininno 2003; Pi and Low 2005); selection of suppliers for optimal order allocation (Araz et al. 2007); Importance of information sharing to avoid Bullwhip effect (Cannella and Ciancimino 2010; Ciancimino et al. 2012; Cannela et al. 2013); The role of information sharing in integrating supply chains (Skjoett-Larsen et al. 2003; Bagchi et al. 2005).

The objective of this chapter is to present a model, which is related to decision making on partnerships focused in the information sharing applied to avoid the bullwhip effect. This framework considers a MCDA perspective with numerical application presented in order to illustrate the use of framework.

2 Partnerships with Suppliers in SCM

A supply chain covers all members involved in all activities from supplier to the final customer. Due to supply chain partnering involves collaborative activities such as sharing information, synchronizing decisions, sharing complementary resources, and aligning incentives (Cao and Zhang 2010), the complexity of relationships between members increases. This type of relationship, which is cooperative in nature, requires real time information to share goals, align processes and systems (Cohen and Roussel 2004; Cao and Zhang 2010).

Hence the relationships with partners are cooperative in nature, it also involves repetitive negotiations. In the context of SCM research, the related terms cooperation, coordination, and collaboration are often used. In a general understanding, these concepts refer to separated entities that work together for a decision alignment in order to improve overall performance (Moharana et al. 2012).

However, some differences in these concepts should be pointed out. Cooperation is defined as acting or working together for a shared purpose or toward a common goal. This concept does not suggest a close operational working relationship, but rather a positive attitude towards each other (Moharana et al. 2012). On the other hand, Coordination refers to a more direct or active cooperation. It is defined as the act of making arrangements for a purpose and the harmonious adjustment or interaction. When compared to cooperation, coordination indicates an interactive, joint decision making process, where separate entities influence each other's decisions more directly. Moreover, collaboration indicates a joint and interactive process that results in joint decisions and activities. In addition, it indicates a higher degree of joint implementation and can be thought of as a teamwork effort (Moharana et al. 2012).

In addition, collaboration can mean several things, involving several types of partners, and can occur at different levels (Cohen and Roussel 2004). Companies collaborate to reduce inventory; to promote on-time deliveries; to develop new products and technologies or improve existing ones; to improve production efficiency; to increase the degree of innovation; to increase the generation and share strategic information through IS and IT (Schary and Skjoett-Larsen 2001; Claycomb and Frankwick 2010). The endeavour of Operation Management related to SCM, has consisted in formalizing how information visibility can be applied to inventory control policies, and how collaborative configurations are distinguished in terms of inventory control policies (Cannella and Ciancimino 2010).

In fact, suppliers are considered an extension of the manufacturing process of the companies and the current competitive environment; processes are dependent on reliable supply flows that respond rapidly to demand variability, which can be achieved through information sharing SCOR model (2006). So, in partnerships, the buyer company shares more information with the provider about their intentions for future purchases. Such perspective about the future allows providers to make better and more reliable predictions about future demand, which can eliminate the bullwhip effect on inventories (Krajewski et al. 2009).

3 Synchronizing Supply Chain to Avoid Bullwhip Effect

The bullwhip effect has been observed throughout several segments of industry for many years and is considered the amplification of demand variability from a downstream site to an upstream site (Ciancimino et al. 2012). The Operation

Management community has focused their efforts onto two different approaches for avoiding and/or limiting the bullwhip effect: collaboration in supply chain and smoothing replenishment rules (Canella and Ciancimino 2010).

It should highlighted that collaboration with partners in supply chain contributes to eliminate bullwhip effect transforming suboptimal individual solutions of individual members of supply chain into a comprehensive solution through sharing customer and operational information (Canella and Ciancimino 2010).

Towil et al. (2007) presented a classification framework for bullwhip effect studies. They identified three observer's perspectives to analyse it: variance lens, shock lens and filter lens. The authors used a mathematical modeling to the bullwhip shock lens aiming to infer on the performance of supply chains for an unexpected change in the market place demand.

Collaboration strategies need to include advanced methods in order to connect suppliers and buyers through information sharing (Park et al. 2010). In this sense, some collaboration and technological tools can be highlighted: Electronic Data Interchange (EDI); Efficient Consumer Response (ECR); Vendor Management Inventory (VMI); Collaborative Planning, Forecasting and Replenishment (CPFR) (Cohen and Roussel 2004; Park et al. 2010; Supply Chain Council 2006).

The IS enabled the coordination of operations in supply chain of separate organizations into a unified entity. One of the main purposes of IS aims to promote collaboration across organizational boundaries. There are several applications, some of them are aimed to customer relationship management; forecasting; inventory; transportation management; among other. Furthermore, it allows an exchange of data in multiple message types between the supplier and customer and also it allows partners to share planning data and requirements (Schary and Skjoett-Larsen 2001).

The potential of instantaneous communication distinguishes SCM from earlier supply systems. Thus, the emphasis in supply chain strategy is on physical product to be substituted for information wherever possible, such as coordination between stages to avoid excess inventory (Schary and Skjoett-Larsen 2001). In this sense, one of the most common problems of miscommunication is the bullwhip effect. Cannela et al. (2013), state that such effect has also been used to describe the distortion of information along the supply chain. This distortion represents a mismatch between consumption patterns and ordering patterns between any two entities in the chain.

Cannella and Ciancimino (2010) point out three configurations in SCM: (i) Traditional supply chain—the information flow consists in the mere transmission of members' orders upstream; (ii) Information exchange supply chain—the information flow consists on the transmission of members' orders in a up-stream direction and on sharing the information on market demand; and (iii) Synchronized supply chain—the information flow consists in the transmission of members' orders, inventory levels, work in progress levels, lead times and safety stock factors upstream, and in sharing the information on market.

In this context, Cannella and Ciancinmino (2010) studied the three supply chain configurations—Traditional, Information Exchange and Synchronised—and found that supply chain collaboration is able to mitigate the bullwhip effect, provide inventory stability, limit lumpy orders and improve customer service level. In addition, considering that there is substantial room for improvement in the assessment of bullwhip avoidance techniques, Cannella et al. (2013) proposed a performance measurement system for bullwhip analysis, which aggregate individual performance measures into a single index of overall performance.

4 Multicriteria Decision Aid—MCDA

The MCDA approach aims to provide decision makers with some tools to allow them to progress in solving decision problems, where several and often contradictory points of view should be taken into consideration. Brans and Mareschal (2005) state that according to our various human aspirations, it makes no sense, and it is often not fair, to select a decision based on one evaluation criterion only. In most cases, at least technological, economic, environmental and social criteria should always be taken into account. In addition, it cannot be said that, in general, one decision (solution, action) is better than another, even if it does not originate from all points of view. Therefore, the concept of optimization is not appropriate in the context of MCDA (Vincke 1992).

Usually, experts in MCDA split methods into three families: (i) the multi-attribute utility theory, (ii) outranking methods and; (iii) interactive methods (Vincke 1992). On the other hand, Roy (1996) calls them, respectively: (i) a single-criterion synthesis approach, which eliminates any incomparability; (ii) an outranking approach, which accepts incomparability and; (iii) an approach of Interactive Local Trial, which uses trial-error interactions. The differences among these approaches based on various authors are described in Table 1.

Basically, a multi-criteria decision problem consists of a situation, in which there are at least two action alternatives to be chosen from. The selection process occurs as a result of the desire to meet multiple objectives that often have conflicting relationships. These objectives have associated variables that represent them and allow each alternative to be evaluated based on each objective, which may be called criteria, attributes or dimensions (Vincke 1992; Roy 1996).

5 Decision Model for Selecting Partners to Share Information in Order to Avoid Bullwhip Effect in SCM

The model proposed in this section includes the MCDA modeling. Specifically, this proposition of partner's management in the context of information sharing to avoid Bullwhip effect model includes two main parts: Suppliers' Evaluation and Suppliers' Sorting, which can be visualized in the Fig. 1.

Table 1 Methods from MCDA approach

Methods	Description
Multi-attribute utility theory or single-criterion synthesis approach	It derives from the American School of thought, the decision maker's preferences for a particular alternative when evaluated by a set of criteria or indicators are aggregated into a single utility value, which is carried out in an additive manner (with trade-offs), it generates a score for each alternative based on performance criteria, so the best alternatives evaluated are those that obtain the best score (Almeida 2011). Among some methods of this approach can be cited the MAUT, SMART, TOPSIS, and AHP
Outranking	It is derived from the French school of thought, the main objective is the construction of binary relations that represent the decision maker's preferences based on the information available between criteria (without trade-offs) (Léger and Martel 2002). Through a pairwise comparison, there is an alternative which is superior in every criterion, establishing a relationship of overcoming the confrontation between two alternatives. The main methods of this approach are those from families ELECTRE and PROMETHÉE
Interactive local trial	These methods are mainly developed within the MOLP—Multi-Objective Linear Programming, which are characterized by possessing computational steps and be interactive, allowing trade-offs (Légel and Martel 2002). The methods seek an alternative that is clearly superior in all objectives set (dominant), which results in the aggregation of preferences of decision makers after mathematical calculations, interactive and successive evaluation of these solutions and, the possible change in the preference structure face the new available information. Some methods of this approach can be cited: STEM, TRIMAP, ICW, and PARETO RACE (Antunes and Alves 2012)

Source Adapted from Légel and Martel (2002), Almeida (2011) and Antunes and Alves (2012)

As it can be verified in Fig. 1, the part of Suppliers' Evaluation includes five steps, which can be established depending on the preferences structure of the decision maker. At this point it is possible: Identify the set of criteria (metrics) able to measure the attainment of objectives; Assign weights to criteria; Identify the rationality of decision maker; Identify alternatives of suppliers; Evaluate and analyze the (suppliers vs. criteria). After accomplish these five steps and depending on the rationality of decision maker, it will be applied a proper MCDA method, from any of the three approaches presented in Table 1.

It is important to point out that, depending on the rationality from the individual or group of decision makers, it is possible to aggregate the preferences in two ways:

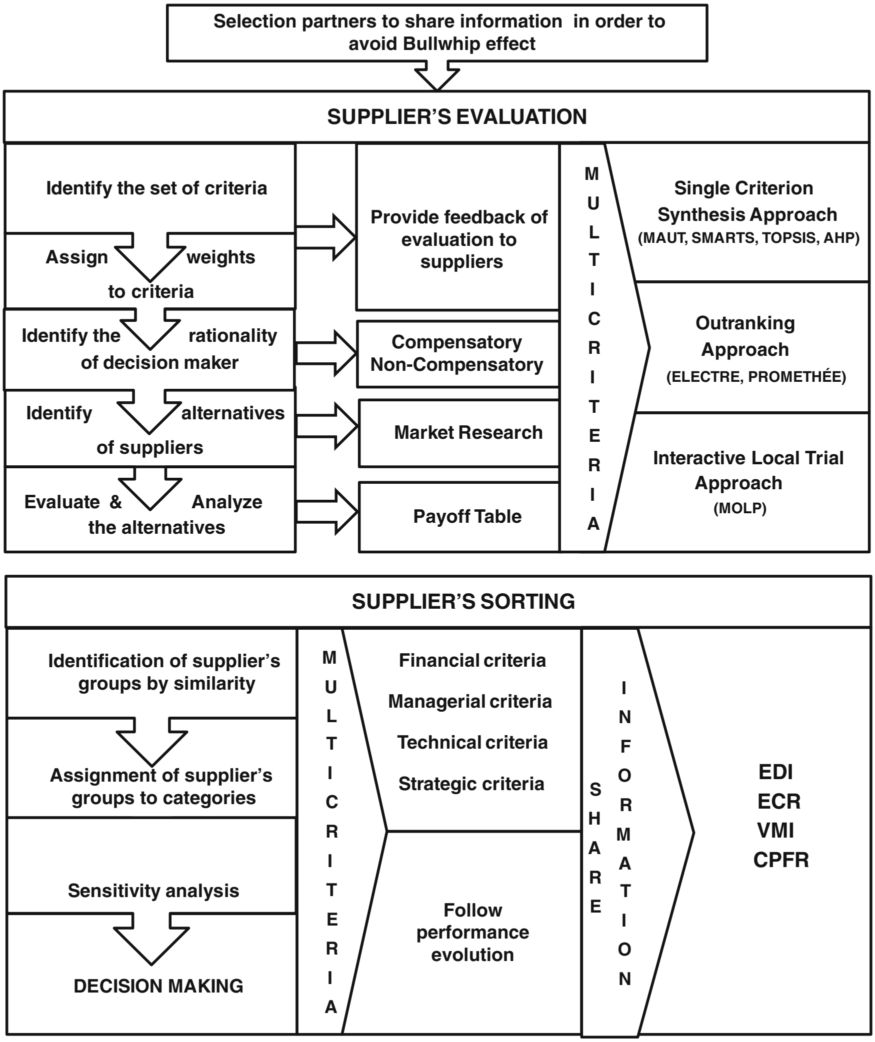

Fig. 1 Decision model. *Source* The author

(i) additive rationality (compensatory): allowing tradeoffs between criteria. For example, whether the supplier has a lower performance in quality it will be offset by a higher performance in cost, and (ii) Non-additive rationality (non-compensatory): do not allowing tradeoffs between criteria, which require that a supplier presents a satisfactory performance in all the criteria to be chosen. This rationality, according to Vincke (1992) provides more balanced solutions. The second part of the model covers the Suppliers' Sorting, which includes the application of the MCDA algorithm of the chosen method. The MCDA method will be able to identify differences and similarities among suppliers and assign them into groups, then into categories.

After the assignment process is done, it is possible to carry out an analysis of sensitivity, changing the values of some parameters to test the data entered in the model, and if the decision maker wishes, he can review some values.

Thus, with this model it is possible to manage suppliers in partnerships focused on information sharing to avoid the bullwhip effect. Besides that, the managers can identify partners' weaknesses and strengths in the set of criteria chosen, and provide them with an evaluation feedback in order to get some improvements in the performance. According to the performance of suppliers on a given set of criteria, the suppliers can be driven to different levels of collaboration, more extensive or more limited.

The model proposed in this article suggests a set of criteria to be used in the decision making regarding information sharing to avoid bullwhip effect, which are split in four groups, shown in Table 2.

The contribution of the proposed model lies in the fact of adding soft factors to usual criteria focused in financial and operational aspects, which are harder to measure and rely on "gut feel" of decision makers in relation to the partner. The criteria called 'soft factors' are mentioned by authors Ellram (1990) and Vieira et al. (2009), which published researches focused in partnerships and collaborative relationships. Similarly, in the model proposed it is suggested the adoption of categories, which were based in those proposed by Cohen and Roussel (2004). The categories were used in order to sort suppliers according their performance in the group of criteria, shown in Table 3. The Table 3 presents the categories and its description.

Considering the categories of collaboration presented in Table 3, the suppliers with a lowest performance in the set of criteria suggested for this model will be allocated in the category of Transactional Collaboration, able to collaborate more limited with the buyer company in terms of information sharing, through EDI; those assigned to Cooperative Collaboration, which presented satisfactory performance, will be able to share information in one way; at the level of Coordinated Collaboration, suppliers will be allocated for closest relationships, sharing information in two ways due to their better performance, and finally, the suppliers with the highest performance will be allocated to the category of Synchronized Collaboration, collaborating extensively with buyer company, generating strategic information conjointly. Moreover, it should be pointed out the flexibility of this model, which enables the decision maker to adapt the parameters and inputs of the method if necessary, adapting, for example, the criteria set and the categories according the reality of company's segment.

Thus, the decision maker can—besides following the performance of partners in the set of criteria proposed—give feedback to suppliers; share information; and adopt information systems and technologies more appropriated to each category of collaboration. In addition, it is important to emphasize that, according the evolution of performance; the partners can be moved up and down in the categories proposed, maximizing the value of the entire supply chain.

Table 2 Groups of criteria of model

Group	Criteria
Financial criteria	In this group the evaluation of suppliers' price is covered, which shall not exceed the average of estimates made by the company. Furthermore, it is considered also the financial stability from suppliers, in order to predict the future viability of partnerships. This group involves quantitative criteria that can include financial accounting and economic indexes and ability to track and target the market price. A partner who does not have financial stability will contribute to difficulties in the partnership, and probably cannot sustain their business for long term
	Criteria cost; financial stability; among others
Managerial criteria	This group involves supplier evaluation in terms of techniques and management tools that contribute to the continuity of business operations and ensure that the product and/or service will be delivered with the required quality, at the planned time and with the lowest cost to add value to entire supply chain. A partner who has no similarity between the company's managerial factors may compromise the final product, cause dissatisfaction and hence bottlenecks throughout the supply chain
	Criteria clients demands response; delivery; flexibility; geographical location; interactive demand forecasting; JIT capacity; processes management and organization; production capacity; quality; among others
Technical criteria	This group requires a review of current techniques and technologies from the supplier and its future technological capabilities. It also includes the ability to perform the routines quickly by using information systems and technologies.
	Criteria existing IS/IT; technological capacity; technical and organizational capacities; technical support; among others
Strategic criteria	In this group many aspects considered as soft factors (Ellram 1990) are involved. These factors are essential in long-term relationships because they analyze whether the supplier is able to work together with the buyer company and to honor the commitments made in the long term or not, besides the willingness to align their strategies with the buyer company to share information through IS/IT. A partnership is designed to be an ongoing relationship. Although the strategies may change over time, an initial adjustment between buyer and supplier in terms of strategic vision is a prerequisite for close and long term relationships
	Criteria innovation; information sharing; cooperation; compromising; trust; goals correspondence; joint actions; top management involvement; ease of inter-organizational communication; initiative; among others

Source The author

6 Numerical Illustration

In order to illustrate the proposed procedure, we present the application of the model, through a numerical application, considering the generic nature of the model.

Some criteria it was defined, as presented in Table 2 and 10 suppliers will be evaluated under a set of 8 criteria. Aiming to proceed with the evaluation it is

Table 3 Categories of the framework

	Categories	Description
Limited	Transactional	In this type of cooperative relationship, sophisticated information systems are rarely required, and thus partners do not share information extensively. This level of collaboration is the most basic and most used today. The risks are low and so are the returns
		Suppliers allocated in this level commonly need to be directed to development programs to improve their overall performance in the group of criteria suggested in this model
	Cooperative	This type of collaboration requires a higher level of information sharing. Also, the partners communicate in one way, in which data relating to sales forecasting, stock availability, purchase orders and delivery status are sent manually or electronically, from one partner to another
		Supplier in this level can share information through EDI, Internet and Extranet
	Coordinated	At this level, partners work more closely and need to trust in the capabilities of each other, which require a two-way information flow, besides synchronized planning and well-structured execution processes. This type of collaboration is reserved for strategically critical partners. Due to its strategic nature, this type of relationship requires proprietary systems to information sharing and a long-term commitment
		Suppliers in this level can share information through VMI and JMI
Extensive	Synchronized	This is the highest level of collaboration and goes beyond the operations in the supply chain to include other business processes. Partners can jointly invest in R&D for new projects, new products, new technologies, development of industrial property etc. The sharing of intellectual and physical assets is intense and this relationship is also known as a strategic alliance. The information in this case is jointly developed and not only transmitted and shared, which requires a strategic vision, besides reliable and long term relationships
		Suppliers in this level can share information through ECR and CPFR

Source Adapted from Cohen and Roussel (2004, p. 144–147)

necessary to compare each supplier under each criterion through a Likert scale with five levels, in which 1 represents the lower level and 5 the upper level.

Moreover, it is necessary to define the weights of criteria, which can be distributed in a scale ranging from 0 to 1 (in real applications the assignment of weights is made by decision maker, in this numerical application these are random values), which means that some criteria can be more important to the decision maker than the other. Based on this information, the payoff table with weights can be verified in Table 4.

Table 4 Payoff table of alternatives versus criteria

Alternatives	Criteria							
	C1	C2	C3	C4	C5	C6	C7	C8
Weights	0.11	0.11	0.11	0.11	0.11	0.15	0.15	0.15
Supplier 1 (S1)	4	3	4	5	4	5	2	5
Supplier 2 (S2)	4	4	5	3	5	4	5	4
Supplier 3 (S3)	5	5	5	3	3	4	4	5
Supplier 4 (S4)	1	3	2	1	2	2	3	2
Supplier 5 (S5)	2	1	3	2	2	1	2	1
Supplier 6 (S6)	5	2	4	1	3	1	1	2
Supplier 7 (S7)	4	2	4	3	4	4	4	3
Supplier 8 (S8)	3	4	1	4	3	3	3	4
Supplier 9 (S9)	2	3	1	1	1	3	2	3
Supplier 10 (S10)	1	2	3	2	1	1	1	2

As can be verified in Table 4, the criteria: C1—cost; C2—quality; C3—delivery; C4— technological capability and C5—glexibility have the same importance to decision makers, then the weights assigned are the same, however C6—correspondence of goals; C7—Top management involvement and; C8—Trust; were considered more important than the other criteria as reflected by the larger weights assigned. This greater importance is due to the strategic nature of information sharing in automotive industries and the consideration of soft factors in this decision context.

Thus, after evaluate suppliers versus criteria it is possible to obtain the following results.

The assignment of suppliers to categories (presented in fourth and fifth columns of Table 5), it was made by Electre Tri method, which was considered more appropriate for the problem related in this numerical application, considering the hypothesis: (i) the handling of qualitative and quantitative criteria; (ii) the sorting of supplier in an ordinal way and; (iii) the non-compensatory aggregation procedure.

The process of an ordinal sorting is reinforced by the determination of the cutoff level (λ), which becomes the assignment processes more or less stringent in two perspectives: pessimistic or optimistic, depending on the profile of the decision maker, respectively more or less severe. It should be emphasized that the cutoff level can vary from 0.5 to 1.0. For the purpose of this numerical application it was assigned a value of $\lambda = 0.76$, which is considered moderated.

Table 5 Assignment of suppliers to categories

Categories	Upper limit	Lower limit	Alternatives	
			Pessimistic	Optimistic
Transactional	2.0	–	S10, S9, S6, S5	S5, S10
Cooperative	3.0	2.01	S4	S4, S9
Coordinated	4.0	3.01	S1, S7, S8	S7, S8
Synchronized	–	4.01	S2, S3	S1, S2, S3

The categories were ordered from the worst (Transactional Collaboration), to the best (Synchronized Collaboration), which means that the suppliers with low performance in the set of criteria will be allocated to Transactional Collaboration, which will share information limitedly with buyer company and can be driven to development programs of suppliers aiming improve their performance; those with a moderated performance will be assigned to Cooperative Collaboration, in which will be able to collaborate, sharing information in one-way with the buyer company through EDI, Intranet e Extranet; those with satisfactory performance will be allocated to Coordinated Collaboration, in which will be able to collaborate related to information sharing in two-way with buyer company through VMI and; finally, those with upper performance will be assigned to Synchronized Collaboration, which can collaborate more extensively with buyer company creating information conjointly through CPFR.

This model can be used permanently for the Buyer Company in order to follow the performance of suppliers chosen by partnerships, giving feedback to suppliers regarding their performance. Also, this process can be performed assessing the performance of each supplier periodically. Furthermore, considering that in the roll of company's suppliers there are those with varied performances, it is applicable adopt different strategies for each group. Thus, allocating suppliers in categories according its performance, it is possible to point out these differences in order to know the full capacities of partners and adopt different strategies to share information with each category.

7 Concluding Remarks

The model proposed constitutes an useful tool as a decision aid for partners, management in the context of information sharing, contributing to avoid the bullwhip effect. Many strategic decisions in the context of SSP are taken considering only the experience and feelings from managers, without systematized frameworks. Besides that, many decisions in this context take into account only financial and operational aspects. In this sense, the model proposed contributes when considering well-defined steps, including the MCDA approach, in order to aggregate the preferences from the decision maker.

Furthermore, the model differentiates from those proposed in the literature on supplier selection, once it is focused on collaborative relationships regarding information sharing through IS/IT. Besides, it considers multiple criteria and includes soft factors more appropriated to strategic relationships with partners in SCM; such issue was not approached properly yet in the context of partnerships under an MCDA perspective.

Moreover, it systematizes the partners' selection regarding information sharing in order to avoid the bullwhip effect, including well defined steps, such as: evaluation, sorting, performance control and evaluation feedback, to provide aid to managers in decision making process. Therefore, by including these concepts on their business, companies reduce the risk of sharing information with an inappropriate supplier, besides avoiding deficiencies in the visibility and control of their supply chain.

Besides that, adopting strategic partnerships, companies can: (i) avoid the consequences of bullwhip effect; (ii) provide inventory stability, (iii) limit lumpy orders and (iv) improve customer service level.

References

Almeida AT (2011) O Conhecimento e o Uso de Métodos Multicritério de Apoio a Decisão (The knowledge and use of multi criteria decision aid methdos). Editora Universitária da UFPE, Recife

Antunes C, Alves M (2012) Programação linear multiobjetivo-métodos interativos e software. (Multiobjective linear programming—interactive methods and software). Anais do Congreso Latino-Iberoamericano de Investigación Operativa, 24 a 28 de Setembro, Rio de Janeiro. 4725–4736

Araz C, Ozfirat PPM, Ozkarahan I (2007) An integrated multi criteria decision-making methodology for outsourcing management. Comput Oper Res 34(12):3738–3756

Bagchi PK, Ha B, Skjoett-Larsen T, Soerensen LB (2005) Supply chain integration: a European survey. Int J Logistics Manage 16(2):275–294

Bozarth CC, Handfield RB (2008) Introduction to operations and supply chain management. Pearson Education Inc., New Jersey

Brans JP, Mareschal B (2005) Promethee methods. In: Figueira J, Greco S, Ehrgott M (eds) Multiple criteria decision analysis: state of the art surveys. Springer Science and Business Media Inc., New York, pp 163–196 (cap. 5)

Cannella S, Ciancimino E (2010) On the bullwhip avoidance phase: supply chain collaboration and order smoothing. Int J Prod Res 48(22):6739–6776

Cao M, Zhang Q (2010) Supply chain collaborative advantage: a firm's perspective. Int J Prod Econ 128:358–367

Ciancimino E, Cannella S, Bruccoleri M, Framinan JM (2012) On the bullwhip avoidance phase: the synchronised supply. Eur J Oper Res 221(1):49–63

Cannella S, Barbosa-Póvoa AP, Framinan JM, Relvas S (2013) Metrics for bullwhip effect analysis. J Oper Res Soc 64:1–16

Claycomb C, Frankwick G (2010) Buyers' perspectives of buyer–seller relationship development. J Ind Mark Manage 39(2):252–263

Cohen S, Roussel J (2004) Strategic supply chain management: the five disciplines for top performance. McGraw-Hill, New York

Dulmin R, Mininno V (2003) Supplier selection using a multi-criteria decision aid method. J Purchasing Supply Manage 9(4):177–187

Ellram LM (1990) The supplier selection decision in strategic partnerships. J Purchasing Mater Manage 26(4):8–14

Krajewski L, Ritzman L, Malhotra M (2009) Operations management: processes and supply chains. Prentice Hall, New Jersey

Lambert DM (2008) Supply chain management: processes, partnerships, performance. SCM Institute, Sarasota

Léger J, Martel JM (2002) A multi criteria assignment procedure for a nominal sorting problematic. Eur J Oper Res 138(2):349–364

Moharana HS, Murty JS, Senapati SK, Khuntia K (2012) Coordination, collaboration and integration for supply chain management. Int J Interscience Manage Rev 2(2):46–50

Park J, Shin K, Chang TW (2010) An integrative framework for supplier relationship management. Ind Manage Data Syst 110(4):495–515

Pi WN, Low C (2005) Supplier evaluation and selection using Taguchi loss functions. Int J Adv Manuf Technol 26(1–2):155–160

Roy B (1996) Multi criteria methodology for decision aid. Kluwer Academic Publishers, Netherlands

Schary PPB, Skjoett-Larsen T (2001) Managing the global supply chain, 2nd edn. Copenhagen Business School Press, Copenhagen

Skjoett-Larsen T, Thernře C, Andresen C (2003) Supply chain collaboration: theoretical perspectives and empirical evidence. Int J Phys Distrib Logistics Manage 33(6):531–549

(2006) SCC—Supply Chain Council. Model SCOR 8.0, Available at http://supply-chain.org/. (Acessed 10 June 2011)

Towill DR, Zhou L, Disney SM (2007) Reducing the bullwhip effect: looking through the appropriate lens. Int J Prod Econ 108(1–2):444–453

Vieira JGV, Yoshizaki H, Ho L (2009) Collaboration intensity in the Brazilian supermarket retail chain. Int J Supply Chain Manage 14(1):11–21

Vincke P (1992) Multi criteria decision-aid. Wiley, New York

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Part IV
Decision Models in Energy and Water Industry

Multicriteria Decision Models in Industrial Energy Management Systems

Antonio Vanderley Herrero Sola and Caroline Maria de Miranda Mota

Abstract Due to the complexity of processes and energy flow in industries, energy management systems play an important role in order to provide guidance to improve energy performance in industrial energy systems, regarding organisational barriers for energy efficiency improvement. Industrial processes are characterized by diverse actors and several criteria (technical, economical, etc.) resulting in a complex decision-making process. Therefore, multicriteria decision models are important tools to support decision makers in energy management systems. A decision model was applied to industrial motor systems using the PROMETHEE II method in order to sort technologies to be replaced. The results present a complete ranking of technologies taking into account the organisation concerns. This contributes for the transposition of some organisational barriers. The work recommends the application of decision model in organisations in order to support decision makers in Energy Management Systems to improve the energy performance.

Keywords Energy management system · Multicriteria model · Industrial energy systems

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1 Introduction

The industrial sector consumes about 30 % of the global final energy, and it is responsible for a high level of gas emission on the planet (IEA 2014). Some countries present higher energy consumption. In Brazil, for instance, the industrial sector consumes almost half of the electricity produced (EPE 2013). In fact, high energy consumption does not necessarily mean inefficiency. However, high power consumption in industries is usually accompanied by a certain potential for improving the efficient use of energy. This potential depends on the level of obstacles presented in organisations. Even with large potential for profitable investments in energy efficiency, these actions may not occur due to internal barriers within organisations, characterizing the phenomenon called *efficiency paradox* (DeCanio 1998).

Several barriers for efficient use of energy have been classified by the literature into the following typology (Weber 1997): institutional; market; organisational; and behavioural. In this work, the main focus is organisations, especially the industrial sector. Industries are differentiated from other sectors due to the technical, economic and behavioural complexity of the organisational structure, and this complexity strongly influences the use of energy. A company has several sectors, such as purchasing, production, finance, engineering and maintenance, and each sector has their own goals and concerns. The use of energy impacts on all these sectors and; therefore, the decision-making process is characterized by various actors and multiple criteria (Lung et al. 2005; McCoy and Douglass 2000; Wang et al. 2009). In this context, energy management system appears as a way to transpose organisational barriers for energy efficiency improvement (Johnson et al. 2014).

Currently, the international standard ISO 50001 specifies requirements for energy management systems. In the production process, there are several criteria to be observed aiming to improve energy performance. Some multicriteria decision models have been proposed by the literature in order to contribute to the improvement of the efficient use of energy in industrial systems. This work initially describes a decision-making approach to the energy management system aiming to show the applicability of multicriteria decision models in manufacturing environments. In the sequence, a multicriteria decision model is presented and applied in an industry.

2 Literature Review

2.1 Organisational Barriers

The existence of several barriers for energy efficiency has been highlighted in the literature. A survey carried out in industries revealed that barriers for improving the energy efficiency are related to the following organisational areas: management system; employees' education and strategic vision (Sola and Xavier 2007). Financial, economic and behavioural are the main barriers for energy efficiency improvements highlighted by Nagesha and Balachandra (2006). High investment costs appear as a barrier for the adoption of energy efficiency measures by small- and medium-sized enterprises, according to Fleiter et al. (2012). A study shows that barriers are related to capital availability as well as information (Venmans 2014). The study concludes that capital budgeting rules and analysis of feasibility and profitability are important actions towards energy efficiency. Among the organisational barriers which influence other barriers are as follows: lack of awareness for the efficient use of energy; lack of education and training in the energy area; lack of information and technological support to improve the energy efficiency in organisations (Wang et al. 2008).

In a company, the main focus is on the production area, not on energy efficiency, as pointed out by McKane et al. (2007). A study carried out by Hasanbeigi et al. (2010) shows that management concern with production rather than energy efficiency is the key barrier for improvement of energy efficiency in industries. An important barrier to the implementation of energy efficiency improvement measures in the manufacturing area is related to the concern with costs and risks associated with production disruptions (Rohdin and Thollander 2006). This concern should be taken into account in the decision-making process linked to energy management.

According to Worrel et al. (2001), some barriers for technology transfer in companies are linked to the decision-making process. An organisation can be viewed as a social system influenced by goals, routines and organisational structures and dominated by decision makers, in which environment asymmetry of information can be a barrier for energy efficiency (Weber 1997). Asymmetry of information occurs when information is not disseminated among the sectors. In addition, the decision maker may not have all knowledge and the necessary information about the opportunities for energy savings, costs and benefits (Tonn and Martin 2000). Therefore, the quality of information can hardly influence the quality of decision-making.

2.2 Energy Management Systems

Energy management practices are relevant and should be considered in order to reach energy-saving targets for the next decades, according to Backlund et al. (2012). The international standard ISO 50001—Energy Management Systems—Requirements with guidance for use—is based on continual improvement (Plan-Do-Check-Act) and was developed to help organisations to improve energy performance by means of establishing necessary systems and processes (ISO 2011). Regarding the process and energy flow complexity in industries, the energy performance shall be precisely determined, requiring a specific approach integrated with the Energy Management System (Giacone and Mancò 2012).

Properly implemented, the international standard can be a way to transpose organisational barriers for energy efficiency (Johnson et al. 2014). The standard can be integrated with other standards (e.g. ISO 9000 and ISO 14000) within the organisation; however, this integration with operational procedures is a big challenge (Dörr et al. 2013; Gopalakrishnan et al. 2014). In order to implement the standard, the organisation can create an energy management system team which should include the company main areas. According to the international standard for Energy Management Systems, 'representative areas may include but are not limited to purchasing, accounting, engineering, design, production, maintenance, facilities management, environmental and external service providers'.

According to ISO 50001, the top management must demonstrate commitment and support to the Energy Management System in terms of energy policy, resources, ensuring energy performance, etc. Normally, energy has no strategic importance in companies and the way to put energy management on the strategic agenda is a centralized energy planning, according to Rudberg et al. (2013). Without a strategic vision, energy utilization is treated in the short term and other concerns are prioritized in decision-making instead of energy.

As for energy planning, the standard recommends that the organisation must develop, maintain and record an energy profile, including identification and prioritization of opportunities to improve energy performance. On the subject of implementation and operation, the standard establishes that, when purchasing energy services, products and equipment with significant energy use, the organisation should inform suppliers that energy efficiency is evaluated.

Nowadays, the literature presents some multicriteria models which are employed in Energy Management Systems with the aim to help managers and practitioners to deal with energy issues. In accordance with the international energy standard, some decision models have been proposed in the literature to evaluate and select current energy resources—such as electricity, coal, and gas—in manufacturing industries using the *ANP* method (Önüt et al. 2008); to determine the inspection interval of condition monitoring in maintenance management using *MAUT* (Ferreira et al. 2009); to select space heating systems in industrial plant using the *AHP* method (Chinese et al. 2011); to rank alternatives for technologies replacement using the *PROMETHEE* method (Sola et al. 2011) or *MAUT* (Sola and Mota 2012); to identify opportunities for managing energy and utility usage in manufacturing processes using *Soft System methodology—SSM* (Ngai et al. 2012); and to select green suppliers using *Fuzzy TOPSIS* method (Kannan et al. 2014). The main methods in decision processes are presented in the next section.

2.3 Decision Analysis Methods

Based on foundations of Operational Research, a decision process occurs according to the following phases (Ackoff and Sasieni 1971):

- *Structuring the problem*—description of objectives, identification of alternatives, recognition of limitations, and restrictions and requirements of the system.
- *Construction of the model*—the model is built using a suitable approach and method.
- *Solution of the model*—the model is applied to find the solution.
- *Validation of the model*—the model is compared with expected results.
- *Implementation of solution*—The solution is implemented.

Regarding the complexity and the dynamic nature of reality within the organisational environment, the decision-making process may face uncertainty and conflict. A proper class of methods is recommended to structure complex problems. The specific literature (Rosenhead and Mingers 2001) has highlighted the following problem structuring methods: strategic option development and analysis (*SODA*); soft system methodology (*SSM*); strategic choice approach (*SCA*); and robustness analysis (*RA*). These methods can help organisations to tackle serious problems and can be used integrated with other methods.

Regarding multidimensionality and complexity of systems, multicriteria decision analysis has been highlighted by the literature in order to aid sustainable energy decision-making (Wang et al. 2009). Sometimes the decision-making process faces an environment of vagueness information and the fuzzy logic is a precise logic of imprecision to deal with the fuzzy world, according to Zadeh (2008). In this context, the fuzzy approach has been widely employed and integrated with multicriteria methods. According to Roy (1996), multicriteria methods are classified according to the approach used, as follows.

(a) *Interactive local judgment*

This class of methods employs interactive approach to discover options to achieve the decision maker's desirable goals or aspirations. The literature (Alves and Climaco 2007) highlights several interactive methods, characterized by human intervention alternated with phases of computation.

(b) *Unique synthesis criterion*

This approach consists of bringing together different points of view into a single synthesis (additive) function. The following methods are highlighted: *MAUT*—multi-attribute utility theory—developed by Keeney and Raiffa (1976); *AHP*—Analytical Hierarchy Process—and *ANP*—Analytical Network Process—developed by Saaty (1990, 1996); *TOPSIS*—Technique for Order of Preference by Similarity to Ideal Solution—proposed by Hwang and Yoon (1981). This class of methods is indicated in the case of compensatory criteria, when high evaluation of one criterion is compensated for lower evaluation of another criterion.

(c) *Outranking*

The outranking methods are indicated in the case of conflicting criteria, when high evaluation of one criterion is not compensated for lower evaluation of another criterion. First of all, the outranking methods use pairwise relations to compare actions, identifying preferences for one over the other. The second step consists of aggregating the preferences in order to solve the decision maker's problem. In this class, two families of methods have been used. The first family is *ELECTRE—Elimination and Choice-translating algorithm*—initially developed by Roy (1996) at University of Paris, Dauphine. The second family is *PROMETHEE—Preference Ranking Organization Method for Enrichment Evaluations*—firstly proposed by Brans and Mareschal (2005) from the Free University of Brussels. These methods have been applied to diverse areas, according to the literature (Behzadian et al. 2010; Wang et al. 2009).

3 The Multicriteria Decision Model

The multicriteria decision model here presented follows the *bottom-up* principle, which consists of evaluating initially the industrial plant, considering the technologies required to reach the demand, with implications on the use of energy and costs (Rivers and Jaccard 2006). Obviously, any action inside the firm depends on top management commitment. Observing this requirement, the analyst meets with all sectors of the industry, including the decision maker, in order to formulate de problem and to stablish the model of preferences. At this stage, the analyst leads the process to establish the problem and to clarify the goal, emphasizing the importance of all sectors in order to define all parameters of decision (criteria, weight and other parameters) by means of group consensus. The main sectors of the plant and the main technologies to be studied are defined. The group indicates the persons who are responsible for providing the data obeying a previously established schedule.

In the data collection phase, the main information is provided. Energy information is collected by an energy audit, using equipment and measurements nominal data. Costs, financial and other information on energy efficient technologies are obtained in the market. The analyst chooses and applies the multicriteria method to sort technologies to be purchased. Regarding the diversity of goals and concerns among the sectors involved in the decision process, which are subject to conflicting criteria, the outranking approach is recommended. As the goal is to sort technologies, PROMETHEE II or ELECTRE II could be chosen. Finally, the recommendation is made for the decision-making. The model is represented in Fig. 1.

4 Application in Industry

4.1 Modelling of Preferences

Following the model previously presented, the modelling of preferences was carried out in a Brazilian industry. Initially, the analyst met the decision maker and managers as well as with the company sector representatives—engineering, maintenance,

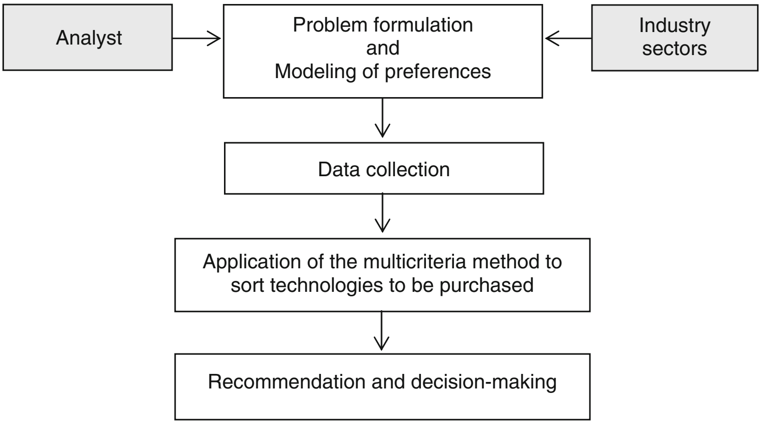


Fig. 1 Decision model to sort technologies

production, purchasing and financial—to clarify the purpose of the project and to define criteria, weights and threshold in a consensual way. The company defined to prioritize some electric motors to be replaced for more energy efficient ones. The industry consumed about 130 MWh per month, and the power consumed by the electric motor system represented about 80 % of the electricity consumed by the plant.

The 'electric power' was the most important criterion defined by the stakeholders, since the large electric motors operated in strategic processes, and this criterion (C1) was assigned the weight 100. Comparatively, the weights were assigned to other criteria, according to the preference level: C2 = 80; C3 = 60; C4 = 50; C5 = 50; C6 = 40; and C7 = 20. As for the criterion 'importance for production', the values received from the sectors varied from zero (least important) to 10 (most important). The 'number of rewinds' indicated how many times the motors suffered burning process, usually by overheating. The 'number of failures' showed abnormalities in the motors causing stops. The criterion 'net present value' was defined as the present value of a time series of cash flows and indicated the profitability of the project. As the low rated loads contributed for the increase in energy losses, the criterion 'motor rated load' was linked to the level of energy losses. The sectors found that the criterion 'motor age in duty' of the engine was important, but to a lesser degree, since a preventive maintenance proper process could reduce losses and extend the equipment operating life. The criteria, preference functions, threshold and the normalized weights are presented in Table 1.

The *net present value (NPV)* is a measure of the expected value of an investment and could be used comparatively in motor system project besides other criteria (Lung et al. 2005; McCoy and Douglass 2000). Considering a fixed *energy saved value (ESV)* and the *motor investment value (MIV)*, the *NPV* formula uses the motor lifetime in years (n) and the effective interest rate (i) and can be calculated using Eq. 1

Table 1 Parameters of decision

Criteria	Preference function	Weights norm	Preference threshold (p)	Indifference threshold (q)	Min or Max
C1—Electric power	V-Shape	0.250	45	0	Max
C2—Importance for production	Linear	0.200	5	1	Max
C3—N° of rewinds	V-Shape	0.150	5	0	Max
C4—N° of failures	V-Shape	0.125	1	0	Max
C5—Net present value	Usual	0.125	–	–	Max
C6—Motor rated load	Linear	0.100	75	5	Min
C7—Motor age in duty	Linear	0.050	10	1	Max

$$\mathrm{NPV} = \mathrm{ESV} \cdot \left[\frac{(1+i)^n - 1}{i \cdot (1+i)^n}\right] - \mathrm{MIV}\,[\$] \tag{1}$$

Considering the *quantity of energy saved (QES*) and the cost per kilowatt-hour (C), the *energy saved value (ESV)* is given by Eq. 2:

$$\mathrm{ESV} = \mathrm{QES} \cdot C\,[\$/\mathrm{year}] \tag{2}$$

The *QES* is calculated by Eq. 3 (McCoy and Douglass 2000):

$$\mathrm{QES} = 0.746 \cdot P_{\mathrm{HP}} \cdot \gamma \cdot t \cdot \left(\frac{1}{\eta_L} - \frac{1}{\eta}\right)\,[\mathrm{kWh/year}] \tag{3}$$

where

P_{HP}	Output power
t	Operation time (h/year)
γ	Rated load—per cent of rated output (%)
η_L	Low efficiency—Eq. 4 (%)
η	Efficiency of new motor given by manufacturer (%)
1 Wh	3,600 J (SI)

The low efficiency is the relation between output power and input power, including energy losses (Kosow 1991) and is determined through Eq. 4.

$$\eta_L = \frac{P_{\mathrm{out}}}{P_{\mathrm{in}}} = \frac{0.746 \cdot P_{\mathrm{HP}} \cdot \gamma}{P_R} \tag{4}$$

where

P_{HP}	Nominal output power [HP]
P_R	Real input power—measured [HP]
1 HP	746 W = 0.746 kW (SI)
γ	rated load [%]
η_L	Low efficiency [%]

Among the ways to improve energy efficiency in motor systems, the replacement of a low-efficient motor for a high efficient one is recommended (McCoy and Douglass 2000; Russel 2005; Sola and Xavier 2007). Before the determination of energy saving, it is necessary to know the real values of load and efficiency of each motor. The mathematical model used for estimating the motor load presented a 99.3 % correlation coefficient with real motor curves (Sola and Xavier 2007). From real measured current (I_R), nominal current (I_N) given by the manufacturer and no load current (I_o), measured or given by the manufacturer, the real load (γ) was determined according to Eq. 5.

$$\gamma = 1 + \frac{1}{\alpha} \ln\left(\frac{I_R}{I_N}\right) \tag{5}$$

where the load current parameter is calculated by Eq. 6:

$$\alpha = -\ln\left(\frac{I_0}{I_N}\right) \tag{6}$$

4.2 Data Collection

The stakeholders established that the study should be carried out in 20 electric motors which worked 8,640 h/year. The nominal data speed (rpm), no load current (Io), full load current (I_N) and the efficiency (η_N) were supplied by the manufacturer. Each motor measurements were taken in order to determine the real electric current (I_R) and the real electric power consumed (P_R) by means of a precision instrument. The values of investment in electric motors with premium efficiency (η_A) were obtained in the Brazilian market. It is important to emphasize that not all electric motors operate at full load; therefore, the real efficiency of the motors varies according to a curve as a function of rated load. Data is shown in Table 2.

Table 2 Electric motor data

	Nominal values				Measured values			Premium efficiency motors	
Motor	Speed	I_o	I_N	η_R		I_R	P_R	η_A	Investim.
	(rpm)	(A)	(A)	(%)		(A)	(W)	(%)	($)
M1	3,480	7.0	16.0	77.0		8.4	2,131	80.0	1,870
M2	3,520	8.4	21.4	87.8		17.5	10,068	91.5	2,100
M3	1,760	8.4	18.5	84.0		9.6	1,887	84.9	1,900
M4	1,760	8.4	18.5	84.0		8.4	2,220	86.0	1,900
M5	3,550	24.3	69.5	92.2		59.0	33,983	94.0	7,050
M6	1,720	5.8	11.7	82.0		7.4	2,320	87.5	1,580
M7	1,765	12.2	30.9	90.2		26.5	13,729	93.4	2,640
M8	1,740	6.0	11.6	90.0		11.4	6,092	91.0	1,580
M9	3,485	2.9	7.4	75.0		2.9	995	77.0	1,220
M10	3,500	4.4	10.7	76.0		5.0	1,767	80.0	1,530
M11	1,760	8.4	18.5	85.0		8.5	3,291	86.0	1,900
M12	3,530	7.0	14.7	75.0		7.9	1,691	76.0	1,870
M13	3,530	17.4	41.7	90.2		27.0	12,406	92.4	4,100
M14	1,770	20.8	57.6	91.7		60.0	33,843	94.4	5,540
M15	1,765	8.1	15.0	83.0		9.9	2,876	87.0	1,790
M16	3,500	4.4	11.1	86.0		8.6	4,684	88.0	1,530
M17	3,500	4.6	11.6	87.0		8.7	4,437	88.0	1,530
M18	3,500	4.6	10.9	88.5		8.9	4,805	89.5	1,530
M19	1,730	6.4	15.0	82.0		7.6	1,910	84.0	1,790
M20	3,485	3.0	7.5	80.0		4.4	1,958	84.0	1,220

4.3 Multicriteria Method Application

The analyst chose the PROMETHEE II to rank the electric motors to be replaced. The method is clear and understandable. In addition, the deviation between two actions on a particular criterion is automatically taken from a previously determined mathematical function. Furthermore, the low level of interaction with the decision maker reduces the uncertainty and the use of precious time for modelling. Specific software might be used in order to obtain the results (http://www.d-sight.com or http://www.promethee-gaia.net).

After definition of all criteria $F = \{g_1, g_2, \ldots g_j, \ldots, g_n\}$ by stakeholders, the weight w_j for each one was established by the decision maker. Some techniques can be used to establish the weights for criteria (Figueira and Roy 2002). The higher the weight is, the more important the criterion is Brans and Mareschal (2005). Considering normalized weights, $\sum_{j=1}^{k} w_j = 1$. Each criterion can be maximized or minimized.

Let $M = \{m_1, m_2, m_3, \ldots, m_n\}$ be a finite set of motors (actions) to be analysed, F a coherent family of criteria and $g_j(m_1)$ the evaluation of the motor m_1 on jth criterion. The preference structure of PROMETHEE II method is based on pairwise comparisons. Thus, the deviation (d) is the difference between the evaluation of two motors and is given by the following formula: $d(m_1, m_2) = g_j(m_1) - g_j(m_2)$. The preference threshold (p) is the smallest deviation above which there is a strict preference by the decision maker, while the indifference threshold (q) is the largest deviation below which there is no preference of one alternative over another. The larger the deviation is (d), the greater the preference is (P). The deviation depends on the preference function established by the decision maker.

Figure 2 shows an example of preference function. Six types of preference functions were proposed by Brans and Mareschal (2005): usual, U-shape, V-shape, V-shape with indifference, Level and Gaussian.

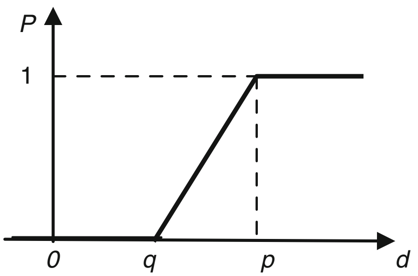
$$P(d) = \begin{cases} 0 & d \le q \\ \frac{d-q}{p-q} & q < d \le p \\ 1 & d > p \end{cases}$$

Considering two motors m_1 and m_2, belong to a set M of motors, the preference function P and the weight w for each criterion j and the preference aggregation indices are given by Eq. 7.

$$\pi(m_1, m_2) = \sum_{j=1}^{k} P_j(m_1, m_2) \cdot w_j \tag{7}$$

Regarding n motors, the positive outranking flow indicates how the motor m_1 outranks all the others (x) and is expressed by Eq. 8. The negative outranking flow indicates how the motor m_1 is outranked by all the others and is determinate by Eq. 9.

$$\phi^+(m_1) = \frac{1}{n-1} \sum_{x \in A} \pi(m_1, x) \tag{8}$$



$$P(d) = \begin{cases} 0 & d \le q \\ \dfrac{d-q}{p-q} & q < d \le p \\ 1 & d > p \end{cases}$$

Fig. 2 V-shape with indifference criterion or linear (Brans and Mareschal 2005)

$$\phi^{-}(m_1) = \frac{1}{n-1}\sum_{x \in A} \pi(x, m_1) \quad (9)$$

The PROMETHEE II is a complete ranking of actions, considering all comparable alternatives and the net flow, according to Eq. 10. As for the preference (P) and indifference (I) between two motors, m_1Pm_2 if and only if $\phi(m_1) > \phi(m_2)$ and m_1Im_2 if $\phi(m_1) = \phi(m_2)$.

$$\phi(m_1) = \phi^{+}(m_1) - \phi^{-}(m_1) \quad (10)$$

When the parameters are established, a certain level of uncertainty is presented. Thus, sensitivity analysis plays a decisive role and can be applied to determine the way the solution behaves when the estimated parameters change (Wolters and Mareschal 1995). Another analysis is done by means of Geometrical Analysis for Interactive Assistance (GAIA), an important tool that aims to give information about the relationship between criteria and alternatives (Brans and Mareschal 2005). The criteria defined by the stakeholders are arranged in an evaluation matrix (Table 3).

Table 3 Evaluation matrix

Motors	C1 (HP)	C2 (note 0–10)	C3 (quant.)	C4 (quant./year)	C5 ($)	C6 (%)	C7 (years)
M1	10	5	2	1	8,872	22	5
M2	15	5	1	0,5	52,440	79	5
M3	12.5	10	0	0	859	17	2
M4	12.5	10	0	0	5,039	20	2
M5	50	10	0	0	78,104	84	2
M6	7.5	10	5	1	18,017	34	40
M7	20	5	0	0	60,574	83	5
M8	7.5	8	0	0	7,328	98	4
M9	5	7	1	0,5	2,252	20	7
M10	7.5	9	1	0,5	10,342	24	10
M11	12.5	10	0	0	3,243	30	1
M12	10	10	0	0	1,120	17	1
M13	30	10	0	0	34,975	50	1
M14	40	10	2	1	122,638	104	4
M15	10	8	2	1	15,981	32	7
M16	7.5	5	2	1	12,777	72	1
M17	7.5	9	0	0	5,247	69	10
M18	7.5	8	0	0	5,685	76	7
M19	10	7	0	0	4,323	21	8
M20	5	7	1	1	11,312	42	7

4.4 Results and Analysis

In multicriteria analysis, there is no action which is better than any other, and consequently, there is no such thing as an optimal solution (Vincke 1992). In fact, the decision maker is interested in the *NPV*, but simultaneously in the importance for production and so on. Therefore, the motors can be substituted following the ranking, in accordance with the company's available resources. Another point is that the technical area can fit the electric motor to load, if necessary, when the new motor is purchased. Table 4 presents the final ranking, where the net flow (Φ) is determined by the difference between the positive flow (Φ^+) and the negative flow (Φ^-).

Sensitivity analysis was carried out varying the weights of criteria from 5 % up to 15 %. The positions in the ranking remained the same for the majority of the motors. Inversions were observed only between the following positions: 1 and 2; 4 and 5; 14, 15 and 16. As the company can change more than one electric motor simultaneously, the decision model can be considered stable.

Information given by the GAIA plane is the relationship among criteria, considering them as vectors and analysing their directions. Two criteria might be defined as: dependent if their directions are coincident; independent if orthogonal; and conflicting if opposites (Brans and Mareschal 2005). The GAIA plane with 73.5 % preserved information is shown in Fig. 3. The decision axis (between C3

Table 4 Complete ranking of motors

Ranking	Motor	Φ	Φ^+	Φ^-
1	M14	0.3750	0.4674	0.0923
2	M6	0.3724	0.4514	0.0790
3	M5	0.2387	0.3932	0.1546
4	M13	0.1661	0.2965	0.1304
5	M15	0.1646	0.2724	0.1078
6	M10	0.0753	0.2114	0.1361
7	M20	0.0270	0.2105	0.1835
8	M1	−0.0096	0.2292	0.2388
9	M16	−0.0305	0.2242	0.2547
10	M2	−0.0632	0.1904	0.2535
11	M4	−0.0652	0.1538	0.2190
12	M11	−0.0663	0.1476	0.2139
13	M12	−0.0938	0.1366	0.2304
14	M7	−0.1235	0.1659	0.2894
15	M3	−0.1285	0.1234	0.2520
16	M9	−0.1307	0.1219	0.2526
17	M17	−0.1373	0.1019	0.2392
18	M19	−0.1697	0.0902	0.2598
19	M18	−0.1860	0.0777	0.2637
20	M8	−0.2147	0.0763	0.2909

Source: Visual PROMETHEE software

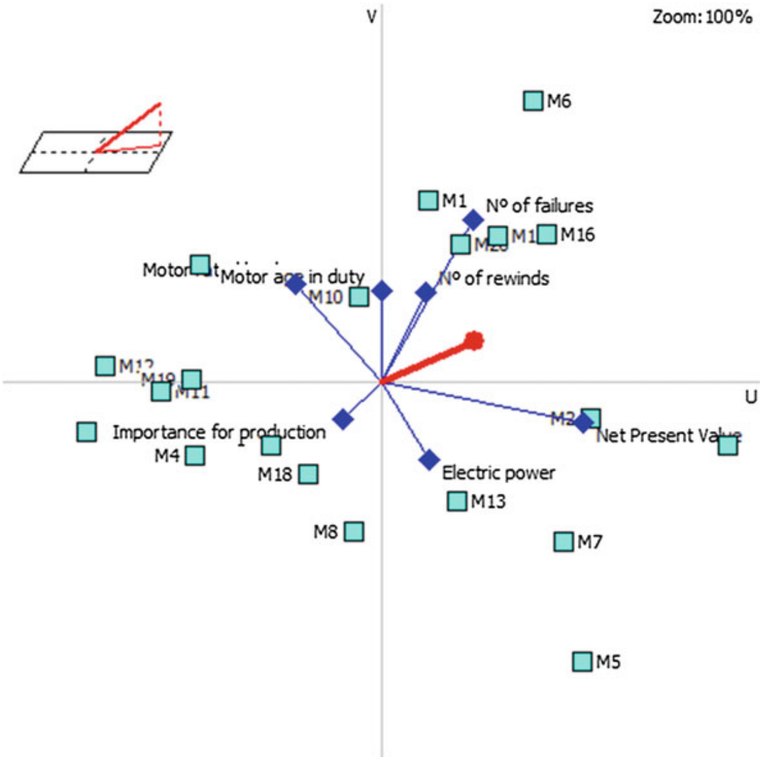


Fig. 3 GAIA visual analysis (Visual PROMETHEE software)

and C5) was short, indicating high level of conflict among criteria. The criteria C1 and C5 conflict with criterion C6 and C7. The criterion C2 is independent of C1 and C6, but it conflicts with C3 and C4, which are dependent criteria.

5 Conclusions

This paper held an approach of multicriteria analysis to energy management systems in organisations. A multicriteria decision model to sort technologies to be purchased was applied in an industry using the PROMETHEE II method. The GAIA analysis shows that a high level of conflict among criteria was verified, although the results also revealed both dependent and independent criteria. The sensitivity analysis showed little variation in the final ranking when the criteria were changed; therefore, the model can be considered stable.

The application of multicriteria decision model can help the decision-making within organisations, subsidizing actions in the energy management systems. The model allows the participation and contribution of all sectors of the company, sharing important information for decision-making. This contributes to the transposition of the barrier resulting from asymmetry of information. The model considers this situation taking into account all the sectors' needs and concerns as well as the decision maker's preferences. Thus, all concerns of the company are respected, in terms of reliability, quality, costs, return on investments, etc. A complete ranking of technologies to be replaced enables the purchasing in accordance with the budget available, and this can minimize the initial cost of equipment impact. Another barrier to energy efficiency is the company focus on the production area.

Although the model was applied to industrial motor systems, it can be applied to purchase or to replace other kinds of technology in industrial energy systems. The decision tool can be applied directly by managers and practitioners within the organisations or by external agents, such as Energy Service Companies and Universities. The application of multicriteria decision model in organisations is highly recommended in order to support decision makers in Energy Management Systems towards the improvement of energy performance.

References

Backlund S, Thollander P, Jenny P, Ottosson M (2012) Extending the energy efficiency gap. Energy Policy 51:392–396

Behzadian M, Kazemzadeh RB, Albadvi A, Aghdasi M (2010) PROMETHEE: A comprehensive literature review on methodologies and applications. Eur J Oper Res 200:198–215

Brans JP, Mareschal B (2005) Promethee methods. In: Figueira J, Greco S, Ehrgott M (eds) Multiple criteria decision analysis: state of the art surveys. Springer Science and Business Media Inc., New York, pp 163–196 (chapter 5)

Chinese D, Nardin G, Saro O (2011) Multi-criteria analysis for the selection of space heating systems in an industrial building. Energy 36:556–565

DeCanio SJ (1998) The efficiency paradox: bureaucratic and organizational barriers to profitable energy-saving investments. Energy Policy 26(5):441–454

Dörr M, Wahrena S, Bauernhansla T (2013) Methodology for energy efficiency on process level. Procedia CIRP, 7:652–657

(2013) EPE—Empresa de Pesquisa Energética (Brasil). Brazilian energy balance 2013–year 2012. EPE, Rio de Janeiro

Ferreira RJP, Almeida AT, Cavalcante CAV (2009) A multi-criteria decision model to determine inspection intervals of condition monitoring based on delay time analysis. Reliab Eng Syst Saf 94:905–912

Figueira J, Roy B (2002) Determining the weights of criteria in the ELECTRE type methods with a revised Simos' procedure. Eur J Oper Res 139:317–326

Fleiter T, Schleich J, Ravivanpong P (2012) Adoption of energy efficiency measures in SMEs—An empirical analysis based on energy audit data from Germany. Energy Policy 51:863–875

Giacone E, Mancò S (2012) Energy efficiency measurement in industrial processes. Energy 38:331–345

Gopalakrishnan B, Ramamoorthy K, Crowe E, Chaudhari S, Latif H (2014) A structured approach for facilitating the implementation of ISO 50001 standard in the manufacturing sector. Sustain Energy Technol Assess 7:154–165

Hasanbeigi A, Menke C, Du Pont P (2010) Barriers to energy efficiency improvement and decision-making behavior in Thai industry. Energ Effi 3:33–52

Hwang CL, Yoon K (1981) Multiple attribute decision making methods and application. Springer, New York

(2014) IEA—International Energy Agency. World energy investment outlook. OECD/IEA

(2011) ISO—International Organization for Standardization. ISO 50001: 2011—Energy Management Systems—requirements with guidance for use. ISO Publications, Geneva

Johnson H, Johansson M, Andersson K (2014). Barriers to improving energy efficiency in short sea shipping: an action research case study. J Cleaner Prod 66:317–327

Kannan D, Jabbour ABLS, Jabbour CJC (2014) Selecting green suppliers based on GSCM practices: using fuzzy TOPSIS applied to a Brazilian electronics company. Eur J Oper Res 233:432–447

Keeney RL, Raiffa H (1976) Decisions with multiple objectives: preferences and value trade offs. Wiley, New York

Kosow IL (1991) Electric machinery and transformers. Prentice Hall, New Jersey

Lung RB, McKane A, Olszewski M (2005) Industrial motor system optimization projects in the US: an impact study. Energy Eng 102(1):61–79

McCoy GA, Douglass JG (2000) Energy management for motor driven system. U.S. Department of Energy (DOE), Washington

McKane A, Price L, De La Rue Du Can S (2007) Policies for promoting industrial energy efficiency in developing countries and transition economies. In: UNIDO—united nations industrial development organization side event on sustainable industrial development on at the commission for sustainable development (CSD-15) Lawrence Berkeley National Laboratory, Berkeley

Nagesha N, Balachandra P (2006) Barriers to energy efficiency in small industry clusters: multi-criteria-based prioritization using the analytic hierarchy process. Energy 31:1969–1983

Ngai EWT, To CKM, Ching VSM, Chan LK, Lee MCM, Choi YS, Chai PYF (2012) Development of the conceptual model of energy and utility management in textile processing: A soft systems approach. Int J Prod Econ 135:607–617

Önüt S, Tuzkaya UR, Saadet N (2008) Multiple criteria evaluation of current energy resources for Turkish manufacturing industry. Energy Convers Manag 49:1480–1492

Rivers N, Jaccard M (2006) Useful models for simulating policies to induce technological change. Energy Policy 34:2038–2047

Rohdin P, Thollander P (2006) Barriers to and driving forces for energy efficiency in the non-energy intensive manufacturing industry in Sweden. Energy 31:1836–1844

Rosenhead J, Mingers J (eds) (2001) Problem structuring methods for complexity, uncertainty and conflict, 2nd edn. Wiley, Chichester

Roy B (1996) Multi criteria for decision aiding. Kluwer Academic Publishers, London

Rudberg M, Waldemarsson M, Lidestam H (2013) Strategic perspectives on energy management: a case study in the process industry. Appl Energy 104:487–496

Russel C (2005) Strategic industrial energy efficiency: reduce expenses, build revenues, and control risk. Energy Engineering 102(3):7–27

Saaty TL (1990) How to make a decision: the analytic hierarchy process. Eur J Oper Res 48:9–26

Saaty TL (1996) Decision making with dependence and feedback: the analytic network process. RWS Publications, Pittsburgh

Sola AVH, Xavier AAP (2007) Organizational human factors as barriers to energy efficiency in electrical motors systems in industry. Energy Policy 35:5784–5794

Sola AVH, Mota CMM, Kovaleski JL (2011) A model for improving energy efficiency in industrial motor system using multi criteria analysis. Energy Policy 39:3645–3654

Sola AVH, Mota CMM (2012) A multi-attribute decision model for portfolio selection aiming to replace technologies in industrial motor systems. Energy Convers Manage 57:97–106

Tonn B, Martin M (2000) Industrial energy efficiency decision making. Energy Policy 28:831–843

Venmans F (2014) Triggers and barriers to energy efficiency measures in the ceramic, cement and lime sectors. J Cleaner Prod 69:133–142

Vincke PH (1992) Multi criteria Decision-Aid. Wiley, New York

Wang GH, Wang YX, Zhao T (2008) Analysis of interactions among the barriers to energy saving in China. Energy Policy 36:1879–1889
Wang J-J, Jing Y-Y, Zhang C-F, Zhao J-H (2009) Review on multi-criteria decision analysis aid in sustainable energy decision-making. Renew Sustain Energy Rev 13:2263–2278
Weber L (1997) Viewpoint: some reflections on barriers to the efficient use of energy. Energy Policy 25(10):833–835
Wolters WTM, Mareschal B (1995) Novel types of sensitivity analysis for additive MCDM methods. Eur J Oper Res 81:281–290
Worrell E, Van Berkel R, Fengqi Z, Menke C, Schaeffer R, Williams RO (2001) Technology transfer of energy efficient technologies in industry: a review of trends and policy issues. Energy Policy 29:29–43
Zadeh LA (2008) Is there a need for fuzzy logic? Inf Sci 178:2751–2779

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Multicriteria Decision Analysis Applied to Water Supply Network

Flavio Trojan and Danielle C. Morais

Abstract Many problems in a water supply network, such as control of physical and economic losses, waste, and lack of a maintenance plan, involve different stakeholders to analyze complex decision making. Thus, several studies and models had been developed to aid decisions making in order to reduce unnecessary exploitation of water, and losses in the water distribution networks. Some successful experiences in this sector regarding models to assist decision makers to deal with problems in the water distribution engineering maintenance area are shown in this chapter. The topics discussed in this chapter involve three major problems that may be addressed with multicriteria analysis in water supply systems: (1) sorting measurement flow areas; (2) ordering maintenance alternatives, which are potentially effective, to be implemented in the priority areas according to several decision makers' point of view; and (3) aggregation of group members' preferences. In the multicriteria analysis, the models developed can help to give a clear view of the problem, making it possible to recognize priority classes to support the maintenance management, and the major potential alternatives to reduce water loss. Several issues will also be approached in the chapter such as water supply and distribution networks infrastructure; economic and environmental impacts; and methods for decision making among others.

Keywords Decision analysis · Group decision · Multicriteria decision aid · Water supply network

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1 Introduction

Although the Earth is covered with water, we still do not have enough technology to use and explore correctly this natural resource, which is apparently abundant. Issues regarding the use of water have been constantly discussed in scientific meetings, and the engineering area explores means to optimize the application of technology, in order to promote the best use of water in its various exploration sites, which comprise underground springs, rivers, lakes, and artificial reservoirs. This concern also leads to the discussion of a structural planning for cities and countries that need to explore, treat, and distribute water to attend the world population necessities.

Population growth, pollution, and the several uses of water in production systems are leading to reflections about the probability of a water crisis in the future. Some publications have already been warning readers about risks involving a global crisis in the water supply, its treatment, and disposal of waste. The World Economic Forum (2013) report shows that there are two major risks appearing in the top five of both impact and likelihood—*chronic fiscal imbalances* and *water supply crisis.*

Several factors must be considered when constructing distribution networks in water supply systems. To start with, the concepts of distribution networks design and transportation lines need to be reviewed. Another approach, which goes beyond the design of transportation lines, must be adopted. The transportation lines design is primarily aimed at meeting hydraulic boundaries, while the design of distribution networks has an extra dimension toward water quality and customer service.

The demand variation is another factor which also influences the design of a distribution network. The demand pattern of an individual house differs from the combined demand pattern of a cluster of houses or industries, for example. The demand pattern of a single house is variable, and there is hardly any continuous flow. In a house with four occupants, the average daily demand would be typically four times 130–150 L, totaling approximately 500–600 L a day, but this might vary greatly depending on the economy and habits that differ from country to country and which directly impact consumption and demand.

In turn, these several demand patterns influence sediment formation and water quality, and studies on maintenance possibilities are needed to control this influence. The ultimate solution to the accumulation problem is to keep the velocity high, so sediment will be held in suspension.

Because all the factors are related and, consequently, affect each other directly or indirectly, such factors and criteria must be considered if efficient water distribution networks in water supply systems are to be constructed.

In addition to the factors and criteria in water distribution networks, a number of variables and indices also influence the system operation and maintenance. Some of these variables are pressure, flow, temperature, density, cost, loss index, and water velocity, among others. The structural problems need to be analyzed in the system project phase. After this, the maintenance sector role would be to keep the system capacity and a normal operation. But, what normally occurs is that the maintenance also needs to deal with structural problems, which result from incomplete analysis of the sanitation projects to maintain the system. Another fact is that the cities are growing without planning or with an incomplete view of the structural analysis.

The problems that are evidenced in the water distribution networks as physical and economic loss control, waste of water, and lack of a maintenance plan, which involve different stakeholders for decision making, might exist due to lack of decision support models, which could give the maintenance manager an overview of the system structure. Certainly, in the management of water supply systems, it is necessary to find an answer to critical questions.

The multicriteria analysis is an opportunity to put together and analyze the critical and structural issues in a matrix of evaluation, considering criteria to conduct to a structural approach to these problems. Such problems need to be solved after the water supply system begins to operate, and they are the reality of many developing countries.

2 Review

2.1 Water Supply and Distribution Networks Infrastructure

In a water distribution system, it is necessary to consider the water demand that varies considerably in the course of a day. Water consumption is highest during the hours in which water is used for personal hygiene and cleaning, and when food preparation and clothes washing are done. Water use is lowest during the night. This variation in flow can be dealt with by operating pumps in parallel and building balancing storage in the system. For small communities, a distribution system with water storage is the preferable option, given that supplies of electricity or diesel to power pumps are usually unreliable. Although it can be kept simple, the construction of such a system may represent a substantial capital investment and the design must be done properly.

Trifunovic (2012) presents that generally the distribution system of a small-community water supply is designed to cater for the domestic and other household water requirements. Livestock watering and garden irrigation may also be provided for. The function of reservoirs is to accumulate and store water during the night so that it can be supplied during the daytime hours of high water demand. It is necessary to maintain sufficient flow and pressure in the distribution system, protecting it against contamination by the ingress of polluted sewage water. For small-community supplies, a minimum pressure of 5–10 mwc (meters of water column) should be adequate in most instances.

While the communities grow and cities are formed, the necessary infrastructure to attend this new demand has to be developed, which requires increasing investments in infrastructure, and this has been observed to have an exponential growth. In addition, the industrial sector in a big city presents a specific demand depending on the industrial activity developed. Thus, the task of designing a system in growth becomes more complex, and so does the maintenance of this system. Therefore, two network designs are important to be considered when constructing the water network infrastructure.

The design and evaluation of community water supply distribution systems has to consider the amount of water for the commercial interests, governmental property, educational facilities, and all classes of residential property as presented above in a general relationship to average the maximum daily consumption demand. Moreover, at any time of the day, any day of the week, or any week in a given year, a fire incident in a building or another fire emergency such as transportation vehicle fires or, in some cases, natural cover fires may erupt. Water is the primary agent of choice to confine, control, and extinguish structural fires.

Thus, each community needs to evaluate and design or redesign the community water system to meet present-day needs as well as to address future demands based on the growth of the built area and population increase.

Concerning layouts, as presented by Trifunovic (2012), there are basically two main types of distribution networks according to the hydraulic connections: the "branched" and the "looped" configurations. Branched networks are predominantly used for small-capacity community supplies delivering the water mostly through public standpipes and having few house connections, if any. Although adequate, having in mind simplicity and acceptable investment costs, branched networks have some disadvantages: low reliability, which affects all users located downstream of any breakdown in the system; danger of contamination caused by the possibility that large part of the network will experience lack of water during irregular situations; accumulation of sediments, due to stagnation of the water at the system ends occasionally resulting in taste and odor problems; and fluctuating water demand producing rather large pressure variations. Branched systems are easy to design. The direction of the water flow and the flow rates can readily be determined for all pipes. This is different in looped distribution networks, where consumers can be supplied from more than one direction.

Looped networks greatly improve the hydraulics of the distribution system. This is of major importance in the event that one of the mains is out of operation for cleaning or repair. A looped network usually has a skeleton of secondary mains that can also be in the form of a branch, a loop, or a number of loops. From there, the water is conveyed toward the distribution pipes and further to the consumers. The secondary mains are connected to one or more loops or rings. The network in an urban distribution system or in a big city will be much more complex. Essentially, it is a combination of loops and branches with lots of interconnected pipes that require many valves and special parts. To save on equipment costs, overcrossing pipes that are not interconnected may be used but at the cost of reduced reliability.

Basically, in a city water treatment and distribution system, urban growth and building of new residences are constant occurrences. In order to meet this growth, the mobilization of investments for infrastructure is necessary. There are several characteristics inherent to these emerging areas, from building homes to meet minimum standards for low-income populations, to upscale residences, residential buildings, and even large industrial areas.

Thus, the level of investment that will be allocated to each area depends on these characteristics and priorities they represent. The branched and looped designs are usually combined to support this urban growth. Thus, a new structure composed of water distribution pipes, connections, fittings, reservoirs (strategically installed to ensure supplies at critical moments), and equipment of measurement, such as control valves, flow meters, and pressure, is required. The system gradually occupies the spaces available with buildings, residences, hospitals, nurseries, and schools, forming a network of operation sectors. It should contain every structure necessary to serve the people who will occupy these spaces. It should also be organized in order not to manage and to meet the characteristics of each area originated from this development. One technique that can be used to manage areas in development is called "*sectorization*"; it is the division or stratification of the macrosystem into small areas (zones) of flow measurement and represents the alternatives in the classification of this model.

Fractionating a problem can often be the best way to solve it. So, this technique is based on the stratification of urban areas served by water supply meshes with the installation of flow meters, in order to meet consumption, usually expressed in cubic meters of each area that makes up the system. Along with the estimates based on relevant characteristics of these areas, are presented information to decision makers who will define about criticality and criteria that should guide the assessment.

The information about the area measurements, which are currently collected by automated means, because companies have been adhering to supply automation projects which contribute immediately to the control and reduction of losses, may be applied to new models of classification of these areas.

2.1.1 Stage of Development for Water Distribution Systems

As discussed by Trifunovic (2012), it is possible to develop a water distribution system in stages, upgrading it in steps when the standard of living of a community improves and funds become available. This is an important point for community consultation, as the initial cost to each household can be limited, while they may foresee future improvement at the service level. When designing the distribution system, an allowance should be made for its later upgrade. The design engineer has to take into account the higher per capita water demand associated with better household water supply facilities.

The cost of a water distribution system depends mainly on the total length of pipes installed, and less on the diameter of these pipes. Hence, it can be advantageous to design the major components directly for the ultimate capacity. This is even so when initially only part of the distribution system is installed for supplying water at a few standpipes. Thus, for a start, fairly wide-spaced standpipes are provided that can probably be supplied from one or a few mains.

In the next stage, additional standpipes will be installed in order to reduce the spacing and thus the distance the water has to be carried to the users. This may mean laying more distribution mains, serving the most densely populated clusters in the community. When this basic level of water service has spread throughout the community, the installation of yard taps and house connections may follow.

After the development of the distribution network installation stage, some specific data are taken from the maps available in the water distribution company.

General view

The general data that can be verified are as follows:

- Topography—ground elevations in the area of the system; some specific natural barriers.
- Type of the system—distribution scheme: gravity, pumping, and combined; location and role of each system component.
- Population—distribution and estimated growth.

Network structure

Nodes—they concern predominantly the supply points of at least a few hundred consumers or major industry, i.e., relevant data for each point with location of coordinates (X, Y) and the system ground elevation with coordinate (Z); average consumption; and dominant category(ies).
Pipes—they concern predominantly the pipes, $D > 50$ mm, i.e., relevant data for each pipe as length; diameter (internal); material and age; and assessment of corrosion level (*k or C value*, if available)
Service reservoirs—type (ground, elevated), capacity, minimum and maximum water level, and shape (e.g., through the "level" curve).
Individual roof tanks—type and height of the tank, capacity, inflow/outflow arrangement, average number of users per house connection, and description of house installations.
Pumping stations—number and type of pumps; duty head and flow and preferably the pump characteristics for each unit; and age and condition of pumps.
Others—description of appurtenances that may significantly influence the system operation (e.g., valves and measuring equipment).

Water demand characteristics

Demand categories present in the system: domestic, industry, public, etc.
Average consumption, patterns of variation: daily, weekly, and seasonal.
Type of domestic water use: direct supply and roof tanks.
Average household size: habits with respect to the water use.
Demand forecasting.

2.1.2 System Operation and Monitoring

Important measurements for calibration of the model are as follows:

- pressure in a few points covering the entire network,
- level variations in the service reservoirs and roof tanks,
- pressures and flows in the pumping stations,
- flows in a few main pipes in the network, and
- valve operation.

All this information may not be easy to collect. However, some knowledge about the system should exist, even in descriptive form, for instance, in which period of the day a certain reservoir is empty (full), a certain pump on (off), a certain valve open (closed), and a certain consumer with (without) water or with (without) sufficient pressure.

Where there is a possibility of continuous measurements, typical days should be compared: the same day of the week in various seasons, or various days of the week in the same season.

2.1.3 Losses and System Maintenance

Water is a major concern for environmental policies. Water losses during transport have a negative impact on the water environment. Water infrastructure, especially in cities, can be outdated or reach the end of their service life causing leakage problems and therefore contributing to the increase in the level of water abstraction in order to keep water supply levels.

Losses of water in the distribution network can reach high percentages of the volume introduced. The problems with leakage are not only related to the efficiency of the network but also to the water quality. Leakage reduction applies to both leakage from company distribution systems and supply pipe leakage (from customers' underground supply pipes). An effective reduction in leakage rates to an acceptable level depends on a range of factors. These include mains pressure, local climate and topography, local value of water, age of the system, type of mains, and soil types. Privatized water companies do not necessarily benefit financially by reducing leakage. Leakage losses are still significant in many cities. Commonly, this is due to the poor condition of water mains. Nonetheless, progress is being made to reduce leakage losses, although the results are uneven within different countries (Lallana 2003).

Physical and non-physical losses

The amount of water that can be billed will always be smaller than the amount supplied. Moreover, the water actually passing through the taps is also smaller than the amount supplied, be it counted or not. The difference is that in the first case it refers to the unaccounted-for water called "non-physical losses," while the second one represents leakage also called "physical losses." Thus, the leakage is a component of unaccounted-for water. Other important sources can be faulty water meters and illegal connections.

Physical and non-physical losses are important elements of water demand and a great concern of many water companies. In some systems, it is the most significant "consumer," reaching up to 50 % of the total water supply. There can be various ways of fighting this problem, but due to high costs of such programs, the real consideration tends to start only when the physical and non-physical loss levels exceed 20–30 %. Limited capacity of the source can also be an important factor in such cases. Water conservation is increasing in importance as more and more regions begin to experience serious water shortages, and reducing physical and non-physical losses is a good way to start.

Leakage is usually the most significant contributor to high physical loss levels. The factors influencing leakage are as follows:

- soil characteristics, soil movement, traffic loading,
- defects in pipes, poor quality of joints,
- poor quality of workmanship, damage due to excavation for other purposes,
- pipe age and corrosion level,
- high pressures in the system, and
- extreme temperatures.

The water service authorities should have procedures for the inspection of distribution networks as part of its criteria for deciding when maintenance is needed.

Other criteria for determining when maintenance is needed should include the frequency of burst mains and the frequency of consumer complaints about drinking water quality, small animals in the water, or low water pressure. The water service authorities should have a program of routine flushing of the network through washouts that would concentrate on those parts of the network where deposits are known to accumulate. For those parts of the distribution network where there are regular difficulties that cannot be adequately controlled by flushing, the water services authorities will need a mains rehabilitation program. This program could include mechanical cleaning of mains, relining of mains, and replacement of mains.

2.2 Economic and Environmental Impacts

These factors should be addressed according to the water service authority bylaws, and the following aspects are of particular importance where water services development plans are incomplete or unclear:

Development impact

Maximum use should be made of local manpower and materials, with training given where appropriate. Local contractors and entrepreneurs should be employed whenever possible. However, the technologies employed—including labor-based construction methods—should be cost-effective.

Health

The improvement of the quality of services should be driven by increased community awareness of health-related problems and their causes. For example, improvements in living standards and public health in a community may be impossible to achieve unless hygiene education is provided and sanitation improvements are made concurrently with the water supply improvement.

Finance

Subsidization of the scheme by bodies outside the community is restricted to the provision of the basic level of service prescribed in the government policy documents. The community must also be able to bear the operational costs involved. There are, however, exceptions to the rule, which can be found in the policy documents. No water supply system should be planned in the absence of a tariff structure and expense-recovery mechanism, agreed to by the client community. The client community must be able to pay for its basic operation and maintenance, with due regard to the free basic water policy of the national government.

Administration

The community should be involved in the project planning, implementation, and maintenance phases.

2.3 Methods for Decision Making

Many times, in the decision-making area, decision makers are faced with subjective choices. For such situations, it is necessary to know and compare every important factor that involves the problem and define the objective to achieve. There are many methods that could support the resolution of such problems for different areas; however, the multicriteria analysis seems to be the best suited for water distribution networks, because it is a technique to structure and analyze complex decisions, which presents economic, social consequences as well as environmental impact.

Hajkowicz and Collins (2007) identified eight areas of application of multicriteria analysis in water resources: catchment management; ground water management; infrastructure selection; project appraisal; water allocation; water policy and the planning of supply; water quality management; and marine protected area management.

Several models were developed to support water resources management decision making using multicriteria analysis such as Raju et al. (2000), Morais and Almeida (2007, 2010, 2012), Silva et al. (2010), Mutikanga et al. (2011), Roozbahani et al. (2012), Trojan and Morais (2012a, b), Markovic (2012), Coelho et al. (2012), and Fontana and Morais (2013).

Some of these models can be specifically related to maintenance management or prioritization of areas to reduce water losses; for example, Morais et al. (2010)

developed a model based on the PROMETHEE I method for prioritizing critical areas of losses. However, the rank achieved by PROMETHEE I was not enough to give an overview of the water distribution network.

Mutikanga et al. (2011) showed an integrated multicriteria decision-aiding framework for strategic planning of water loss management. The PROMETHEE II method was applied within the framework of prioritizing water loss reduction options for Kampala city. It was based on the decision makers' preferences, together with seven evaluation criteria characterized by financial–economic, environmental, public health, technical, and social impacts. And then, a strategic plan was developed that combined maintenance in the main water networks and pressure control as priorities to achieve the result of "best compromise." The results of such work revealed that the most preferred options are those that enhance water supply reliability, public health, and water conservation measures.

Following this idea, Trojan and Morais (2012a) developed a model where critical areas of losses were sorted in five classes of priority maintenance, arising from division of flow measurement areas, using ELECTRE TRI. Fontana and Morais (2013) developed a model for rehabilitating the greatest number of leakage points in a water network, which respects the constraints that a water company may face. PROMETHEE V was used to assist the decision maker in selecting a set of feasible alternatives for rehabilitating the network from the criteria and the constraints set by the decision maker on the problem.

Roozbahani et al. (2012) developed a study with a new group multicriteria decision-making (MCDM) method introduced by combining PROMETHEE and multiattribute decision making with dominance of the criteria methods, called precedence order in the criteria (PPOC). In such approach, the PPOC method was applied to the case study of Melbourne water supply system previously analyzed in the literature, to assess a number of operation rules with respect to eight criteria evaluated under single or group decision-making situations. The proposed method is applicable to different decision-making problems in urban water supply management.

Thus, it is notorious that several developments have been studied until now, seeking to solve the general problems in water supply systems. In this approach, the focus is on maintenance management, because nowadays, it is an important issue for the modern managers. Actually, the future managers cannot forget the maintenance importance in their productive processes. The maintenance management has been present in the majority of solutions that improve productivity and efficiency in the industries.

Issues related with prioritization of alternatives, or decision making in organizations in general, are always among the main conflicts between managers and the different interests to meet different objectives. The fact that there is more than one decision maker in a decision process may involve several conflicts, which are linked to the priorities or service goals and objectives. Still, when considering a large number of alternatives and criteria that should weigh these decisions, the issue becomes more complex. Currently, many techniques of multicriteria decision support have been studied and applied to assist in solving problems in several areas, which have both subjective and conflicting characteristics.

In the maintenance management of public water supply, the differences may become even greater, because the decision makers of this sector are involved with environmental and economic issues simultaneously. Thus, what seems an ideal alternative to a manager in a given time interval might not please or be a very attractive option to another. There is an urgent need to make correct decisions in the application of preventive and remedial measures, in order to have at least the control of the distribution system loss levels or keep them at acceptable levels, thus aiming to extend the supply of the natural resource and reduce impacts to the environment.

3 Decision Model for Water Supply Network

Below is the description of a multicriteria decision model developed by the author of this chapter that goes through phases with multicriteria methods to aid managers in the decision process to reduce water losses in distribution networks. It is a newly developed that joins in a condensed model parts of some works published by authors in the last years. The flowchart in Fig. 1 shows the overview of the model with the perception of the model structure and its stages. It is possible to visualize the sequence of stages and tasks that must be completed to achieve the efficiency of the model presented. In the next section, an application updated in a sanitation company that was built using the model phases is reported.

Every water distribution network is stratified into areas according to similar characteristics. Then, in the first phase of the model, the objective was to sort out these areas through critical flow measurement into three categories of maintenance control: proactive, preventive, and corrective classes. The target of this phase was to collect information about critical areas, which required immediate maintenance. These areas should contain major characteristics that guaranteed the population welfare and the city development basic conditions.

Firstly, a thorough survey about the relevant data from the flow measurement areas was proposed. The information should be about relevant aspects, such as population, measured volume, and number of residential, industrial, commercial, and public economies, in order to place these areas in the maintenance categories. After data collection, the next step proposed in the model was to elicit the characteristics needed for the classes and the maintenance actions that could be performed to verify each class the alternatives belonged to. These characteristics were normally built based on the water supply system aspects together with the decision maker's opinion, when it comes to the relevant points for each class and criterion.

Thus, in the "definition phase" of the model, it is possible to reach a delimitation of maintenance actions required in each class, number of classes, and their priorities as well as the appropriate moment for the intervention, and then the relevant criteria for analysis. The multicriteria definitions should occur in a sequence of steps that define weights and the limits between classes. After this, a method was necessary to carry out the sorting of alternatives allocating them according to the common

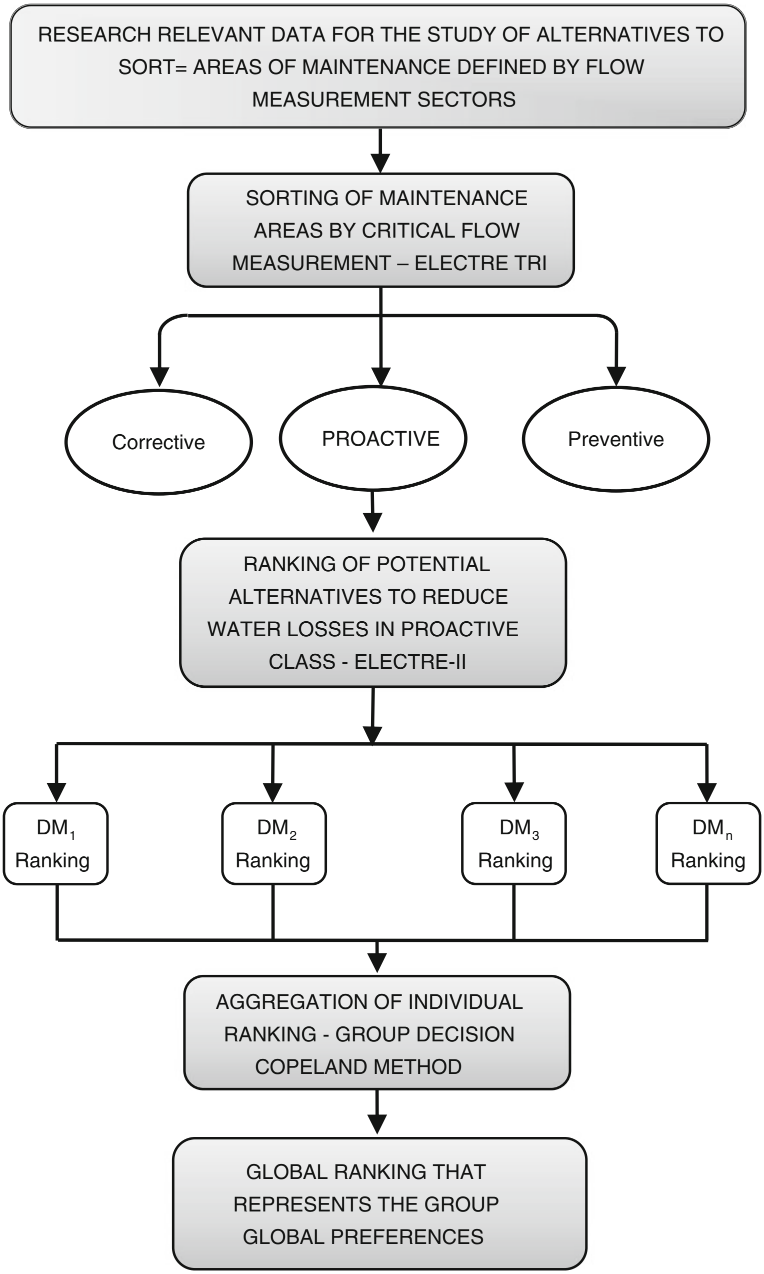

Fig. 1 Flowchart of decision model to water supply network

characteristics. For this analysis, several methods could be applied. However, one method was shown interesting, the ELECTRE TRI by Mousseau et al. (2001), Yu (1992), because it has no compensatory relationships among various criteria. These characteristics were inherent in the problem under study.

In order to evaluate the alternatives to be applied in areas previously classified as proactive maintenance, multiple decision makers from different sectors of the water company were questioned. This class was chosen because it concentrates the most important sectors of the system and need investments to reduction of losses. After that, the alternatives and criteria were defined by an elicitation process.

In this phase with the ELECTRE II method, the comparisons between alternatives were carried out at the last level of decomposition and in pairs, through the establishment of a relationship that followed the margin of preference dictated by the decision agents, seeking an order from the set of potential alternatives, through the concept of dominance (Mousseau et al. 2002).

In the sequence, in the last phase, a new matrix of alternatives was created, in which the decision makers were now considered as criteria, and the performance of each alternative was the ranking generated in the second stage. In the final phase of the model, an aggregation analysis was performed with the application of the Copeland method. This was based on the Condorcet matrix, whose objective was to give support to the generation of a global order that represented the decision makers' opinions or preferences. The Copeland's method can be considered a compromise between the opposing philosophies of Borda and Condorcet, combining as much as possible the advantages of both methods.

4 Application of the Decision Model

This model was applied in a Brazilian city with approximately 320,000 inhabitants and with 100,000 connections of water supply, according to data collected from the urban center. The data were surveyed through an automated and specialized system, which provided the most important information about the system. This real application was, in part, based on this chapter author's works, referenced along the text.

This application had the purpose to analyze the proposed decision model in a situation with relative number of regions (alternatives) to sort into classes of maintenance procedures, evaluating in relation to some criteria. The distribution network maintenance situation at the time of data collection can be viewed through the information about losses and volume in each region of measurement. At this stage, data from a specialized monitoring system (SMS) were used (Trojan and Marçal 2007). This monitoring system was based on theories of artificial intelligence and provides the flow monitoring of measured areas. The data were updated on 2014, based on rates of Brazilian Institute of Geography and Statistics (IBGE).

Trojan and Morais (2012a) pointed out that the strategies or actions could be employed to achieve the objectives separately and some alternatives were generated to the expected result for the goals. These actions were listed based on statistical data system and decision maker's experience, such as registration information, delivered or distributed volumes (total water volume available in the city distribution networks) and macromedia (the sum of volumes measured in each consumer unit), information equipment useful life, when maintenance or replacement should occur, areas with higher rates of leakage and assistance, information on administrative and financial conditions, information on the level of automation of the system, and raising the pressure on networks.

At the entrance and in some cases within each defined area, electromagnetic flow meters were installed, which indicated the flow consumption of each of them. This procedure makes it possible to raise the number of connections, population, network meters, and public economies. Table 1 presents a survey of relevant data generated by the SMS. This data were listed with 30 alternatives (areas of flow measurement). The areas of flow measurement were divided according to geographical features and extensions for power main line of supply.

After data had been collected, it was necessary to allocate the alternatives in the classes defined to focus on the criteria that could be performed on alternate view to see to which class each alternative belonged. In order to define the weights in this application, an elicitation was carried out with decision makers.

For the performance calculation, a range was considered (0–100) to define the performance of the alternatives and the occurrence of a situation in which the items considered in each criterion received a percentage value relative to the number of items listed to examination.

The criteria defined were the following:

g_1 Number of water connections (units)
g_2 Percentage of losses (percentage);
g_3 Population (inhabitants);
g_4 Volume measured (cubic meters per month);
g_5 Network meters connections (meters per connections); and
g_6 Number of public economies (units)

Only the criterion g_2 (percentage of losses) had the characteristic of minimizing, while the others were maximizing. Subsequently, each criterion had an aggregated performance and this result should be taken for the calculation of concordance and non-discordance.

When a value exceeded the average value, it was assigned 100 and below the average values were represented by a relation between the average values and multiplied by 100 to calculate the value referring to the performance of the alternative against the analyzed criteria. Regarding the criteria—losses, networks, and public economy—the maximum values were considered instead of the average as a relevant threshold to the calculation. This procedure was adopted to minimize the differences between areas with major and minor concentrations.

Table 1 Data from the study updated on 2013 and alternative performance calculation

a_n	Connec. unit	Index by avrg.	Measured (m^3/month)	Index by avrg.	Losses (%)	Index by max	Net. m/con.	Index by max	Popul. inhab.	Index by avrg.
a_1	817	23	11,468	27	40.19	55	14.03	87	2,804	23
a_2	3,009	85	53,373	100	37.94	52	15.32	94	13,831	100
a_3	1,710	48	17,687	42	28.76	40	9.86	61	5,982	48
a_4	1,211	34	15,542	36	51.87	72	12.90	80	3,945	32
a_5	1,102	31	10,563	25	36.07	50	8.63	53	3,752	30
a_6	2,573	73	27,940	66	35.78	49	11.60	72	9,449	76
a_7	13,290	100	166,959	100	53.51	74	12.22	75	44,789	100
a_8	3,140	89	30,453	72	49.51	68	9.69	60	10,701	86
a_9	2,425	69	30,678	72	63.21	87	12.64	78	8,171	66
a_{10}	2,569	73	33,096	78	50.14	69	10.98	68	9,393	75
a_{11}	3,038	86	42,330	99	38.38	53	11.33	70	10,864	87
a_{12}	2,041	58	18,844	44	42.71	59	9.62	59	7,071	57
a_{13}	3,082	87	32,798	77	40.19	55	10.19	63	10,653	86
a_{14}	2,483	70	24,499	58	37.68	52	9.85	61	8,560	69
a_{15}	21,703	100	280,088	100	33.05	46	11.95	74	77,257	100
a_{16}	1,693	48	20,776	49	64.40	89	11.86	73	5,756	46
a_{17}	8,012	100	85,692	100	45.46	63	10.42	64	27,632	100
a_{18}	4,737	100	49,386	100	31.69	44	10.42	64	15,965	100
a_{19}	1,576	45	17,798	42	59.74	82	10.93	67	5,437	44
a_{20}	799	23	10,044	24	44.86	62	11.17	69	2,844	23

(continued)

Table 1 (continued)

a_n	Connec. unit	Index by avrg.	Measured (m^3/month)	Index by avrg.	Losses (%)	Index by max	Net. m/con.	Index by max	Popul. inhab.	Index by avrg.
a_{21}	900	25	8,467	20	62.76	87	9.67	60	3,041	24
a_{22}	673	19	6,919	16	64.66	89	10.03	62	2,330	19
a_{23}	1,705	48	18,621	44	52.38	72	10.74	66	5,882	47
a_{24}	2,738	77	32,103	75	63.63	88	11.44	71	9,804	79
a_{25}	4,240	100	47,334	100	38.15	53	10.11	62	14,542	100
a_{26}	1,994	56	33,601	79	26.66	37	16.21	100	8,389	67
a_{27}	4,185	100	46,443	100	72.46	100	11.09	68	14,372	100
a_{28}	1,734	49	21,406	50	35.90	50	11.66	72	6,123	49
a_{29}	4,300	100	52,048	100	50.78	70	11.60	72	15,061	100
a_{30}	2,565	73	30,642	72	57.72	80	11.56	71	8,938	72
Avrg. = 3,535		Avrg. = 42,587		Max = 72.46		Max = 16.21		Avrg. = 12,445		

Table 2 shows the development of the steps above. The considerations on thresholds (thresholds) of indifference and preference should be defined at this stage with the purpose to allow small variations that are covered by these thresholds.

To calculate the performance of the alternatives, the withdrawal amount for each alternative was considered in relation to the average or the maximum number of samples to the considered criteria. The parameters that define the region boundaries between classes were defined at this point, as shown in Table 3.

For the classification categories allocation of alternatives, this experiment considered the cutoff level $\lambda = 0.76$, a value that gives intermediate level of strictness to examination (for $\lambda \in [0.5, 1]$).

With the data tabulated and information elicited from the next step, it is summarized in the application of the ELECTRE TRI method for measuring the results of area classification.

Table 3 shows the results of this stage, finally presenting the classification according to the criteria listed and possible alternatives.

In order to apply the ELECTRE TRI, the software ELECTRE TRI 2.0a, available in Lamsade, was used (Paris-Dauphine University, Paris, France).

The proactive class ($\boldsymbol{CL}_1$) was naturally the point that was focused, because it represented an advanced philosophy of maintenance management. It was confirmed in this application, where there was a small number of concentrated areas in one class only, but of great importance to the city. At this stage, the decision makers focused their attention on the prioritization of investments and maintenance actions in areas classified as proactive. This distinction ensured that decisions were being

Table 2 Parameters for the boundaries between classes

Classes	Maintenance	Border	g_1	g_2	g_3	g_4	g_5	g_6
$\boldsymbol{CL_1}$	Proactive	b_1	90	40	90	90	10	90
$\boldsymbol{CL_2}$	Preventive	b_2	45	80	40	40	55	50
$\boldsymbol{CL_3}$	Corrective							
$\boldsymbol{CL_n}$ → Classes; $\boldsymbol{g_n}$ → Criteria								

Table 3 Results of classification by ELECTRE TRI

Classes	Maintenance	PESSIMISTIC assignment	OPTIMISTIC assignment
$\boldsymbol{CL_1}$	Proactive	–	a_2, a_7, a_{15}, a_{17}, a_{18}, a_{25}, a_{27}, a_{29}
$\boldsymbol{CL_2}$	Preventive	a_7, a_{12}, a_{13}, a_{14}, a_{15}, a_{17}	a_3, a_6, a_8, a_9, a_{10}, a_{11}, a_{12}, a_{13}, a_{14}, a_{16}, a_{23}, a_{24}, a_{26}, a_{28}, a_{30}
$\boldsymbol{CL_3}$	Corrective	a_1, a_2, a_3, a_4, a_5, a_6, a_8, a_9, a_{10}, a_{11}, a_{16}, a_{18}, a_{19}, a_{20}, a_{21}, a_{22}, a_{23}, a_{24}, a_{25}, a_{26}, a_{27}, a_{28} ,a_{29}, a_{30}	a_1, a_4, a_5, a_{19}, a_{20}, a_{21}, a_{22}

directed to the areas that really had great importance to the context. Table 4 presents the characteristics of decision makers, who were asked to develop the elicitation process, in order to rank potential alternatives for maintenance in proactive class, sorting from the previous stage.

Firstly, the strategies or actions defined by the water company director to achieve environmental and economic goals were verified separately. These were called individual alternatives, which generated the expected results for these targets. These alternatives were listed based on statistical data for the system or even based on political desire or the availability of public funding for the sector and were presented in sequence:

Action A—Target to reduce water loss indices

A_1 Pressure reduction in distribution networks: This strategy aims to minimize the occurrence of leaks in distribution networks and consequently to reduce the loss rate. By reducing the average pressure in the pipes, the flow of leakage will also be reduced and the volume of lost water, therefore, will be lower.

A_2 Implementation of pressure and maneuver sectors: This action aims to subdivide large areas into smaller areas of supply to provide control over the maintenance operations. In other words, it seeks to avoid a shortage occurring over a large area when maintenance is needed on a specific location, rather than only influencing the restricted area that contains the relevant location.

Table 4 Decision makers' characteristics

Decision maker	Acting	Responsibilities
DM 1	Administrative/planning	1. People management 2. Elaboration of management plans 3. Financial management and accounts 4. Administrative and general service contracts 5. Legal issues management
DM 2	Production management; water/sewage treatment	1. Production: treatment and water storage 2. Treatment and disposal of sewage 3. Control of water quality 4. Environmental management
DM 3	Commercial management	1. Customer management 2. Levy 3. Reading water meters and billing 4. Levying of fines 5. Commercial records 6. Management of major customers and government 7. Management of micromeasurement
DM 4	Maintenance management of waterworks	1. Pressure control in networks 2. Preventive and corrective maintenance 3. Cutoffs 4. Technical Register network 5.Expansion and improvement projects

A_3 Automation: The automation of processes has also been targeted by sanitation companies, mainly to monitor and control water loss. In spite of requiring high investment, it contributes to a reduction in the system loss rate in the medium term. The cost–benefit ratio ends up being advantageous for systems with high levels of losses.

Action B—Target to reduce cost

B_1 Preventive maintenance, reduction in maintenance costs: In the maintenance of water distribution networks, preventive maintenance plays an important role in the anticipation of events that trigger high maintenance costs. An effective action of preventive maintenance can help the maintenance manager to avoid emerging problems.

B_2 Investment in new materials: Investment in new materials can mean aggregation of technology and new techniques to support optimal system operation. The costs can initially represent a barrier, but the long-term results are worth the effort to implement this type of action.

B_3 Training in preventive maintenance: Qualification is essential to the proper functioning of any company, particularly in the maintenance area; employees' skills can bring about economic gain when required routines are performed more efficiently than before. With the knowledge of these actions, several combinations that can achieve the goals outlined in the previous stage can be visualized. These combinations bring viable solutions for both goals (environmental and economic).

However, one cannot attend to one or the other goal in its entirety. So, an alternative needs to be found that represents the level of confidence that the group has in the combination of actions that might help them reach the goals, without being dominated by other alternatives. The relevant combinations are listed in Table 5.

Along with alternatives, criteria were also defined and the criteria were also imposed by the water company director, due to the fact that the financial resources used must meet these criteria, which represent levels of efficiency for this industry.

Evaluation criteria

g_1 Index of physical losses: The alternatives will be evaluated by the decision makers according to the efficiency that each individual action or combination of actions will have in reducing the system loss rate. This is a percentage index, and it is calculated according to the lost volume (distributed volume—measured volume) divided by the amount distributed in the networks,

g_2 Setting number of maneuver sectors: For this criterion, the alternatives will be evaluated subjectively in relation to what the decision maker prefers. The alternative may cause an increase in the number of sectors of maneuver, maintain the current number, or promote a significant increase in that number,

g_3 Automation level of the system: The automation level is related to the ability of the alternative to promote an increase in the percentage level of implementation to achieve the optimal level of automation in the system,

g_4 Cost with corrective maintenance: The alternative in this case will be assessed by the ability to promote a decrease, increase, or significant increase in costs related to corrective maintenance,

Table 5 Alternatives of solution

Alternatives	Actions
a_1	A_1
a_2	A_2
a_3	A_3
a_4	B_1
a_5	B_2
a_6	B_3
a_7	A_1B_1
a_8	A_1B_2
a_9	A_1B_3
a_{10}	A_2B_1
a_{11}	A_2B_2
a_{12}	A_2B_3
a_{13}	A_3B_1
a_{14}	A_3B_2
a_{15}	A_3B_3

$\boldsymbol{g_5}$ Cost with investment in training and preventive maintenance programs: This criterion exploits the ability of the alternative to improve employees' skills as well as the effective implementation of preventive maintenance,

$\boldsymbol{g_6}$ Investment cost: The evaluation of alternatives will be also considered for its cost of implementation. The decision maker might consider the cost of investment in alternatives to be evaluated as low, medium, or high. The maximum values of the numerical scales of the criteria considered to be benchmarks in the context of maintenance of water networks, which were used to create the "Social Assessment of Alternatives," are shown in Table 6.

The criteria were previously established; however, their weights should be assigned by the decision makers according to the vision that they have for the process, as shown in Table 7. Consequently, each decision maker will choose the weight that suits each criterion or that will have more influence in their field.

The subjective variables were defined with values "high," "medium," and "low" for Criterion $\boldsymbol{g_6}$ and "decrease," "increase," and "increase significantly" for the criteria $\boldsymbol{g_2}$, $\boldsymbol{g_4}$, and $\boldsymbol{g_5}$, and represented the personal choice of each element of the group. It was expected that some differences of opinion would occur because decision makers have their own experience in different areas such as network maintenance, management, planning, production, and business.

The results of the individual evaluations of each decision maker were constructed based on data from assessments made by decision makers, which represent the different areas of the company, an array of concordance and discordance of ELECTRE II can be built, and so achieve the ordination—strong ($p = 0.5$; $q = 0.7$) and weak ($p = 0.7$; $q = 0.5$)—and a final ranking, characterized by the average of the strong and weak ordinations for each decision maker.

Table 6 Values and scales of criteria

Criteria	Levels	Numeric scale
g_1 (%)	20 35 45 55 70	1.00 0.75 0.50 0.25 0.00
g_2	Maintain Increase Increase significantly	0.00 0.50 1.00
g_3 (%)	60 80 90	0.00 0.50 1.00
g_4	Decrease Increase Increase significantly	1.00 0.50 0.00
g_5	Decrease Increase Increase significantly	1.00 0.50 0.00
g_6	Low Medium High	1.00 0.50 0.00

Table 7 Weights of evaluation criteria

Criteria	DM 1	DM 2	DM 3	DM 4
g_1	0.20	0.30	0.30	0.30
g_2	0.10	0.10	0.10	0.20
g_3	0.10	0.20	0.10	0.10
g_4	0.10	0.10	0.10	0.10
g_5	0.20	0.10	0.10	0.10
g_6	0.30	0.20	0.30	0.20

With the application of the ELECTRE II method, it was possible to order the alternatives under the individual preferences of each element for a group of decision makers. The goal was then to aggregate this information into a single ordinance, which would represent the preferences of the group in agreement.

The aggregation analysis was based on the Copeland method; this method represents the number of victories each alternative has in a pairwise comparison.

Due to the fact that the Borda and Condorcet methods may present incompatibilities when applied, in this study, the Copeland method, which combines the virtues of the other two, and uses the structure of both to calculate the final ranking was chosen.

Thus was constructed a matrix configuration of the Copeland method and the interactions between the lines and columns to generate the Copeland ordination. The establishment of rules regarding the tie between the alternatives was necessary because the initial intention was not to have alternatives that presented ties with one another. Thus, the number of defeats of the alternatives was defined as a tie-breaking rule, or the number of defeats is equal to the order of the definition of alternatives.

Therefore, considering the tied alternatives, one that accounted for the lowest number of defeats or that was set later in the choice of alternatives would take a privileged position over others. The weight related to the decision makers was considered equal; in other words, all four decision makers have the same importance in the decision-making process.

The Table 8 shows a comparison between results of the decision makers at individual analysis and the global results arising from the application of the Copeland method.

First of all, it was possible to notice that the decision makers did not reach consensus when the initial choices were analyzed. The first places found for decision makers in the individual analysis, presented by bold number on the table, initially were totally discordants. Subsequently, the Copeland result also shows a different position for the first. But, if we analyze the alternatives chosen, there was a convergence of opinions.

For instance,

- The DM_1 (administrative manager) chose the alternative a_{13} (A_3B_1—automation, monitoring of flow—reduced maintenance costs);
- The DM_2 (production manager) chose the alternative a_{14} (A_3B_2—automation, monitoring of flow—investment in new materials);
- The DM_3 (commercial manager) chose the alternative a_3 (A_3—automation, monitoring of flow);
- The DM_4 (maintenance manager) chose the alternative a_{10} (A_2B_1—sectorization —reduced maintenance costs), and
- The Copeland result was the alternative a_{15} (A_3B_3—automation, monitoring of flow—training on preventive maintenance).

Every manager was looking for the alternative that would enable reduced costs and monitoring of the system in general. For this reason, the Copeland captured the common preferences as in a voting process.

The results presented, resulting from the application of the classification proposed in the model, revealed a scenario with some areas placed in classes more adapted to maintenance alternatives, which denoted a certain balance in the maintenance system. This also indicated a preference to attend higher priority classes with maintenance actions.

The fact that most of the alternatives became concentrated in classes with preventive and corrective maintenance indicates the need for more structured planning and actions in the long term to solve prominent problems in distribution networks. Also, the corrective classes presented consistency because the areas allocated in these classes had underperformed the criteria with the highest weights. This classification showed that these areas may be irrelevant from the point of view of prioritizing interventions, but also require long-term planning.

Table 8 Comparison: global ranking and ranking per decision maker

	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	a_{11}	a_{12}	a_{13}	a_{14}	a_{15}
DM 1	11°	14°	8°	12°	13°	5°	3°	9°	15°	2°	4°	10°	**1°**	7°	6°
DM 2	14°	9°	6°	12°	15°	10°	8°	13°	11°	4°	5°	7°	3°	**1°**	2°
DM 3	12°	7°	**1°**	13°	15°	6°	11°	10°	14°	5°	2°	9°	8°	3°	4°
DM 4	10°	12°	3°	14°	15°	6°	5°	13°	9°	**1°**	8°	7°	4°	11°	2°
Copeland	12°	10°	4°	14°	15°	8°	7°	11°	13°	2°	5°	9°	3°	6°	**1°**

When analyzing the results of the classification procedure only, one can see the demarcation, with concentrations on the important areas in relation to the decision makers' set of preferences. The other areas that presented indifference or incompatibilities regarding classes to which they belong were naturally classified as performance on different criteria.

Some incompatibilities were detected when the alternatives could not be analyzed, since the criteria that define the comparison did not present any over-classification in relation to the parameters or preferences listed by the decision maker. Therefore, the procedure adopted was optimistic. The optimistic procedure (or disjunctive) $\boldsymbol{CL_h}$ assigns the lowest category to which the upper profile $\boldsymbol{b_h}$ is preferable to. When using this procedure, an alternative can be assigned to category $\boldsymbol{CL_h}$ when $\boldsymbol{g_j(b_h)}$ exceeds $\boldsymbol{g_j(a)}$ (at some threshold) at least one criterion (disjunctive rule).

The results of the model ordinance application can be measured in two moments:

- After construction of the concordance and discordance matrices with the individual sorting by ELECTRE II method;
- After submitting Condorcet Matrix to the representation used in the COPELAND method.

By analyzing the results of individual ordinances promoted by the application of ELECTRE II, one can notice some slight differences between the preferences of decision makers in the group. However, points of convergence for individual and group opinions can also be seen. This was made possible after making the aggregation of the results (ELECTRE II) applying the second method (Copeland).

The results of this combination of the ELECTRE II and Copeland methods and both, concomitantly, provide decision makers with a clearer view on which alternative may help more consistently to achieve multiple objectives with which they were faced and still promote consensus among the group's views. The result matrix afforded by the Copeland method brings the concept of the vote present in this method.

The final ranking matrix revealed that the group presented points of convergence in some evaluations and preferences. The opinions were unanimous about the final result. Certainly, each decision maker had considered their individual preferences when interviewed to generate the evaluation matrix of the ELECTRE II. For this reason, the opinions ended up converging in a natural way, and then, by applying the Copeland method, it was possible to obtain the aggregation to the solution of "better compromise."

5 Concluding Remarks

This chapter brought a view about some problems and reflections related to structures and prioritizations in maintenance management of water distribution networks. The presented model applied in a company of water distribution was constructed with the experiences of authors in scientific studies about maintenance and distribution networks and theirs particularities. The model classification phase allowed immediate viewing of critical classes, and the maintenance sector of distribution networks of a supply system was presented. This result can give information to act quickly in situations that need to meet the maintenance priorities. Carrying out previous classification of areas optimizes the performance of the maintenance sector and makes it possible to design investment plans in accordance with the necessities found. Subsequently, some alternatives are ranked to answer to necessities listed in the previous stage using the managers' different experiences to solve maintenance problems and investments.

This approach broadens the horizons of action maintenance management systems for public water supply. By applying the multicriteria methods, relevant results could be achieved from the point of view of the goals of care and a more complex scenario in the maintenance of water distribution was addressed, in which multiple objectives and targets and a select group of decision makers were involved. This model of decision support can certainly help managers visualize a core of viable alternatives for solving maintenance problems inherent in public water supplies, such as loss, running maintenance alternatives, deployment of automation, and monitoring priority areas. With this proposal, the decision making becomes more comfortable, since there is a tendency to maximize attendance preferences of decision makers in the group so that the objectives are met, with the likelihood of better results.

The multicriteria approach does not provide just a solution for one problem, but brings about all the possible alternatives of a more consistent decision with the optimization of the decision process. The multicriteria methods have the subjective and objective aspects, presenting the ability to add all the features considered important in the problem, in order to enable transparency of the process related to the decision-making problems.

Thus, the present work fulfills the goal of building classification models alternative priority and thereafter preference aggregation group, with consideration of subjective and objective aspects at the same time to assist in decision making on maintaining distribution networks in the water supply public system.

Therefore, this work presents a new development with regard to the management and automatic routing of effective maintenance actions, which consequently will generate quality improvements, operation, and customer satisfaction. These provide the maintenance manager with decisions of higher quality, allocated to address the critical issues of maintenance, which usually affect the population directly. The study also aims to establish an appropriate level of maintainability for the overall management of the maintenance of water supply networks, composed of various equipment and materials, through the allocation of maintenance alternatives, with a view to reducing unnecessary maintenance, according to previously established criteria.

References

Coelho AC, Labadie JW, Fontane DG (2012) Multicriteria decision support system for regionalization of integrated water resources management. Water Resour Manag J 26:1325–1346

Fontana ME, Morais DC (2013) Using Promethee V to select alternatives so as to rehabilitate water supply network with detected leaks. Water Resour Manage 27(11):4021–4037

Hajkowicz S, Collins K (2007) A review of multiple criteria analysis for water resources planning and management. Water Resour Manage 21:1553–1566

Lallana C (2003) Water use efficiency (in cities): leakage. Eur Environ Agency. Version 01.10.03:1–5

Markovic M (2012) Multicriteria analysis of hydraulic structures for river training works. Water Resour Manage 26:3893–3906

Morais DC, Almeida AT (2007) Group decision-making for leakage management strategy of water network. Resour Conserv Recycl 52:441–459

Morais DC, Almeida AT (2010) Water network rehabilitation: a group decision-making approach. Water SA 36(4):487–493

Morais DC, Almeida AT (2012) Group decision making on water resources based on analysis of individual rankings. Omega (Oxford) 40:42–52

Morais DC, Cavalcante CAV, Almeida AT (2010) Priorização de Áreas de Controle de Perdas em Redes de Distribuição de Água. Pesquisa Operacional 30:15–32

Mousseau V, Figueira J, Naux JP (2001) Using assignment examples to infer weights for ELECTRE TRI method: some experimental results. Eur J Oper Res 130(2):263–275

Mousseau V, Figueira J, Roy B (2002) Electre methods. Universit´e Paris–Dauphine, Paris, pp 1–35

Mutikanga HE, Sharma SK, Vairavamoorthy K (2011) Multicriteria decision analysis: a strategic planning tool for water loss management. Water Resour Manage 25:3947–3969

Raju KS, Duckstein L, Arondel C (2000) Multi-criterion analysis for sustainable water resources planning: a case study in Spain. Water Resour Manage 14:435–456

Roozbahani A, Zahraie B, Tabesh M (2012) PROMETHEE with precedence order in the criteria (PPOC) as a new group decision making aid: an application in urban water supply management. Water Resour Manage 26:3581–3599

Silva VBS, Morais DC, Almeida AT (2010) A multicriteria group decision model to support watershed committees in Brazil. Water Resour Manage 24:4075–4091

Trifunovic N (2012) Pattern recognition for reliability assessment of water distribution networks. Doctorate Thesis, Delft University of Technology and of the Academic Board of the UNESCO-IHE Institute for Water Education, Netherlands

Trojan F, Marçal RFM (2007) Study and implement of a specialized monitoring system (SMS) to orient decisions and reduce losses in the public water supply systems. In: ICICIC-2007 international conference on innovative computing, information and control, Kumamoto, Japan

Trojan F, Morais DC (2012a) Using ELECTRE TRI to support maintenance of water distribution networks. Pesquisa Operacional 32(2):423–442

Trojan F, Morais DC (2012b) Prioritising alternatives for maintenance of water distribution networks: a group decision approach. Water SA 38(4):555–564

World Economic Forum: Global Risks (2013) 8th edn. ISBN: 92-95044-50-9, Geneva, Switzerland

Yu W (1992) ELECTRE TRI—Aspects Methodologiques et Guide d'Utilisation, Document du LAMSADE. Université de Paris-Dauphine, Paris

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Part V
Decision Models in Public Policies

Decision Model on Basic Sanitation Management Using Environmental Kuznets Curve (EKC)

André Luiz Marques Serrano, Paulo Augusto Pettenuzzo de Britto and Patricia Guarnieri

Abstract Discussions addressing basic sanitation frequently revolve around the question of urban drainage and solid waste. In this context, the management of public policies in Brazil has been undergoing an intense change in recent years, with the incorporation of new methods and tools for analysis of areas of intervention, public programs monitoring, and in decision making in general. This chapter illustrates the use of information by a public official in order to decide whether to invest and how much to invest in basic sanitation and waste collection. The information is paramount to evaluate the prospects of a policy. In order to demonstrate the decision-making process regarding the systematic relation between alterations in income and the quality of the environment, we use the environmental Kuznets curve (EKC).

Keywords Basic sanitation · Decision making · Environmental Kuznets Curve · Public management

1 Introduction

Basic sanitation can be defined as the provision of a treated water supply and a sewage removal system with the latter comprising both sewage and solid waste collection and treatment. Discussions addressing basic sanitation frequently revolve around the question of urban drainage and solid waste. Urban drainage consists of

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transporting and disposing of rainwater runoff, and solid waste is considered to be all solid and semisolid residues resulting from human activities. With those two definitions established, the basic sanitation cycle can be addressed on a broader scale embracing those two aspects and bearing in mind that their improper destination places a pollution load on natural water resources.

In general, a public program on sanitation involves inter-sector efforts from different areas and with various goals. So the decisions related to the priority areas for implementation of public policies require the combination and analysis of various criteria (indicators), mainly related to costs, health, and environmental protection. In a broad perspective, basic sanitation can be considered to be an activity stemming directly from human behavior. Communities need basic sanitation to reduce the risk of environmental degradation, health damage, and loss of economic capacity and assets, among other effects.

The management of public policies has always been undergoing intense changes resulting from the incorporation of new methods and tools for analysis of areas of intervention, public programs monitoring, and decision making in general. Besides that, it is important to emphasize the need of more specific, reliable, and updated information, which requires more structured techniques for decision-making process in public policies (Jannuzzi et al. 2009). On the other hand, the absence of appropriate wastewater sanitation is one of the leading killers in the developing world (Winters et al. 2014).

There is a considerable body of literature on the relations between human activities and the environment. From the economic point of view, that literature is largely based on studies of the effects of economic growth on the environment and especially the relation between income and pollution. The economic literature on this particular is permeated by the idea that the environment suffers high levels of deterioration in the early stages of economic development and tends to be recuperated in the more advanced stages (Dinda 2004).

That systematic relation between alterations in income and the quality of the environment is referred to as the environmental Kuznets curve (EKC) and is based on the premises that in the initial stages of economic development, there is little or no concern for the environment; in the advanced stages, structural changes occur, favoring less polluting technology and economy of services as well as the appearance of growing social concern for the environment. Hence, the EKC is usually depicted as having the shape of an inverted-U.

In this chapter, we intend to investigate government policies toward basic sanitation. In particular, we discuss the decision-making process under which a public official decides whether to invest or not in basic sanitation taking into account long-run prospect regarding socioeconomic development. To do so, the chapter is structured as follows: Sect. 2 discusses the decision making related to public/government policies; Sect. 3 introduces the decision model; Sect. 4 presents the application of the decision model to basic sanitation investment; and finally, Sect. 5 presents the conclusions.

2 Decision Making Related to Public/Government Policies

Sanitation and solid waste management systems have recently received major attention through the United Nation Millennium Development Goals (MDGs) (Tukahirwa et al. 2013). Thus, the understanding of the relationship between environmental factors and public health is becoming critical to improving sustainability. In this context, there are several challenges to provide safe and adequate sanitation in informal settlements for improved health and sustainable livelihood. This includes social, environmental, economic, institutional, and demographic characteristics, which should be considered in decision-making process (Isunju et al. 2011). Besides that, it is important to recognize that environmental health involves a complex and diverse range of institutions, processes, and actors, which make difficult the decision-making process (Allison 2002).

In some developing countries, public managers decide to not invest in sanitation, considering that it is cheaper to allow toilets to empty into floodwater drainage schemes and other watercourses than to pay the costs of the development of private septic tanks (Winters et al. 2014). In East African cities, for example, it is possible to find public schemes, private schemes, and all kinds of public–private mixes in sanitation and solid waste management, increasing the role of civil society organizations [community-based organizations (CBOs) and non-governmental organizations (NGOs)], which are philanthropic in nature (Tukahirwa et al. 2013). This fact occurs in response to the failure of the provision of basic sanitation and waste management from government, increasingly arising frameworks of interaction between civil society and government (Allison 2002).

Sanitation and solid waste management systems are among the public services in developing countries that need attention and significant improvements (Tukahirwa et al. 2013). In general, governments do not invest in wastewater because there are often financial constraints, under which governments lack the resources to fund public service. The construction of urban wastewater infrastructure is costly, particularly because of the costs of urban land acquisition and the challenges of installing new underground piping in densely populated areas (Winters et al. 2014).

It is important to emphasize that all government decision making about wastewater systems takes place with the knowledge that capital costs will be very high contrasting with the need of environmental protection and health for population. On the other hand, according Winters et al. (2014), there is often a problem of government accountability, where the government is able to overcome the financial constraint but is not willing to use available resources for public service delivery. Scott et al. (2013) highlight that providing services to informal areas has been an ongoing dilemma for many governments.

In such a situation, government should step in either to directly provide the public good of environmental protection that the market will not provide, to provide information that changes individual preferences, or to otherwise create superior incentive structures that reduce exploitation of the commons (Winters et al. 2014).

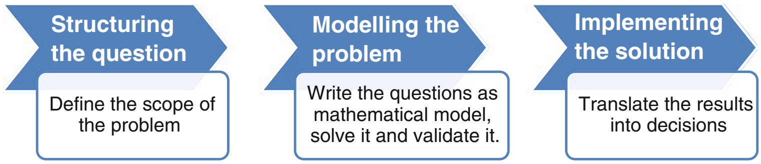
Therefore, proposals to evaluate the status of environmental health in a region must consider factors including the diversity of indicators, geographical scale, incomplete or inaccurate data, and the need for focused methodologies that capture the complexity of this subject.

3 Decision Model

The decision model focuses on the use of information by a public official in order to decide whether or not to invest in basic sanitation and waste collection. Not only the information but also the knowledge about the problem is paramount to evaluate the prospects of a given policy. In order to represent the decision-making process, we recall the methodology proposed by Ackoff and Sasieni (1975) and Armentano et al. (2007) which can be summarized as follows:

(i) Structuring the question: Define the scope of the problem being studied;
(ii) Modeling the problem: Write the questions as a mathematical model; solve the model using known algorithms; and validate the solution in order to verify whether the model makes a suitable representation of the problem;
(iii) Implementing the solution: Translate the results obtained using the model into decisions, and chose the one more suitable for the problem in hand.

In a graphical representation, the decision-making process becomes



4 Application of the Decision Model

Suppose a public official, e.g., a mayor, deciding whether and how much to invest in environmental projects aimed to reduce environmental pressure. To do so, the mayor has to define the problem, generate knowledge, and implement a solution, if any. Regarding the knowledge, the mayor and his team have to not only have projects in hand, but also foresee with some degree of confidence how the project will perform in the future related to other aspects such as economic growth, social development, and so on.

In the case of environmental policies, it is paramount to know what the literature says regarding environmental degradation and socioeconomic development, or the literature known as EKC. Based on that literature, the mayor's team knows that the earliest studies on the relationship between the environment and economic growth date back to the 1990s. In 1991, Grossman and Krueger published a document in the form of a discussion text for the National Bureau of Economic Research in which they highlighted how the economic gains obtained by the North American Free Trade Agreement (NAFTA) had deleterious impacts on the environment. However, they have shown that there was a point of inflection in that curve such that, beyond a certain level of development, marginal gains in per capita income would induce improvements in the quality of the air (Grossman and Krueger 1991). Theirs was the first empirical description of the inverted-U-shaped relationship between economic growth and environmental degradation.

In 1992, Shafik and Bandyopadhyay published a study as part of the World Bank's 1992 World Development Report that also explored the economic aspects of the relation between economic growth and the quality of the environment. Their findings showed that income has a consistently significant effect on the quality of the environment and that many of the indicators showed a tendency to be better for countries with a medium income level, thereby providing evidence to support the inverted-U relationship (Shafik and Bandyopadhyay 1992).

The same relationship was found in 1993 in an article by Panayotou, published in the form of a discussion text for the International Labor Organization's (ILO) World Employment Programme Research. The article found empirical evidence that per capita income levels could explain CO_2 emissions and deforestation, both with relation in the form of inverted-U (Panayotou 1993).

That relation in the form of an upside-down U can be explained by the fact that, all other things being equal, production causes pollution, and that is the predominant effect in the ascending part of the curve. However, above a certain income threshold, the "all other things being equal condition" is violated and the reduction in pollution is explained by other factors such as the increased demand for environmental quality, cleaner forms of production resulting from technological progress, the substitution of polluting inputs, and the reduction of the costs of controlling pollution stemming from the economic growth process itself.

Based on this theoretical relationship, the mayor's team decided to measure the expected impact of economic development in the environment in order to estimate how much investment will be necessary.

4.1 Methods and Procedures

A research is set out to investigate an eventual relationship between the level of socioeconomic development and variables representing sewage collection and solid waste collection. The research hypothesis is that communities with higher levels of socioeconomic development would show greater concern for environmental management and henceforth be prepared to invest more financial resources into those areas.

The unit of analysis is set to be the municipality. To measure the degree of socioeconomic development of each municipality was chosen as a proxy the Firjan Municipal Development Index (IFDM), a reference index designed to measure socioeconomic development of Brazilian municipalities which is regularly published by the Federation of Industries of the State of Rio de Janeiro. The IFDM is calculated on the basis of official government statistics covering the fields of income and employment, education, and health. The value attributed to each municipality ranges from 0 to 1, being 1 the index associated with the municipality with higher level of socioeconomic development.

The problem addressed by the mayor's team, as mentioned before, is to decide whether or not to invest in basic sanitation. Henceforth, the environment-related variables selected for the analysis were as follows: coverage of the sewage collection network and coverage of the solid waste collection system. Given that data available, the analysis was restricted to 607 municipalities from the State of São Paulo.

Nowadays, 22 % of the entire Brazilian population resides in the state of São Paulo and the state is responsible for generating 33 % of the Brazilian GDP. The state's area is 248,209.426 km^2 divided into 645 cities/municipalities. Population density is 165.7 inhabitants/km^2, and 94.6 % of state residents live in urban areas. Annual per capita income is 32 thousand Brazilian reals, three times higher than the national figure registered by the Brazilian Geography and Statistics Institute (IBGE 2011).

Regarding the development index, 23.9 % of São Paulo municipalities have IFDM higher than 0.8 and are considered to be at a high stage of development, 75 % have IFDM ranging from 0.6 to 0.8 corresponding to a moderate level of development, and 1.1 % have levels of development ranging from 0.4 to 0.6.

The situation regarding basic sanitation as reported by the IBGE's 2010 Demographic Census and the Brazilian National Basic Sanitation Survey for 2008 is that all municipalities in the state of São Paulo provide some kind of sanitation service. There is a sewage collecting system in 99.8 % of them, and 78.6 % have some kind of sewage treatment installation. All municipalities undertake solid waste management, but only 72.1 % have properly licensed waste disposal areas. Regarding the frequency of solid waste collection, in 77.4 % of municipalities, the waste is collected three or more times a week in the urban areas.

On the basis of the above information, linear regression models were estimated to describe the relations between the independent and detailed dependent variables which are set out in Table 1.

Two models were estimated, each one making use of cubic equations. The aim was to identify any causal relations between development and the two measures associated with sewage and waste. The empirical models were as follows:

$$\mathrm{SEWAGE}_i = \beta_0 + \beta_1 \cdot \mathrm{DEVELOP}_i + \beta_2 \cdot \mathrm{DEVELOP}_i^2 + \beta_3 \cdot \mathrm{DEVELOP}_i^3 + \varepsilon_{1i} \quad (1)$$

$$\text{WASTE}_i = \delta_0 + \delta_1 \cdot \text{DEVELOP}_i + \delta_2 \cdot \text{DEVELOP}_i^2 + \delta_3 \cdot \text{DEVELOP}_i^3 + \varepsilon_{2i} \quad (2)$$

with the ε_{ki} parameters in equations $k = 1, 2$ representing the stochastic errors. Considering the ordinary least squares method estimates for the five cubic equations, the object of the analysis is to observe whether each model is significant and also to verify the shape of the estimated curve.

For each of the dependent variables set out in Table 1, there is an expectation based on the economic theory which is presented below in Table 2.

4.2 Discussion of the Results

Both models were identified using the ordinary least squares method with the robust variance–covariance matrix being estimated according to the principles of the Newey–West technique. The results obtained in that way are presented in Table 3. It must be stated that the F-test showed that all the regressions are globally significant to the level of 1 % so that the values obtained for the coefficient of determination R^2 are significant for showing the relation between the independent variable and the explanatory variables in each model.

The plots of the estimated equations are shown below. They indicate that increases in development induces increase in both sewage and solid waste collection for the municipalities. However, it is interesting to note that in the case of the sewage collection system, the increase in coverage reaches 100 % of the households at a level of development of approximately 0.47. The explanation is twofold: It may indicate less pressure on the environment as a result of development or that further increases in the system of sewage collection are more costly. As of the solid waste collection, the monotonic increase in the system indicates that more development does not induce less waste generation and that further increases in the collection system are not so costly (Figs. 1 and 2).

Table 1 Description of the variables included in the models

Variable		Theoretical reference	Empirical reference
Dependent	Percentage of households connected to sewage collection system (SEWAGE)	Grossman and Krueger (1995)	Saxena et al. (2010)
	Percentage of households served by waste collection service (WASTE)		
Independent	Index of development (DEVELOP)	Grossman and Krueger (1995)	Saxena et al. (2010)

Table 2 Economic expectations

Dependent variable (equation)	Impact on the environment	Economic expectation
Percentage of households connected to sewage system—SEWAGE (1)	Less pressure on the environment	The DEVELOP is expected to have a negative sign as higher levels of development would be associated with a greater coverage of the sewage system. To be in agreement with that hypothesis underlying the EKC, there needs to be a positive value associated with both the squared and the cubed terms indicating that if development levels were sufficiently high, marginal increases would induce a reduction in sewage system coverage
Percentage of households with waste collection—WASTE (2)	Less pressure on the environment	Once again, a negative sign is expected for the DEVELOP, indicating that increased levels of development will lead to increases in the daily production of waste. To be in line with the EKC hypothesis, positive parameters must be associated with the quadratic and cubed terms

Table 3 Results of the estimates for the relations between development and basic sanitation

Estimated equation	Explanatory variable	Estimated coefficient
(1) Dependent variable: percentage of households connected to the sewage system	DEVELOP	2.177
	$DEVELOP^2$	−0.996
	$DEVELOP^3$	−0.169
	Constant	0.218
(2) Dependent variable: percentage of households with waste collection	DEVELOP	14.519
	$DEVELOP^2$	15.085
	$DEVELOP^3$	−7.320
	Constant	6.974

An analysis of the results reveals that not all the expectations for the relations among the variables in each estimated equation were confirmed. Table 4 succinctly sets out the results obtained.

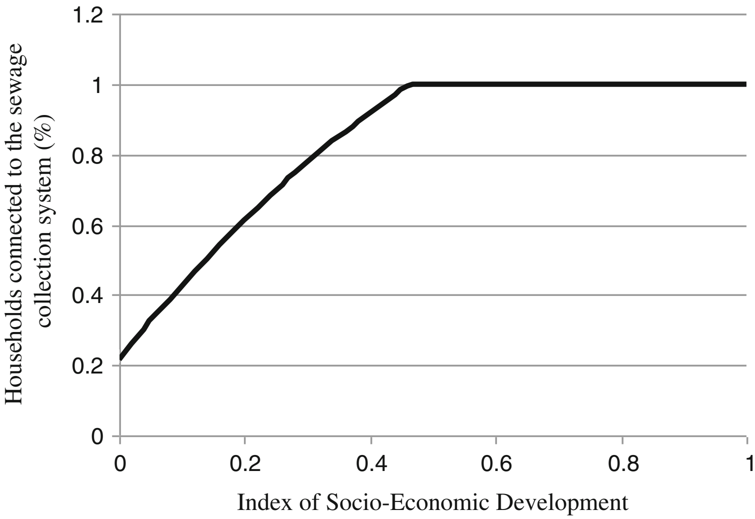


Fig. 1 The relationship between development and percentage of households connected to the sewage collection system

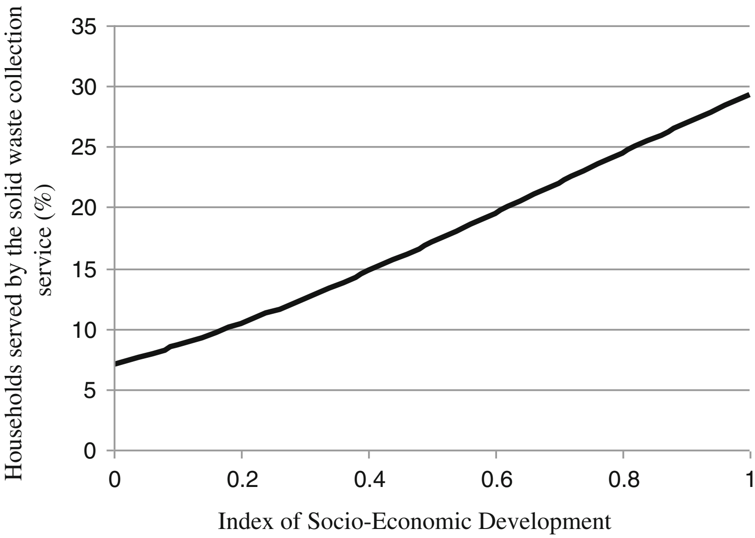


Fig. 2 The relationship between development and percentage of households served by the solid waste collection service

Table 4 Results

Estimated equation	Economic relations identified
(1) Dependent variable: percentage of households connected to the sewage network	The estimated equation shows that the percentage of households connected to the sewage network increases in the early stages of economic development, reaches a peak, and then begins to decrease. The result obtained for this environmental variable does not coincide with the theory insofar as the pressure on the environment goes down in the early stages of development and goes up in the final stages. The sewage system reaches 100 % of the households for a level of development of approximately 0.47
(2) Dependent Variable: percentage of households with solid waste collected	The percentage of households with waste collection goes up consistently with the increase in the DEVELOP in a monotonic relation meaning that the percentage of households with waste collection service provided increases with development. Although the cubic term is negative, it is not big enough to create a point of inflection in the curve

5 Concluding Remarks

Investment in sewage and solid waste management increases along with the population and also with the economy, as higher consumption per capita is observed. Those factors generate more pressure to the environment and, consequently, demand more public spending in services related to sewage and solid waste. However, it might be the case that socioeconomic development induces less pressure to the environment, as shown in the literature related to the environment Kuznets curve and, therefore, reduces the needs for investments in basic sanitation.

The purpose of this chapter was to discuss the decision-making process of a public official regarding the investments in sewage and solid waste management systems considering not only the size effects derived by increase in population and consumption, but also considering an eventual impact of socioeconomic development. An application was developed to illustrate how the decision is influenced not only by information, but also by knowledge. At the end, the illustration showed how socioeconomic aspects might affect the decision on basic sanitation investment contributing, in general, for a more comprehensive public planning.

References

Ackoff RL, Sasieni MW (1975) Pesquisa operacional. (Moura, JL Trad.) Rio de Janeiro, Brazil

Allison MC (2002) Balancing responsibility for sanitation. Soc Sci Med 55(9):1539–1551. doi:10.1016/S0277-9536(01)00286-6

Armentano VA, Arenales M, Morabito R, Yanasse HH (2007) Pesquisa operacional. Elsevier, Rio de Janeiro

Dinda S (2004) Environmental kuztnes curve hypothesis: a survey. Ecol Econ 49:431–455

Grossman GM, Krueger AB (1991) Environmental impact of a North American free trade agreement. National Bureau of Economic Research, Cambridge (Working Paper 3914)

Grossman GM, Krueger AB (1995) Economic growth and the environment. Quartely J Econ 110 (2):353–377

IBGE (2010) Atlas do Censo Geográfico 2010. Ministério do Planejamento, Orçamento e Gestão. Instituto Brasileiro de Geografia e Estatística. Diretoria de Geociências. Rio de Janeiro: IBGE

IBGE (2011) Atlas de Seneamento. Ministério do Planejamento, Orçamento e Gestão. Instituto Brasileiro de Geografia e Estatística. Diretoria de Geociências. IBGE, Rio de Janeiro

Isunju J, Schwartz K, Schouten M, Johnson W, Van Dijk M (2011) Socioeconomic aspects of improved sanitation in slums: a review. Public Health 125:68–376

Jannuzzi PM, Miranda WL, Silva DSG (2009) Análise Multicritério e Tomada de Decisão em Políticas Públicas: Aspectos Metodológicos, Aplicativo Operacional e Aplicações. Informática Pública, ano 11(1):69–87

Panayotou T (1993) Empirical tests and policy analysis of environmental degradation at different stages of economic development. Technology and employment programme, International Labor Office, Geneva (Working Paper WP238)

Saxena S, Srivastava RK, e Samaddar AB (2010) Towards sustainable municipal solid waste management in Allahabad city. Manage Environ Qual Int J 21(3):308–323

Scott P, Cotton A, Sohail Khan M (2013) Tenure security and household investment decisions for urban sanitation: the case of Dakar, Senegal. Habitat Int 40(2013):58–64. doi:10.1016/j.habitatint.2013.02.004

Shafik N, Bandyopadhyay S (1992) Economic growth and environmental quality: a time series and cross-country evidence. J Environ Econ Manage 4:1–24

Tukahirwa JT, Mol APJ, Oosterveer P (2013) Comparing urban sanitation and solid waste management in East African metropolises: the role of civil society organizations. Cities 30 (2013):204–211. doi:10.1016/j.cities.2012.03.007

Winters MS, Karim AG, Martawardaya B (2014) Public service provision under conditions of insufficient citizen demand: insights from the urban sanitation sector in indonesia. World Dev 60:31–42. doi:10.1016/j.worlddev.2014.03.017

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A Proposal Based on Hard and Soft Systems for Public Policies Supporting Family Farms

Lúcio Camara e Silva, Natallya de Almeida Levino and Lúcio dos Santos e Silva

Abstract Family farming is one of the primary generators of work, employment and income in rural areas of Brazil. Based on this knowledge, the federal government has adopted incentives for producers in an attempt to make this productive sector more competitive and efficient. However, much remains to be done to make the development truly sustainable. By evaluating this dynamic, this paper proposes a model based on multimethodologies to assist the actors in defining and applying public policies. To facilitate and provide a greater understanding of the problem, the Strategic Options Development and Analysis (SODA) method was applied through cognitive maps in conjunction with the Strength, Weakness, Opportunities, Threats (SWOT) approach, which allowed a higher level of analysis of the alternatives. With the alternatives available, the multicriteria method PROMETHEE II was applied to ranking the alternatives to be implemented. The proposed model provides the people involved with a greater level of insight into the problem to be analysed and facilitates the adoption of public policies that meet the needs and preferences of farmers.

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Keywords Family farming · Public policies · PROMETHEE II · Strategic options development and analysis (SODA) · SWOT

1 Introduction

According to Guanziroli et al. (2001), the family farming sector is known for its roles in providing employment and in food production, particularly for self-directed activities, i.e., it focuses more on social functions than characteristic economics, given its lower productivity and technological development. However, it is necessary to emphasize that family production, in addition to reducing the rural exodus and acting as a resource for families with low income, also contributes significantly to the generation of wealth, considering not only the economy of the agricultural sector but also the country itself (Eid and Eid 2003).

Family farming is, according to the 2006 Agricultural Census, the primary generator of employment in rural Brazil, involving more than 12 million people in the field and accounting for over 74 % of the farming population.

In recent years, issues relating to family farming emerged and the need for change was identified. The reorientation to development on a sustainable basis requires actions to foster the application of innovative technologies that enable quality, add value to products, and ensure the competitiveness and sustainability of business (Kester et al. 2012).

As a result, Decree 6.882 of 06.12.2009 established the Sustainable PRONAF [Ministry of Agrarian Development—Ministério do Desenvolvimento Agrário (MDA)]—a new program from the Federal Government for the family farm. The goal of the program is to treat the farm as a whole, directing, coordinating and monitoring the deployment of funding, taking into account social, economic and environmental factors with respect to local specificities. The program's principles and guidelines are as follows: Improving the quality of actions and policies to support rural development, family farming and agrarian reform settlers; Better use of natural resources, particularly land and water; Productive diversification and value addition with systemic focus; Recognition of human relationships and their interactions with the environment as a central focus of sustainable rural development; Monitoring and evaluation of outcomes and social, environmental and economic implications of the policies to support rural development; Increasing production and productivity of units of family farming and agrarian reform settlements.

According to Junker and Schutz (2011), Brazil has recently been adopting new approaches to agricultural policy. In addition to promoting its economically important and export-oriented agriculture, Brazil is supporting small and poverty-threatened family farms. Although problems in the implementation of the agricultural policy still exist, they are being addressed in direct collaboration with industry.

Reaching productivity and environmental objectives while considering farm and policy constraints is a complex activity (Groot et al. 2012). In this context, several papers were written for different purposes. Gomes et al. (2007) proposed a multicriteria approach to evaluate land and labour productivity measurements jointly. They evaluated the performance evolution of a group of family farmers from Brazil. Gomes et al. (2009) combined DEA models with regression models to evaluate farmers' group sustainability in agriculture, identifying the factors affecting the efficiency measurements. Dogliotti et al. (2014) presented an approach to diagnose and re-design vegetable and mixed family farm systems, considering important common problems and consequences for the performance of the farms, although with different relative levels of importance for each farm.

The objective of this paper is to develop a multicriteria decision model to prioritize certain actions in the short and long terms, based on a SODA and a SWOT analysis, which will assist in strengthening the development of family farming.

This paper is organized into five sections, in addition to this introduction. In Sect. 2, we will show the theoretical concepts that form the basis for our work. Section 3 will present the multicriteria decision model for the family farm. Section 4 presents the application of the model. Finally, Sect. 5 summarizes the paper and offers concluding remarks.

2 Literature Review

As in the work of Junker and Schutz (2011), the term *agriculture* in Brazil can be used in two forms. The first is associated with large-scale, export-oriented agricultural production. The second is frequently characterised by insufficient marketing opportunities and lack of access to credit, insurance and agricultural inputs. Taking note of this discrepancy, the Brazilian government has been focusing on an agricultural policy that is specifically oriented to the needs of family farms.

In this type of problem, the opinions of many managers, such as those from the municipal mayor of the target area, the agricultural agencies, banks, and farmers, are frequently taken into account. Thus, a group decision-making (GDM) approach is required. Nevertheless, GDM often involves an environment filled with uncertainties, given that the different preferences of the actors involved in the decision may generate conflicts, complicating the decision-making process and resulting in a decision not reflecting the wishes of the majority.

GDM consists of procedures to aggregate opinions in decision problems when two or more independent concerned parties must make a joint decision (Chen et al. 2012). In this sense, the use of structuring methods with multicriteria methods assists members in making a decision by reducing uncertainty and conflicts.

In the context of family farming systems, multicriteria models were developed for different purposes. Reichert et al. (2013) developed a project whose objective was to evaluate organic potato production systems through a multicriteria methodology to identify the criteria that farmers deem important in this production system. In Balezentis (2011), the author focuses on the development and application of a multi-criteria decision making framework for estimating farming efficiency across different farming types. Borec et al. (2013) presents a partial survey of the Mediterranean region to establish the perspective of farms concerning their succession status, using a multi-attribute method for the analysis.

2.1 Problem Structuring Methodologies

The structure of the problem represents the complexity of the situation and incorporates elements judged as relevant by the decision makers. In the literature, such as Rosenhead (1989), there are various methods that address this issue, such as: strategic option development analysis (SODA), SWOT analysis, soft systems methodology (SSM), and strategic choice approach (SCA).

This step provides a better understanding of the problem, taking into account the identification of the actors, the alternatives, and the criteria characterizing the problem.

2.1.1 SWOT Analysis

SWOT analysis is one of the simplest approaches that supports the development of strategy and planning. It focuses on subsidies for the organization's existence in its current situation, development of strategies and selection of one or more strategies to implement (Rosenhead 1989).

As described by Rosenhead (1989), the principles of SWOT analysis include the identification of strong/weak points within the organization and its opportunities/external threats. If a large number of points have been identified, it may be necessary to make an assessment of each point to prioritize them.

2.1.2 SODA

The SODA methodology is a framework for "designing problem solving interventions" using cognitive mapping. For Georgiou (2011), SODA is a problem structuring method incorporating a particular approach to cognitive mapping that draws from the psychological theory of personal constructs.

The basic theories that inform SODA derive from cognitive psychology and social negotiation, where the model acts as a continuously changing representation of the problematic situation—changing as the views of a person or group shift through learning and exploration (Ackermann and Eden 2010).

The maps aid the negotiation between perceptions and interpretations of the problem among decision makers and facilitators; and incorporate feelings, values and attitudes within a decision-making process.

The methodology begins with the construction of the label issue. The facilitator and the actors define the label that represents the problem. Then, each actor provides his viewpoint of the problem. The composition described above is called the concept (idea or node); a concept consists of two poles, the main and the opposite.

Arrows connect the concepts expressed by the decision makers, each pointing in a different direction. An arrow leading out of a concept can lead to—have implications for or have as a result—another concept. At the tip of each arrow is an end, a consequence of a subordinate concept, which is at the tail.

It is the facilitator's function to link the concepts of the decision-makers to form the cognitive map. At the end of this process, the facilitator compiles the information to form the map of the actors. The map is built by the facilitator in the presence of the group that can insert or remove concepts that are relevant to the problem. When the approved map is built, then the alternatives and criteria are built.

The use of formalities for the construction of the model makes it amenable to a range of analyses and encourages reflection and a deeper understanding (Ackermann and Eden 2010). The analyses enables a group or individual to discover important features of the problem situation, and these features facilitate agreement on an improved solution.

2.2 Multicriteria Decision Method

Another basic aspect of a decision problem is the choice of a multicriteria method. This depends on the context, the problem of preference structure and problematics (Roy 1996).

2.2.1 PROMETHEE

The PROMETHEE method is based on two steps: construction of an outranking relationship, adding the information between alternatives and criteria, and the exploitation of this relationship for decision support (Brans and Mareschal 2002). In this case, the decision maker must establish for each criterion a weight p_i that reflects the importance of this criterion, providing the $\pi(a, b)$, the degree to which alternative 'a' outranks alternative 'b', for each pair of alternatives (a, b) according to the following Eq. (1):

$$\pi(a, b) = \sum_{i=1}^{n} p_i F_i(a, b), \tag{1}$$

where

$$\sum_{i=1}^{n} p_i = 1 \tag{2}$$

In Eq. (1), $F_i(a,\ b)$ is a function of the difference $[g_i(a) - g_i(b)]$ between the performance of the alternatives for criterion *i*. The preference function for each criterion is also determined by the decision maker (Albadvi et al. 2007). This describes the intensity of a preferred alternative '*a*' over alternative '*b*', for a given criterion *j* (Vincke 1992). This preference is expressed by a number in the range [0, 1], with 0 indicating not preferred or indifferent and 1 a strict preference. For this work, we used the common criterion function, in which there is no parameter to be set. Thus, $F_i(a,\ b) = 1$, when $g_i(a) > g_i(b)$; otherwise $F_i(a,\ b) = 0$. In this case, the outranking degree $\pi(a,b)$ will have in its composition the weight p_i of each criterion *i*, for which an alternative '*a*' has better performance than '*b*'.

The next phase corresponds to the exploitation of the outranking relation for decision support, in which two indicators are used, namely: (1) the output outranking flow $\Phi^+(a)$ of the alternative '*a*', which represents the preference intensity of '*a*' over all alternatives '*b*' in the set *a*, represented by Eq. (3). Therefore, the higher the flow, the better the alternative (Macharis et al. 2004); (2) the entry outranking flow $\Phi^-(a)$ of the alternative '*a*', represented by Eq. (4).

$$\Phi^+(a) = \sum_{b \in A} \pi(a,b) \tag{3}$$

and

$$\Phi^-(a) = \sum_{b \in A} \pi(b,a) \tag{4}$$

Among the methods of the PROMETHEE family, PROMETHEE II provides a complete ranking of the alternatives from best to worst through the net flow, as described in Eq. (5), which is the difference between the positive flow and negative flow, and represents the balance between the strengths and weaknesses of each alternative. The higher the net flow of the alternative, the better is its evaluation 45.

$$\Phi(a) = \Phi^+(a) - \Phi^-(a) \tag{5}$$

Based on this indicator, the alternatives are arranged in descending order, establishing a complete pre-order between the alternatives based on the preference described by Eq. (6) and indifference relations described by Eq. (7).

$$\text{aPb se}\,\Phi(a) > \Phi(b) \tag{6}$$

$$\text{aIb se}\,\Phi(a) = \Phi(b) \tag{7}$$

For further information on preference functions and the procedures used in the calculations of PROMETHEE II, we suggest references such as Belton and Stewart (2002), Vincke (1992) and Macharis et al. (1998), (2004).

3 Decision Model

According to Wilson et al. (1986), improving the lot of small-scale farmers in developing countries is receiving considerable attention from national and international agencies worldwide. The Program to Support the Family Farm [Programa Nacional de Fortalecimento da Agricultura Familiar (PRONAF)], created in 1995 by the Brazilian government, was an initiative to accelerate rural development by expanding the availability of agricultural credit to poor farmers. However, meeting the goals of sustainable growth of food production and reducing rural poverty requires assisting family farmers in developing more productive, profitable, resource efficient and environmentally friendly farms (Dogliotti et al. 2014).

Although problems with the implementation of the agricultural policy still exist, they are being addressed in direct collaboration with industry. Given the complexity of the decision process in family farming, this paper offers a tentative approach to clarifying this question, creating the model (Fig. 1) based on multimethodologies to assist the actors defining the public policies. In a general overview, the model helps members understand the problem by facilitating the construction of alternatives and criteria and the evaluation of these alternatives considering the internal and external environment, through the SODA and SWOT analysis. Finally, a ranking of the alternatives is obtained by using a multicriteria method.

The first step of the model is structuring the problem. The choice of SODA analysis reflects the nature of interactivity and understanding of problematic situations that are extremely useful in solving problems involving family farming. It provides a learning process and better understanding of the problem by facilitating the decision-making, allowing actors to express their views and reach a compromise solution.

According to Eden and Ackermann (2006) SODA is characterized by its ease of handling qualitative factors, structuring difficult situations and developing

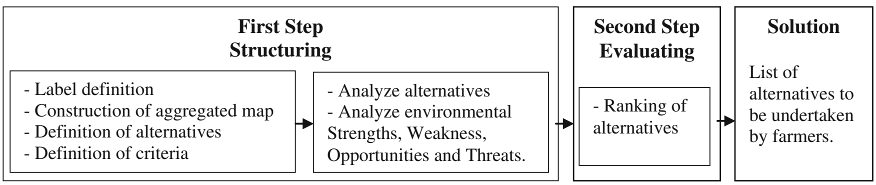

Fig. 1 Decision model flow

strategies. It is particularly useful for dealing with complex situations, such as problems present in family farming.

The SWOT analysis allows the actors to evaluate the alternatives in terms of the internal and external environments, enabling them to better assess the possibilities and reduce conflicts in the group. This will be accomplished through meetings of members who will express how they evaluate the organization. The actors will identify the strengths, weaknesses, opportunities and threats of the organization.

In the second step of the model, a ranking of the alternatives is developed by the members using a multicriteria method. In this paper, the PROMETHEE II method is chosen because it provides a complete rank of a finite set of alternatives from best to worst and it is useful when actors want or need to take more than one action to solve the problem in question.

4 Application of the Decision Model for Family Farming

This study applies the proposed model to family farming problems in the state of Pernambuco, Brazil. This application is relevant because it shows the applicability of the model to a problem involving multiple decision makers.

4.1 Structuring the Problem

In the family farming environment, the structuring phase is important because it will allow the actors to express their preferences and provide a better understand of the problem. In addition to offering the players greater education and interaction, it will reduce conflicts, allowing communication between the actors and increasing the scope of compromise. It also supports the definition of alternatives to solve the problem.

The use of procedures facilitates structuring the process of decision making by offering a greater understanding of the problem. The combination of SODA and SWOT methods seeks to improve the communication of members, reducing conflicts through a compromise solution.

4.1.1 SODA

In the structuring phase, all actors should be involved in reducing conflicts and ensuring that the final decision reflects the wishes of the majority.

An initial meeting should be held with all stakeholders and those actively involved in the process to clarify the methodology to be used. For mechanisms forming public policies that support family farming, we can restrict the actions that are taken and executed by, for example, the governor of the province; the municipal

Fig. 2 Aggregate map

mayor of the target area; the agricultural agencies; the Banks; and the farmers (Wilson et al. 1986). In Brazil, we can consider the banks, the Ministry of Labour and Employment—[Ministério do Trabalho e Emprego (MTE)], the university, the Agronomic Institute of Pernambuco—[Instituto Agronômico de Pernambuco (IPA)], and technical representatives belonging to these organisations. At least one member from each sector should participate in the process such that everyone believes that they are represented.

After selecting participants from each sector, the facilitator defines the problem label, which in this paper is: *Consolidation of family farms in the state*. For the construction of the map, the facilitator used the software Decision Explore (Banxia 1996). Then, all actors present their view points and perspectives for solving the problem. After this process, the facilitator gathers the information forming the aggregate map, as shown in Fig. 2.

The finalized map is presented to the actors who can insert or remove relevant concepts. With the map approved, the facilitator, together with the actors, defines blocks of alternatives (Silva et al. 2012), based on types of actions for family farms, as shown in Table 1.

Table 1 Type of actions

Type of actions	Definition
Social welfare actions	Actions that generate opportunities for productive inclusion of families
Administrative actions	Actions developed within organizations
Strategic nature actions	Actions that generate incentives for competitiveness

Table 2 Set of alternatives to solve the problem

Type of actions	Alternatives descriptions
Social welfare actions (SWA)	SWA_1—stimulate and expand the differentiated education in the field, through the pedagogy of alternation, in which the children of producers pass on knowledge acquired to the family
	SWA_2—develop or deliver courses with sufficient information to enable the farmer family to identify other activities beyond rural and productive uses of the property, such as ecotourism, and rural tourism
	SWA_3—promote digital inclusion among rural farms
	SWA_4—promote good communication practices
Administrative actions (AA)	AA_1—implement policies to guarantee minimum prices for family farmers
	AA_2—encourage the creation of central marketing and product certification (associations, cooperatives etc.) for family farm products
	AA_3—develop a financing facility
Strategic nature actions (SNA)	SNA_1—encourage the provision of technologies and practices aimed at sustainability in family farming, to contribute to increased productivity, income and quality of life for producers' families
	SNA_2—encourage closer relations among the representative bodies of family farming, research bodies and technical assistance
	SNA_3—implement organizational strengthening strategies of municipal advisors and community associations
	SNA_4—encourage market access with producer participation in fairs promoted by partner institutions, focusing on distribution and direct selling

Table 3 Set of criteria

Criteria	Definition
Cost—Cr1	Cost of implementing the alternative, such that the alternatives considered to be lower cost will be chosen
Time—Cr2	Time of deployment; the alternatives with shorter execution times must be chosen
Economic return—Cr3	Refers to financial returns that farmers can receive from a certain alternative, one that has been chosen is based on larger earnings
Social reach—Cr4	Reflects the deployment of alternatives within communities, alternatives being valued for generating greater welfare for farmers

Based on the decision axes defined by the actors, the facilitator, together with the members, lists the alternatives that may solve the problem presented. Table 2 shows these alternatives.

According to the cognitive map and based on the defined alternatives, the following criteria were established (Table 3).

With the alternatives and criteria, actors must assess their implications in the internal and external environments.

Table 4 SWOT Analysis for the family farm

Strength	Weakness
Integration with local trade	Low education
Food supplier to the domestic (internal) market	Little organization and articulation for productive management
Food and nutrition security	Difficulty in addressing the health and environmental requirements
Labour is family based	Produce without first defining your destination
Pluriactivity	Insufficient information on public policy
Diversification of production	Low participation of women, youth, indigenous and Maroon in decision making
	Low quality in the preparation of projects
Opportunities	Threats
Government food market	Low presence of sewage systems
Regional, national and international markets	Deficits in coverage of water
Activities generated by the 2014 World Cup	Inequality in income distribution
Agroecological production	Difficulty in trafficability and production flow
Non-agricultural activities	Legal impediments to trade associations
	Low availability of training, technical assistance and technology
	Difficulty in accessing finance
	Climate change

4.1.2 SWOT Analysis

The participation of a facilitator is crucial to the construction of the SWOT analysis because the facilitator is impartial and ensures that members are involved. With the actors defined in the previous step, the facilitator and the actors review the organization's internal and external environment.

This paper is based on a recently published study (Silva et al. 2012), that presented a SWOT matrix (Table 4), with participants from the state of Pernambuco. Based on this matrix, the group of decision makers evaluated the alternatives in terms of the environment. The alternatives are then arranged in order to be checked for their order of execution.

4.2 PROMETHEE II

The subsequent step in structuring the problem corresponds to the application of the PROMETHEE II multicriteria method to establish an order of the alternatives to be implemented, as well as their sequence.

Table 5 Alternatives ranking for each actor

Alternative ID	Ordering of the alternatives in the ranks			
	DM-1	DM-2	DM-3	DM-4
SWA_1	1	2	4	5
SWA_2	4	1	10	1
SWA_3	2	9	2	9
SWA_4	6	7	1	7
AA_1	10	4	9	6
AA_2	11	6	6	2
AA_3	7	8	11	11
SNA_1	8	10	8	4
SNA_2	9	3	7	8
SNA_3	3	5	3	3
SNA_4	5	11	5	10

This paper recognizes that decision makers are able to rank the alternatives from best to worst, without using a methodology, i.e., the ability to evaluate the alternatives is intrinsic to each decision maker. Therefore, it is expected that actions are taken in accordance with the suggestions set out by the actors involved (Table 5), which are: Banks (DM 1), TEM (DM2), University (DM 3) and IPA (DM 4). It should be noted that each decision maker has equal authority in the decision process. However, it is necessary to obtain a consensus.

Although the individual evaluation criteria are not analysed in this work, the criteria serve as a basis for evaluation. However, that analysis is a suggestion for future study.

The ranking of the alternatives using the PROMETHEE II method, which represents the preferences of the group, is seen in Table 6.

Through the proposed aggregation of preferences, alternative SWA_1 was evaluated as the best, while alternative AA_3 was the least preferred. However, in the decision environment, those involved are shown to have divergent opinions. In the case of a differentiation of the weights in the final decision, the rankings can be changed.

Therefore, a sensitivity analysis was developed to check the consistency of the final solution when changes were made to the importance of each decision maker, that is, the relative importance of the DM groups, by ±10 % to their weights. However, the analysis showed that the scenario is unlikely to alter the order. Therefore, the DM should make himself/herself fully aware of the strengths of his/her preferences and the consequences that arise from these.

Table 6 PROMETHEE II ranking

Ranking	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°
Alternatives	SWA_1	SNA_3	SWA_2	SWA_4	SWA_3	AA_2	SNA_2	AA_1	SNA_1	SNA_4	AA_3
ϕ	0.6	0.5	0.4	0.15	0.1	−0.05	−0.15	−0.25	−0.3	−0.35	−0.65

5 Concluding Remarks

The support of family farm systems has become a concern worldwide because it is the primary generator of employment in rural Brazil. For this reason, many research studies are being undertaken to address and mitigate this problem.

Because problems in the implementation of the agricultural policy still exist and improvement in the sustainability of family farms in Brazil is needed, we presented a proposal in this paper, based on hard and soft systems, for management of public policies to strengthen the development of family farm production. The model that addresses the question of the adoption of alternatives on family agriculture and sustainable development, was based on two principles: a SODA and a SWOT analysis for structuring the problem, which allows a better understanding of the problem, and the multicriteria method PROMETHEE II to provide a preference order of the alternatives. The model was developed to assist the decision-making process and reduce conflicts and uncertainties in favour of improving the management of family farming, limited to the prioritization of the alternatives studied.

To demonstrate the applicability of the model presented, a simulation with 11 alternatives associated with social welfare, administrative and strategic nature actions were used. Four criteria for evaluating alternatives were used, and four decision makers, farmers and technical advisers, were involved as primary participants. The simulated case used the PROMETHEE II method to obtain a ranking of alternatives while respecting the decision makers' preferences. The results showed that social welfare alternatives received more attention.

Despite the simplicity of the illustrated example, the proposed model can be applied in real cases because, much of the necessary data should already be surveyed by the governor of the province; the municipal mayor of the target area; the agricultural agencies; the banks; and the farmers (Wilson et al. 1986).

It is suggested that future studies of this theme develop an approach based on this proposed model, able to insert new alternatives and criteria, and consider, for example, cost and time restrictions.

References

Ackermann F, Eden C (2010) Strategic options development and analysis. In: Systems approaches to managing change: a practical guide. Springer, Berlin, pp 135–190

Albadvi A, Chaharsooghi SK, Esfahanipour A (2007) Decision making in stock trading: an application of PROMETHEE. Eur J Oper Res 177:673–683

Banxia Software (1996) Decision explorer, version 3.0.4 analyst user guide. University of Strathclyde, Glasgow

Balezentis T (2011) A farming efficiency estimation model based on fuzzy multimoora. Manage Theory Stud Rural Bus Infrastructure Dev 5:29

Belton V, Stewart TJ (2002) Multiple criteria decision analysis. Kluwer Academic Publishers, The Netherlands

Borec A, Bohak Z, Turk J, Prisenk J (2013) The succession status of family farms in the mediterranean region of Slovenia. Sociológia 45(3)
Brans JP, Mareschal B (2002) Promethee—Gaia: une méthodologia d'aide à La décision em présence de critères multiples. Éditions de L'Université de Bruxelles, Bruxelles
Chen Y, Kilgour D, Hipel K (2012) A decision rule aggregation approach to multiple criteria-multiple participant sorting. Group Decis Negot 21(5):727–745
Dogliotti S, García MC, Peluffo S, Dieste JP, Pedemonte AJ, Bacigalupe GF, Scarlato M, Alliaume F, Alvarez J, Chiappe M, Rossing WAH (2014) Co-innovation of family farm systems: a systems approach to sustainable agriculture. Agric Syst 126:76–86
Eden C, Ackermann F (2006) Where next for problem structuring methods. J Oper Res Society 57 (7):766–768
Eid F, de Oliveira Eid RMC (2003) Marketing and family farming: a cooperative study of Agrarian reform. In: Proceedings of XXIII national meeting of production engineering—Ouro Preto, 21–24 Oct 2003
Georgiou I (2011) Cognitive mapping and strategic options development and analysis (SODA). Wiley Encyclopedia of Operations Research and Management Science, New Jersey
Gomes EG, Soares de Mello JCCB, Mangabeira JFC (2007) Aggregation of partial ordinal productivity: a case study in family farming. Investigação Operacional 27:199–213
Gomes EG, Soares de Mello JCCB, Souza GS, Angulo Meza L, Mangabeira JAC (2009) Efficiency and sustainability assessment for a group of farmers in the Brazilian Amazon. Ann Oper Res 169:167–181
Groot JCJ, Oomen GJM, Rossing WAH (2012) Multi-objective optimization and design of farming systems. Agric Syst 110:63–77
Guanziroli C, Romeiro A, Buainain AM, di Sabbato A, Bittencourt G (2001) Family farming and agrarian reform in century XXI. Garamond, Rio de Janeiro
Junker F, Schutz K (2011) When poverty reduction and market access go hand in hand. How Brazilian agricultural policy is promoting family farms. Available at http://www.rural21.com/uploads/media/rural_2011_4_36-39_01.pdf
Kester LV, dos Santos EM, Sartin KR (2012) Role of supporting social economy institutions with family farms: case of the agroecological farmers in Cacoal-RO. In: Proceedings of XXXII national meeting of production engineering, Bento Gonçalves, 15–18 Oct 2012
Macharis J, Brans P, Mareschal B (1998) The GDSS PROMETHEE procedure. J Decis Syst 7:283–307
Macharis C, Springael J, de Brucker K, Verbeke A (2004) PROMETHEE and AHP: the design of operational synergies in multicriteria analysis: strengthening PROMETHEE with ideas of AHP. Eur J Oper Res 153:307–317
MDA—Ministry of Agrarian Development. Available at http://www.mda.gov.br/portal/
Pernambuco Sustainable Rural Project—PRS/Prorural (2011) Department of Agriculture and Agrarian Reform—SARA, Support Program in small farmers—Prorural
Reichert LJ, Gomes MC, Schwengber JE, Pereira AS (2013) Evaluation of organic potato production systems in southern of Rio Grande do Sul. Horticultura Brasileira 31(2):220–230
Rosenhead J (1989) Rational analysis for a problematic world: problem structuring methods for complexity, uncertainty and conflict. Wiley, England
Roy B (1996) Multicriteria methodology goes decision aiding. Kluwer Academic Publishers, The Netherlands
Silva LC, Levino NA, dos Santos SL (2012) Sustainable development and family farming: a SWOT analysis. In: Proceedings of XXXII national meeting of production engineering, Bento Gonçalves, 15–18 Oct 2012
Vincke P (1992) Multicriteria decision aid. Wiley, Bruxelles
Wilson KK, Philipp PF, Shaner WW (1986) Socio-cultural effects on the farming systems research and development approach. Agric Syst 19:83–110

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Part VI
Decision Model in Civil Engineering

PROMETHEE IV as a Decision Analyst's Tool for Site Selection in Civil Engineering

Pedro Henrique Melo Albuquerque

Abstract Choosing the correct location for a construction project is a crucial decision in the practice of civil engineering; in fact, knowledge of the economic potential of available locations can orient the analyst in the decision analysis process to optimise her/his resources, aiming for a profit that overcomes the cost of construction. In this context, PROMETHEE IV and its kernel density estimator can help the analyst through her/his decision analysis process in what is known as decision-making for civil engineering. In this chapter, we present how PROMETHEE IV and the kernel density estimator (KDE) could be used to choose available locations for construction, aiming to choose the best locations and to avoid the worst. In addition, an application using Columbus data from Anselin (1988) is also presented.

Keywords Civil engineering · Decision analysis · PROMETHEE IV · Site selection

1 Introduction

Managers and engineers must often make decisions regarding their projects, which have specific characteristics that often conflict with each other, making the process complex and challenging. In this context, a problem faced by organisations in the civil engineering field is the choice of the optimal site for a construction project; the choice involves not only the contact information of the possible construction sites but also future projections about the financial return of these sites.

In this sense, this chapter aims to present the modified PROMETHEE IV through the density kernel estimator as a tool for choosing the most favourable site

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for the construction of buildings in terms of relevant variables selected by the managers.

Specifically, the field of decision-making is one of the most important in operational research (OR) because all decision-makers must address a large set of alternatives and criteria when they make decisions concerning the process. This process of choice is often complicated because some criteria must be maximised, while others must be minimised, and the alternatives could have positive or negative impacts on any criteria. These features usually make the decision process a complex system that requires methods capable of simplifying and assisting the decision-maker's operations.

The PROMETHEE family is frequently used to simplify the decision process because they transform a multiple criteria decision-making process into a simple decision-making process. This transformation occurs due to the ranking of the net flow scores. The least studied and applied method of this family is PROMETHEE IV.

PROMETHEE IV was developed by Brans et al. (1984, p 488); since its development, few applications and innovations concerning the method were presented in the OR literature, even though it is able to treat continuous sets of viable solutions, which are the most observed contexts in practical situations. The income criteria, for example, could assume infinite values because they represent continuous random variables, but only some sample points are observed. When a decision-maker uses PROMETHEE IV, the sample points must be compared with all infinite possible values belonging to the alternative set (sample space).

The next section of this paper presents a literature review of the applications of PROMETHEE IV, revealing the existing gap of this method in the OR and engineering field and the absence of practical applications. In addition, the third section describes the decision model, which is a modified version of PROMETHEE IV that could be used when the set of criteria is assumed to have continuous random variables, a situation that is commonly encountered in engineering decision-making problems. It is assumed that these continuous random variables are sampled from a hypothetical infinite population and used to construct PROMETHEE IV through kernel density estimation, thereby contributing to the practice of decision-making in the OR and engineering field.

Section 4 presents a theoretical application of the decision model using Columbus's data provided by Anselin (1988) for ranking the best sites for construction in Columbus, Ohio. Finally, in the last section, the concluding remarks are presented.

2 Literature Review

Briefly, the PROMETHEE family emerged in Europe, primarily based on the work of Brans et al. (1984); its goal is to find the most convenient solution in situations where decision-makers previously identified criteria and alternatives, i.e. it does not address the structuring phase but only addresses evaluation and prioritises the most suitable alternatives, providing management with an overview of the business and enabling better decisions. This family of methods is summarised in Table 1.

The civil engineering field is permeated by a large number of continuous variables, such as the size of the area, the expected site profit and the risk of construction. An example of a tool that can be used to rank the best sites for construction is the PROMETHEE IV (Preference Ranking Organisation method for Enrichment of Evaluations), developed by Brans et al. (1984, p 488). This method is capable of constructing a rank of net flow scores using a set of continuous alternative values for each criterion. However, in spite of the large amount of possible continuous sets of alternatives for the criteria (e.g. income, risk and percentage) that are useful to the process of decision-making, few articles try to explore PROMETHEE IV.

Moreover, it was realised that the decision-making process for managers and engineers should consider multiple criteria, which is essential for a good decision-making; as a result, the use of the PROMETHEE approach is valid and provides support to the decision analyst to choose the most appropriate alternative in a structured and systematic way.

The historical timeline of PROMETHEE IV starts with Brans et al. (1986). The authors described outranking methods in multi-criteria analysis using PROMETHEE, which is considered to be a simple, clear and stable approach. Brans et al. (1986) explained that the parameters fixed in the PROMETHEE family have an economic significance for the decision-maker to easily determine their values. The authors, nevertheless, only commented on the features of PROMETHEE IV, without applying them.

Hendriks et al. (1992) mentioned that interest in multi-criteria decision-making techniques is increasing. Considering this, the authors provided a theoretical description of some of these techniques and an overview of the differences and similarities between them. The authors only mentioned PROMETHEE IV as a method that was developed for one to address an infinite set of alternative actions.

Table 1 PROMETHEE family overview. The author (2014)

PROMETHEE I	Establishes a partial pre-order between the alternatives, ordering them as preferred, indifferent or incomparable
PROMETHEE II	Establishes a complete pre-order between the alternatives, ranking the most efficient to the least efficient. The difference between assessments generates the sort index and the net outranking flow, which is used to make decisions
PROMETHEE III	Extends the notion of indifference, with a probabilistic framework of flows (interval preference)
PROMETHEE IV	Establishing a full or partial pre-order, which is used for ranking problems of choice and intended for situations where the set of feasible solutions is ongoing
PROMETHEE V	Starts with a complete ordering among the alternatives (PROMETHEE II) for later introduction of restrictions to the selected alternative, using integer programming methodologies

Almeida and Costa (2002) proposed a decision modelling approach to select the modules of an information system. This new method presents an ordering of the module information systems based on the establishment of criteria weights and on the decision-maker's preferences regarding each criterion. The priority information system is characterised as a problem that supports multi-criteria decision-making. In their work, Almeida and Costa (2002) only explained that both PROMETHEE III and PROMETHEE IV methods manage to address more sophisticated decision problems, particularly those with a stochastic component.

Brans and Mareschal (2005) presented an overview of the PROMETHEE methodology. They performed a sensitivity analysis procedure over the PROMETHEE IV. According to their analysis, PROMETHEE IV provides additional information to the decision-maker in his own multi-criteria problem. PROMETHEE IV allows one to appreciate whether the problem is either difficult or easy according to the opinion of the decision-maker.

Cavalcante and De Almeida (2007) argued that in the PROMETHEE family, method IV refers to either a partial or a complete pre-order. PROMETHEE IV is related to choice and to ordering problems. Another characteristic of PROMETHEE IV is that it is aimed to be applied to situations in which the set of feasible solutions is continuous.

Behzadian et al. (2010) indicate that PROMETHEE III, PROMETHEE IV, PROMETHEE V, PROMETHEE VI, GDSS and module GAIA were developed to address more complicated decision-making situations. PROMETHEE IV was developed for the complete or partial ranking of alternatives when the set of viable solutions is continuous.

Tzeng and Huang (2011) explained the concept of the PROMETHEE methods. These authors began their work by mentioning the seminal work of Brans et al. (1984). The authors explained the function of PROMETHEE IV, which can be used when a set of feasible solutions is continuous. They argue that PROMETHEE IV extends the use of PROMETHEE II and that these types of infinite sets occur, for example, when the actions correspond to percentages, dimensions of a product, compositions of an alloy and investments.

In civil engineering, no articles were found using PROMETHEE IV; in fact, regarding the most often cited works, which involve water distribution systems and project evaluations, such as Abu-Taleb and Mareschal (1995) and Nowak (2005), respectively, none of these studies used PROMETHEE IV.

In all of the researched papers, PROMETHEE IV is only referenced as a possible tool, mainly because of the apparent difficulty in the usage of a set of continuous alternatives. However, Eppe and De Smet (2012) explained that the PROMETHEE IV was never applied in empirical research, except by the seminal text of Brans et al. (1984), which presented a theoretical application of the PROMETHEE IV. Hence, this chapter provides the reader not only with a new way to use PROMETHEE IV but also with an empirical application in civil engineering of this method.

3 Decision Model

The proposed model that could be used in the decisions in management and civil engineering begins with $k = 1, \ldots, m$ criteria and $i = 1, \ldots, n$ alternatives, which were assumed to draw from the sample space A_k with the probability density function given by $f_k(x)$. In a statistical viewpoint, the collected data are assumed to be drawn from an infinite and therefore imagined population consisting of all possible values, including all deviations from the population parameter due to measurement error or other stochastic environmental effects (Fisher 1950, p 700). Usually, the sample units are available to the decision-maker in a *tableau* form, such as the one represented by Table 2.

Because the values x_{ik} for $k = 1, \ldots, m$ and $i = 1, \ldots, n$ are sampled from a continuous sample space A_k, PROMETHEE IV is appropriate for the decision analysis. However, some questions might arise if the analyst wants to use the classical PROMETHEE IV, such as "Which integrals limits should be used?"

In fact, if the integral limits are plus and minus infinity, the integral will diverge for most of the preference functions, so finite limits should be used, such as the minimum and maximum values of the sample. If the range is large, then the integral result will be large and the usefulness of the analysis could be spoiled; furthermore, not all of the values should have the same impact on the integral. Another interesting question that may arise from the analysis is related to the fact that because the observations rely on a data generating process specified by $f_k(x)$, values near the mode should have more impact on the integral in comparison with rare elements, i.e. values near the distribution tail. Nevertheless, classical PROMETHEE IV equally weights all observations, which can be inadequate if the decision-maker requires more impact for the most frequent data.

With this in mind, it is possible to propose a new version of PROMETHEE IV that can treat a continuous alternative set in a probabilistic framework dealing with infinite limits in the integral and weighting the sample points according to their frequency.

Consider a preference function $P_k(x_{ak}, x_{bk}) = \mathcal{P}_k\left(\delta_k^{ab}\right)$, where $\delta_k^{ab} = x_{ak} - x_{bk}$ for the ath and bth alternatives, with $k = 1, \ldots, m$ and $(x_{ak}, x_{bk}) \in A_k$. The leaving

Table 2 Tableau form used in the PROMETHEE methods. The author (2014)

Alternative	Criteria 1	…	Criteria k	…	Criteria m
Alternative 1	x_{11}	…	x_{k1}	…	x_{1m}
⋮	⋮	…	…	…	⋮
Alternative i	x_{i1}	…	x_{ik}	…	x_{im}
⋮	⋮	…	…	…	⋮
Alternative n	x_{n1}	…	x_{nk}	…	x_{nm}

flow, the entering flow and the net flow for the continuous set A_k are defined as follows:

$$\phi^+(x_{ak}) = \int\limits_{A_k} f(x_{bk})\, P_k(x_{ak}, x_{bk}) \mathrm{d}x_{bk} \quad (1)$$

$$\phi^-(x_{ak}) = \int\limits_{A_k} f(x_{bk})\, P_k(x_{bk}, x_{ak}) \mathrm{d}x_{bk} \quad (2)$$

$$\phi(x_{ak}) = \phi^+(x_{ak}) - \phi^-(x_{ak}), \quad (3)$$

and the complete flow is described by the follow equation:

$$\phi(x_{a.}) = \sum_{k=1}^{m} w_k \left[\phi^+(x_{ak}) - \phi^-(x_{ak})\right] \quad (4)$$

Here, $w_k > 0$, $k = 1, \ldots, m$ represents the weight for the kth criteria, in a way that $\sum_{k=1}^{m} w_k = 1$ and $f(x_{bk})$ is the probability density function for the random variable $X_{.k}$. Note that Eqs. (1) and (2) represent the expected values for the preference functions $P_k(x_{ak}, x_{bk})$ and $P_k(x_{bk}, x_{ak})$, respectively, thereby providing them with an intuitive interpretation. In other words, the leaving flow and the entering flow could be observed as expected values of the preference functions. Because the probability density function is usually unknown, it is possible to estimate it using kernel density estimation (Silverman 1986):

$$\hat{\phi}^+(x_{ak}) = \int\limits_{A_k} \hat{f}(x_{bk})\, P_k(x_{ak}, x_{bk}) \mathrm{d}x_{bk} \quad (5)$$

$$\hat{\phi}^-(x_{ak}) = \int\limits_{A_k} \hat{f}(x_{bk})\, P_k(x_{bk}, x_{ak}) \mathrm{d}x_{bk}, \quad (6)$$

where $\hat{f}(x_{bk}) = \frac{1}{nh_k} \sum_{i=1}^{n} K\left(\frac{x_{bk} - x_{ik}}{h_k}\right)$ and h_k is the bandwidth for the kth criteria and $K(.)$. The estimated net flow and the complete flow are obtained using $\hat{\phi}^+(x_{ak})$ and $\hat{\phi}^-(x_{ak})$ as plug-in estimators into (3) and (4). This implementation has the ability to increase the preference function's weight for criteria near the mean and decrease the weight for the extreme difference values, producing convergent integrals for the net flow scores. The modified PROMETHEE IV can be expressed by the follow steps (Fig. 1).

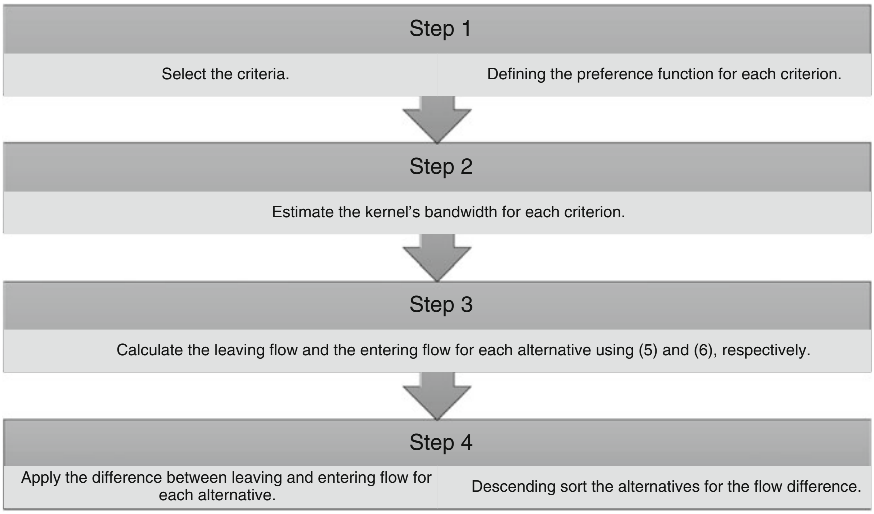

Fig. 1 Decision process steps in PROMETHEE IV. The author (2014)

The ranking created by modified PROMETHEE IV is then used to choose the best alternatives because its rank sorts the best to the worst alternative and provides a tool for decision-makers considering multiple criteria, directions and preference functions.

4 Application of the Decision Model

With the use of the previously proposed method, an empirical application was developed for civil engineering; specifically, the data provide from Anselin (1988) was used to make this empirical application. The data consist of 49 contiguous planning neighbourhoods in Columbus, Ohio; these data correspond to census tracts or aggregates of a small number of census tracts in 1980 and are representative of the type of data used in many empirical urban analyses (Anselin 1988, p 187). Our purpose is to evaluate the most propitious sites for construction, so we defined the follow variables, directions, preference functions, parameters and weights.

In Table 3, p and q are the indifference and preference parameters, respectively; furthermore, the bandwidth for each criterion's kernel density estimator was calculated using the approach proposed by Silverman (1986, p 48, Eq. (3.31)). The results are shown in Fig. 2.

Figure 2 shows the best sites at which to build; specifically, when the darker the polygon is, the lower is the quality based on the net flow generated by PROMETHEE IV. Note that the centred polygons were the worst sites at which to build; in

Table 3 Variables used in PROMETHEE IV through kernel density estimation. The author (2014)

Variable	Direction	Preference function	Parameters	Weight
Housing value, in $1,000	Maximise	V-sharp	$p = 5$	0.25
Household income, in $1,000	Maximise	Level criterion	$p = 0.5$, $q = 2$	0.10
Residential burglaries and vehicle thefts per 1,000 households	Minimise	Linear criterion	$p = 5$, $q = 10$	0.25
Open space (area)	Maximise	Quasi-criterion	$p = 0.5$, $q = 1$	0.20
Percentage of housing units without plumbing	Minimise	Linear criterion	$p = 0.5$, $q = 1$	0.20

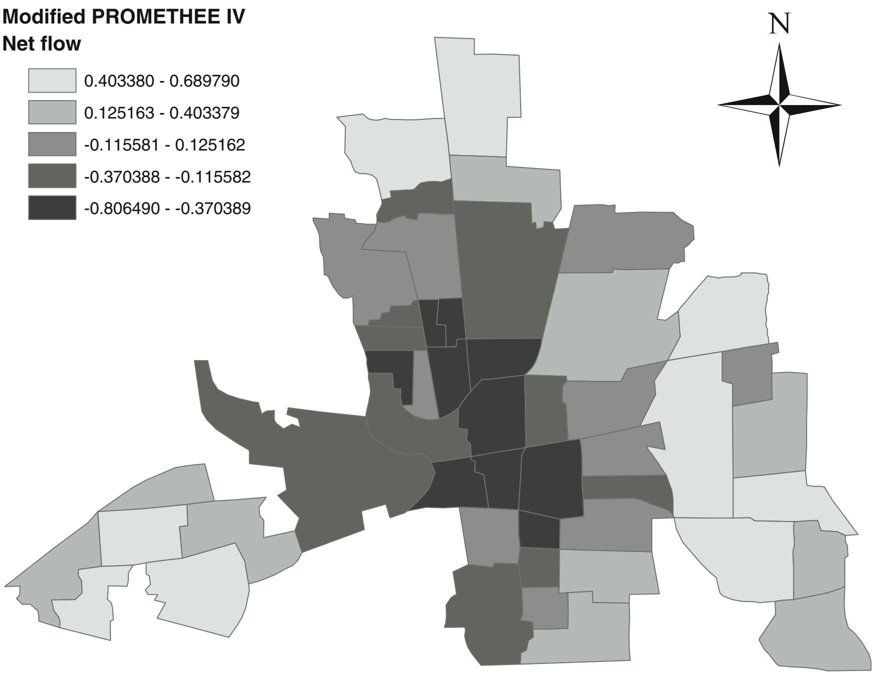

Fig. 2 Net flow generated by the modified PROMETHEE IV method for the criteria specified in Table 2. The author (2014)

fact, these results agree with the findings of Anselin (1988). It is possible evaluate the geographical sensitivity of PROMETHEE IV by using Moran's Index (1950), which provides the value of 0.592168 for the spatial autocorrelations with a p-value less than 0.001 corroborating for the statistical significance for the index.

Because the null hypothesis of spatial independence between the sites was rejected, it is possible to infer that some of the best (and worst) sites for construction are spatially correlated, which is important information for the civil engineering decision process. Hence, the best sites are spatially close; thus, the decision of which site to choose is restricted to a smaller sample, thereby facilitating the decision-making.

5 Concluding Remarks

This paper presented a new version of PROMETHEE IV that considers the empirical distribution of the criteria through kernel density estimation to evaluate the alternatives. The method developed has the ability to treat criteria according its distribution. Criteria with small variance should weigh the criterion in a different way than the weights for criteria of large variance. The proposed method can be used for the managers and civil engineers who must make decisions involving multiple continuous criteria. In fact, the engineering field is filled with continuous variables that can be analysed using, PROMETHEE IV.

Note that PROMETHEE IV was applied in only a few reports in the literature, probably because of the divergent integrals generated by the classical PROMETHEE IV; our proposed modification overcomes this difficulty with kernel implementation, enabling the analyst to use this decision-making tool in practice.

One limitation of the proposed method is that the down weighting of the extreme values by accounting for their low probability may actually skew the decision in the wrong direction because it is affects the net flow scores, thereby leading to a high-risk exposure or foregone benefits of the right decision, mostly in the case with significant heterogeneity within the criteria. However, this effect can be controlled choosing another preference function by defining a large preference or indifference parameters for these functions or by using fat-tailed kernels.

Other questions—such as the impact of the usage of other bandwidth estimators in the ranking evaluated, as proposed by Scott (1992) and Sheather and Jones (1991)—remain open. As a limitation, note that the proposed method could only be used for continuous data. In the case of discrete data or mixed data, other approaches could be proposed, for example, using discrete kernels (Rajagopalan and Lall 1995).

Furthermore, proposed future work involves an evaluation of the PROMETHEE IV method in comparison with other PROMETHEE family members using a tool to measure their sensitivity. Specifically, according to Wolters and Mareschal (1995), the results obtained through the application of a multiple criteria decision aid method are strongly related to the actual values assigned to these data; therefore, a sensitivity analysis should be performed.

As previously reported, classic PROMETHEE IV could produce divergent integrals, which could be the reason why it has been little explored in the literature. The proposed method overcomes this situation because large values (i.e. values that sufficiently deviate from the mean) have little weight compared to values near the mean.

Finally, an empirical application using the proposed method was developed, demonstrating the implementation of this new method for decision-making in civil engineering for Columbus, Ohio, which aims to select the best sites for construction based on some continuous data.

References

Abu-Taleb MF, Mareschal B (1995) Water resources planning in the middle east: application of the PROMETHEE V multicriteria method. Eur J Oper Res 81:500–511

Almeida AT, Costa APCS (2002) Multicriteria model for decision prioritization of information systems based on PROMETHEE. Gest Prod 9:201–214

Anselin L (1988) Spatial econometrics: methods and models, vol 4. Springer, Berlin

Behzadian M, Kazemzadeh RB, Albadvi A, Aghdasi M (2010) PROMETHEE: a comprehensive literature review on methodologies and applications. Eur J Oper Res 200:198–215

Brans JP, Mareschal B, Vincke PH (1984) PROMETHEE: a new family of outranking methods in multicriteria analysis. In: Brans JP (ed) OR'84

Brans JP, Vincke P, Mareschal B (1986) How to select and how to rank projects: the PROMETHEE method. Eur J Oper Res 24:228–238

Brans JP, Mareschal B (2005) PROMETHEE method. In: Multiple criteria decision analysis: state of the art surveys. Springer, Berlin

Cavalcante CAV, De Almeida AT (2007) A multi-criteria decision-aiding model using PROMETHEE III for preventive maintenance planning under uncertain conditions. J Qual Maintenance Eng 13:385–397

Eppe S, De Smet Y (2012) Approximating PROMETHEE II's net flow scores by piecewise linear value functions CoDE-SMG–technical report series

Fisher RA (1950) Theory of statistical estimation. In: Contributions to mathematical statistics. Wiley, New York

Hendriks MM, de Boer JH, Smilde AK, Doornbos DA (1992) Multicriteria decision making. Chemometr Intell Lab Syst 16:175–191

Moran PAP (1950) Notes on continuous stochastic phenomena. Biometrika 37:17–23

Nowak M (2005) Investment projects evaluation by simulation and multiple criteria decision aiding procedure. J Civ Eng Manag 11:193–202

Rajagopalan B, Lall U (1995) A kernel estimator for discrete distributions. J Nonparametric Stat 4:409–426

Scott DW (1992) Multivariate density estimation: theory, practice, and visualization. Wiley, New York

Sheather SJ, Jones MC (1991) A reliable data-based bandwidth selection method for kernel density estimation. J Roy Stat Soc B 53:683–690

Silverman BW (1986) Density estimation for statistics and data analysis, vol 26. CRC press, Boca Raton

Tzeng GH, Huang JJ (2011) PROMETHEE method. In: Multiple attribute decision making: methods and applications. CRC Press, Boca Raton, p 95

Wolters WTM, Mareschal B (1995) Novel types of sensitivity analysis for additive MCDM methods. Eur J Oper Res 81:281–290

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Part VII
Decision Model in Waste Management

Decision Models in E-waste Management and Policy: A Review

Lúcia Helena Xavier and Belarmino Adenso-Díaz

Abstract Environmental regulation compliance and economic benefits represent the main motivation factors for electronic waste (e-waste) management improvement. Some issues regarding social and economic advantages, environmental impact mitigation, and technological improvement of devices seem to be conflicting; at the same time, stakeholders need to be prepared to lead with a wide range of knowledge to minimize error during decision-making, and for assisting in those tasks, information systems seem to be a very helpful tool. A considerable number of modeling tools are available to waste electrical electronic equipment (WEEE) management and for decision analysis, ranging from supporting in the location of logistic facilities to more operational issues such as deciding what to do with end-of-life (EOL) devices. In this context, we analyze different decision-making tools [decision support systems (DSS)], dealing with the management of e-waste, showing the opportunities that arise around these computer-assisted models. In order to provide sharper information and inspire stakeholders, this review presents a chronological approach about the main tools available, as well as digs looking for promising new approaches that in this context could be useful for the decision makers.

Keywords Decision support system (DSS) · Electronic waste (e-waste) · Decision-making · Models · Policy

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1 The Problem of WEEE Management

Waste management often represents an important area to be regarded by municipalities all over the world. It is a matter of significant complexity that combines aspects related to sanitation, cultural heritage, population economic status, educational level, as well as environmental, social, and economic impacts.

Environmental regulation compliance and economic benefits represent the main motivation factors for electronic waste (e-waste) management improvements. Some issues regarding social and economic advantages, environmental impact mitigation, and technological improvement of devices seem to be conflicting; at the same time, stakeholders need to be prepared to lead with a wide range of knowledge to minimize error during decision-making, and for assisting in those tasks, information systems seem to be a very helpful tool.

One can note that frequent discussions on waste management took place in the last few years regarding, for example, strategies (Bamontia et al. 2011; Desa et al. 2012), technologies (Emmanouila et al. 2013; Iona and Gheorgheb 2014), as well as recent approach on economic and energetic issues (Slavik and Pavel 2013; Dong et al. 2014; Park and Cherlow 2014; Eriksson et al. 2014).

Some authors have been discussing the financial sustainability of waste management (Wilson et al. 2013; Lohri et al. 2014), while others focus on operational aspects (Marshal and Farahbakhsh 2013; Plata-Díaz et al. 2014) or contribute to waste management aspects in developing countries (Ojha et al. 2012; Guerrero et al. 2013). The decision-making process seems to be a common facet to be regarded in all of those different aspects mentioned.

A considerable number of modeling tools are available to waste of electrical and electronic equipment (WEEE) management and for decision analysis, ranging from supporting in the location of logistic facilities to more operational issues such as deciding what to do with end-of-life (EOL) devices. In this context, we analyze different decision-making tools [decision support systems (DSS)], dealing with the management of e-waste, showing the opportunities that arise around these computer-assisted models. In order to provide sharper information and inspire stakeholders, this review presents a chronological approach about the main tools available, as well as digs looking for promising new approaches that in this context could be useful for decision makers.

1.1 *What Is WEEE About?*

WEEE is defined as discarded and EOL electronic products ranging from simple to sophisticated devices (Geethan et al. 2012). Also known as e-waste or technological waste is one of the fastest growing waste streams and has been identified as priority by the European Union (EU) (Dimitrakakis et al. 2009).

There is not only one model for solid waste management or WEEE management to be followed. Different criteria must be regarded in order to accomplish environmental goals, mainly specific rules and laws. While developed countries presented the first environmental laws over than two decades, the developing countries had a later environmental law contribution. In these last countries, the pursuit to become part of global markets seemed to be one of the main reasons to environmental compliance required on legal documents.

The Brazilian National Policy on Solid Waste (NPSW), for example, enacted by Law No. 12305 (Brazil 2010), outlines the hierarchy of options in waste management decision-making, as follows: non-generation, reduction, reuse, recycling, treatment of solid waste, and environmentally sound disposal of waste. Based on this understanding, these aspects should be prioritized throughout the decision-making process related to solid waste management. However, in Europe, the directives suggest the reduction and reusing before the disposal alternatives and always according to producers' responsibility approach.

In practice, what happens is that each locality pursues proposals to meet the local needs. For example, areas with major production of organic waste and an insignificant plastic waste generation tend to focus on composting techniques or energetic use of organic waste rather than focus on plastic recycling facilities.

Another scenario to be regarded is related to waste classification. Whether a residue category is classified as hazardous, regardless of quantity, one must steer efforts to enable the environmentally appropriate disposal. This is exactly the case of e-waste management that requires specific methods and technology in the accomplishment of reverse logistics systems.

It is also worth to mention that the presence of valuable recyclable materials and products in e-waste attracts informal sector in developing countries. Many researchers have been described cases of contamination from handling hazardous waste without suitable safety procedures (ONGONDO 2011). The amount of e-waste produced per year is another aspect to be regarded.

It is shown in Table 1 that USA is the world leader on technological waste producing, followed by China and India, respectively. This aspect is straightly related to consumption habits. Despites being the second and third major e-waste producer, the total per capita amount produced in China and India are one of the lowest due to the large amount of inhabitants in those countries—most of them unable to consume technological products. In some cases, the postconsumer products and materials are exported not as waste, but as reusable devices.

WEEE management is included in the scope of waste management activities, a predominantly urban issue that has gained importance in recent years worldwide, mainly after the Basileia Convention, a transboundary movement regulation on hazardous products, as WEEE.

While in the European Community, even in the early 1990s, the tone of the discussion reference was the impacts of lead on human health, which resulted in the banning of that element in the production of electrical and electronic equipment (EEE), in Latin American countries, the discussions also point to the role of

Table 1 Amount of e-waste generated in some countries

Country	Kg/ha	Kiloton/year (2012)
United States	29.78	9,358.78
China	5.36	7,253.01
India	2.25	2,751.84
Japan	21.49	2,741.76
Germany	23.23	1,899.64
Russia	10.41	1,477.66
Brazil	7.06	1,387.85
France	21.09	1,337.24
Mexico	8.99	1,032.74
Canada	24.72	860.74
Spain	18.01	832.93
Australia	25.23	572.31
Argentina	10.71	439.53
New Zealand	17.04	76.04
Ecuador	5.18	78.91
Chile	10.89	18.98

Source http://step-initiative.org/

scavengers in this chain and, consequently, income and jobs generated from the management of these materials.

The risk of WEEE may be subtle for common users and by this reason result in significant environmental and health impact. While cathode ray tubes (CRT), used in computer and TV monitors, contain hazardous phosphor powder, leaded glass, copper, and other rare metals, fluorescent lamps contain mercury vapor (Aucott 2004). The contamination resulting from e-waste generation seems to be a product of (i) the lack of development, (ii) dissemination of information and knowledge related to the best practices of waste management, (iii) methods for handling hazardous materials, or (iv) managerial and political decision power.

On the one hand, WEEE represents a considerable environmental liability still ignored by producers in developing countries; on the other hand, it is also a market niche that demands knowledge and technology for effective environmental management.

The electronic equipments tend to be reconditioned and reused in developing countries, including in the postconsumer stage. This option is known as consumer consumption cascade, where the equipment which use was discontinued (whether as a result of filing failures or simple replacement by more modern equipment) is refurbished and reused in another phase of its life. Thus, the life cycle of EEE may vary according to the country's economic situation and technological options, among other criteria.

2 Support for Policy Making in WEEE Management

As discussed previously, the lack of information and knowledge is a critical aspect to be regarded on technological waste management. Nevertheless, even if data are available, it would be worthless if there are no tools that could assist in the data processing for the generation of reliable information that could help, in the last instance, to improve the decision quality.

Therefore, specific methods have been developed in order to support complex decisions. Some of these methods use to consider the hierarchy structure, while others consider a set of criteria or only a single criterion, in accordance with the analysis purpose. A DSS applied to waste management may be perceived as a set of methods, tools, and techniques for data management through previous criteria. This outline is provided by legal requirements and managerial procedures, as well as other aspects as business, economic, or political forces. At the same time, the analysis resulting from DSS may contribute for decision-making and policymaking.

Also known as environmental decision support systems (EDSS), the DSS originally designed for environmental management has enjoyed innovative tools (Adenso-Díaz et al. 2005; McIntosh et al. 2011), such as by means of geographical information system (GIS) as suggested by Tavares et al. (2011) in a multicriteria GIS-based analysis.

The decision for sale an appliance is the first part of the cycle where the consumer plays the most important role because it is regulating the market, buying equipment coming from sustainable companies that have respect for the consumer, attesting to the product quality and safety of consumers, and is also concerned with showing your disposal. Nevertheless, the consumer responsibility is not always clear enough. Moreover, other agents of reverse logistics system have portions of responsibility in the management of products and postconsumer materials.

The extended producer responsibility (EPR) was adopted by different countries as a policy instrument together with collection, disposal, and treatment fees. In this context, Korea seems to be pioneer in the proposition of the waste recycling fund (WRF), with the first project for integrating all the private recycling programs, a model replicated later by Taiwan and other countries (Lin et al. 2010).

Coordinated action between different actors and spheres of interest may also be significant. According to Milavantseva and Saphores (2013), the deficiencies in the implementation of legal instruments process could be mitigated from actions connecting economic incentives and environmental education of citizens.

Waste management begins when the consumer has no more their expectations met with the product purchased and therefore decides to discard. According to the 2011 STEP report (STEP 2014), reuse should be prioritized instead of discard, as a means to reduce environmental impacts of electronics equipment. Reuse is a response to the trend of shortening the lifetime of the product, through the maintenance of functionality from actions such as repairing, reconditioning, or remanufacturing. Only when the product is considered obsolete and no longer in condition for reuse, shall be then to consider the following steps for allocation or, in special cases, final disposal.

The 2014 world map on e-waste proposed by STEP report presents an up-to-date overview of generation and management of this waste category.

In summary, we realize that the option for consuming or intended for discard in an environmentally appropriate manner requires knowledge about the alternatives, benefits, and impacts—in order to increase the decision quality.

Table 2 summarizes some of the main countries and also European laws on e-waste. South Korea and Taiwan were pioneers on e-waste management regulation in the 1990s. After that, the European regulation consolidates through the Directives WEEE and RoHS in the early 2000s. Nowadays, 37 states from the United States have specific regulations on the management of e-waste, while Canada, Australia,

Table 2 Specific law on WEEE in some countries (STEP 2014)

Country	Law
Argentina	Buenos Aires—Law No. 14,321 of 2011
Australia	Regulation No. 200, 2011
Brazil	Law No. 12,305 of 2010—National Policy on Solid Waste Decree No. 7,404 of 2010 E-waste law: 9 state laws and 8 municipal laws
Canada	Export and Import of Hazardous Waste and Hazardous Recyclable Material Regulations (EIHWHRMR)
China	Environmental Protection Control for Imported Waste Electric Motors as Raw Materials, Standard GB 16487.8-2005 Regulations on Waste Electrical and Electronic Equipment, Order No. 551, 2008 Circular Economy Law, 2008
Europe	RoHS and WEEE Directives—regulate 11 categories of WEEE for European countries
India	Management of e-Waste, Guidelines, 2008 E-waste (Management and Handling) Rules, Statutory Order 1035 (E), May 2011
Japan	Law for the Promotion of Effective Utilization of Resources (LPUR) of 2001 Law for the Recycling of Specified Kinds of Home Appliances (LRHA) of 2009
New Zealand	AS/NZS 5377, March 2012
South Korea	Introduction of Waste Deposit-Refund System, 1992 Guideline for Improvement of Material/Structure of Products for Stimulating Recycling, 1993 Extended Producer Responsibility System, 2003 Resource Recycling of Electrical and Electronic Equipment and Vehicles, Act No. 8405, 2007
Taiwan	Environmental Protection Administration Taiwan (EPAT) established the Recycling Fund Management (RFM) system, 1998.
United States	Plug-Into eCycling, Guidelines for Materials Management, 2004 Hazardous Waste Management and Cathode Ray Tubes, Final Rule, 40 CFR Parts 9, 260, 261, 271, 28 July 2006 Responsible Recycling (R2) Practices for Use in Accredited Certification Programs for Electronics Recyclers, Best Practice Document, 2008

and New Zealand already have regulations that stipulate fees for cases of inappropriate disposal. Of developing countries, examples such as Brazil, China, and India already have specific regulations. In Latin America, Chile, Argentina, and Colombia have related documents still in progress (RELAC 2014; STEP 2014).

The process of environmentally sound disposal of waste depends on meeting a series of criteria to approach the conceptual model, which would be considered ideal. The model assumes the closing of the cycle with the return of materials to the productive sector and minimizing landfilling.

Brazil was the first developing countries to consolidate a set of regulations regarding waste management and regulation regarding the management of waste EEE. Therefore, management alternatives have emerged, mainly through the National Solid Waste (Law No. 12305 of 2010).

The EC suggests that the electronic equipment is classified into 11 categories. This distribution tends to facilitate discrimination of risk potential of each product class in terms of specifics such as life, composition by type of material and size of equipment, among other requirements for categorization. In 2012 was also reviewed Policy 96, 2002, and a new version was published (Directive 2012/19/EU) (Table 3).

Parallel to the Basel Convention and the EU Directives, the NGO EPEAT, an American initiative for sustainability, proposed the evaluation of electronic products. According to the evaluation result, each electronic product is categorized according to its sustainable profile. The profile bronze is awarded to products that reach all the basic criteria required the silver profile equivalent to products that reach all the basic criteria and at least 50 % of the optional criteria. As the skilled products such as gold are those that reach beyond the basic criteria also reach at least 75 % of the optional criteria.

International proposals for the management of WEEE encourage the elimination of the use of heavy metals such as lead, for example, reducing the impact along the chain and therefore reducing the costs of the steps of post-treatment use and disposal, as transport and disassembly, facilitating further process stages and even the

Table 3 WEEE categories according to Directive 2012/19/EU

1. Large household appliances
2. Small household appliances
3. IT and telecommunications equipment
4. Consumer equipment
5. Lighting equipment
6. Electrical and electronic tools (with the exception of large-scale stationary industrial tools)
7. Toys, leisure, and sports equipment
8. Medical devices (with the exception of all implanted and infected products)
9. Monitoring and control instruments
10. Automatic dispensers
11. Others

final return, and recycling as a raw material of these materials. Investment in sustainable design is also another aspect of great importance in the production, because if this equipment is designed to facilitate disassembling and reuse of parts or materials of its composition, this will facilitate the whole process, generating less waste and increasing recycling rate.

Since the first initiative from EU on the WEEE directives, producers become responsible for their products until the EOL stage (Gamberini et al. 2008). The WEEE and RoHS directives (respectively, 2011/65/EC and 2012/19/EU) were recently updated and remain as the most complete reference on WEEE regulation (Renteria et al. 2011). Some initiatives on e-waste management take into account the alternative of coordinated or integrated actions between different agents engaged due to its high complexity (Grunow and Gobbi 2009).

The importance of e-waste management policy definition is highlighted from different points of view. Achillas et al. (2010a) discusses the importance of the development of necessary infrastructure and the stakeholders' performance in policy making. Other authors, such as Mladineo (1992), focus on public policy decision, and Claassen (2007) regards economical performance. A more complete analysis is proposed by Delden et al. (2011), considering the integration of some criteria, such as drivers, processes, and characteristics of real-world system; economic, environmental, and social domains; interest groups and end-users; engagement with policy process; and ability to provide added value to the decision practices.

The search for suitable decision-making tools is an increasing aspect observed in different countries due to the large degree of uncertainty in the decision-making process related to certain supply chains. The management of e-waste is one of these channels and, therefore, has required special tools that allow the improvement of data collection, the improvement in the generation and management of information, and monitoring of reverse logistics (RL) processes. However, the countries' diversities must be regarded on economic and political areas, the presence or lack of natural resources, as well as the work force availability to RL activities. Thus, some studies have focused case study in developing countries. The income increasing in the last decade, for example, is one of the reasons for the significant technological market increasing and also WEEE generation in Brazil (Araújo et al. 2012).

Beyond environmental sustainability or economic viability, technical efficiency seems to be a primary goal to be pursued regarding the development of tools for decision-making. In this context, Grunow and Gobbi (2009) also emphasize the importance of reliability, one item not much emphasized in the main works done on this subject in recent decades.

3 DSS for Logistics Operations in WEEE Recovery

Recovery and treatment steps of waste management are the core part of a reverse logistic system. The complexity of this system relies on the data reliability and the interrelation among all the stakeholders. Thus, many models, methodologies, and techniques are proposed in order to provide consistency and credibility to any automated information or analysis generated thereafter.

According to Achillas et al. (2012), RL "is one of the most important parameters in the management of waste equipment, and it is particularly important for the manufacturers to control relevant cost in order to be market competitive." They estimate a 50–70 % of total cost the cost of reverse logistics. In other words, reverse logistics seems to be have a central role on waste management system and is responsible for valorization of the reverse supply chain. The higher costs of reverse logistics are emphasized by Kaynak et al. (2014):

> The cost of RL is 9 times higher than the cost of forward logistics because the distribution of the new manufactured goods can be consolidated but as proposed earlier the consolidation of reverse delivery/shipment is possible with the involvement of multiple firms and shared resources (e.g. trucks, inspection units, technology, equipment, facility).

Since the first reviews regarding modeling of this phase (Fleischmann et al. 1997), it was clear the potential in savings and a better use of resources. However, as shown by Morrissey and Browne (2004) and Shih (2001), most of the researches were around municipal solid waste planning or products such as paper or carpets, neglecting the WEEE problem that at the beginning of the decade was receiving full attention.

In general, most of the logistics networks models are based on thinking on the problem as a graph, where nodes are the stakeholders. Figure 1 shows what could be a general conceptual model for WEEE collection. In a real case study, it must be considered criteria such as the generation of e-waste, population to be served by the structure, access routes, types of transportation modes available, location of areas of

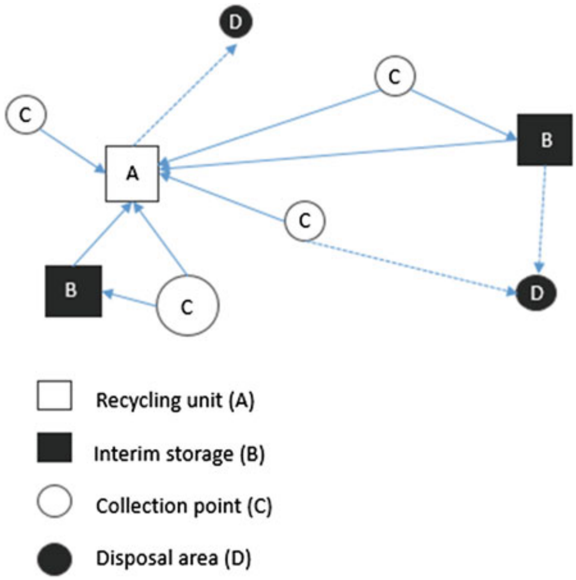

Fig. 1 E-waste reverse logistics network conceptual model (*source* The authors, 2014)

collection, storage, sorting, processing, recycling, and landfill industry, among other criteria that may be relevant. In this schema, the recycling units (A) are able to receive material and products both from the interim warehousing (B) as well as the collection points (C). All the residues produced from the recycling units and that cannot be reinserted in the reverse logistics system must go to landfills (D). The dashed lines show the fluxes from the other activities and the reception in landfills, an alternative that must be regarded in the last case.

One of the first works regarding electronic appliance recycling modeling was due to Sodhi and Reimer (2001). They considered an integral vision of the problem dealing with the different linear models they figured out, seeing the reverse channel as network of flows among three stakeholder (generators, recyclers, and processors) interacting. They defined a *source model*, differentiating among different scenarios (there can be many different appliances at the same location to pick up, or one appliance to collect in different locations); some *recycler models with and without disassembly* (deciding what materials to collect and how to make them flow); and finally a *smelter model* whose objective is how to maximize profits.

A similar approach is due to Gamberini et al. (2008), as well as to Shih (2001), who considers four stakeholders: collection, storage, disassembly, and recycling, and disposal points (i.e., secondary material market, final treatment, and landfill). He defines a MILP formulation to look for the optimal flow among them with the objective of maximizing the revenues minus all costs (treatment, operation, fixed, transportation, and subsidy). As most of the forthcoming papers, after the estimation of the corresponding parameters, his model is applied and tested in a real environment, in this case a region of Taiwan under six different scenarios.

Most of the reverse logistics network definition models defined later on were designed considering an European case, as result of the European directives passed those years as commented above. For instance, Grunow and Gobbi (2009) focused on the Danish WEEE network, specifically assigning collection points to one of the companies (collection schemes) that pick up the appliances. They consider this an important decision because in that way, it is guarantee that all the waste will be collected efficiently. Theirs is a MILP with binary variables defining which scheme will visit which point, with a dynamic version that starting from the current situation will reassign some of the points looking for a fairer distribution as the volumes to pick up evolve.

Achillas et al. (2010a) designed a DSS for optimizing the RL network for WEEE collection in a Greek region. Their model is a MILP formulation that considers the existing facilities, different transportation alternatives, management costs, and types of containers. They claim savings close to one million euros with the new configuration.

Perhaps the only paper dealing with the design of the network in a whole country (Portugal) is due to Gomes et al. (2011). Given a potential superstructure, the volume to collect, capacities, and costs (compensation fees, freight, processing, storage as well as the social cost of non-collection), they determine the hubs and plants location, flows, storage capacity, and volume per facility. The objective is the cost minimization.

Mar-Ortiz et al. (2011) developed a model to redesign the WEEE collection in the Spanish Northwestern region of Galicia. More than three million of tones of WEEE must be picked every year from more than 700 collection points. Their work could be paradigmatic of the types of approaches usually developed for this logistics problem. The two main decisions here, namely facility location and vehicle routing problems (VRP), are in fact closely interrelated. However, given their algorithmic complexity, they tend to be addressed independently in literature, and that was the approach these authors took, considering a hierarchy of decision problems along three phases (see Fig. 2): In the first one, the output will be the location of the depots to be open. According to this design, each collection point is assigned to a depot that will make the first picking up, consolidating all the waste to be sent to the treatment plant. In the first phase, therefore, the location of the best number of depots (including their capacity and types of vehicles) as well as the set of collection points operated from there is determined.

For doing so, a MILP model was defined which could be optimally solved using a commercial solver. In that way, they identified the best set of depots, consisting of five facilities (while previously there were seven in operation in the region, see Fig. 3), thus reassigning all the collection points to the new configuration.

The second phase consists in defining for each depot (and its assigned collection points) the weekly routing to perform. This corresponds to a special version of the VRP that needs to consider the possibility of split loads, with a heterogeneous fleet able to visit all the city’s streets, and date windows to answer in the required time the pickup call (Mar-Ortiz et al. 2013).

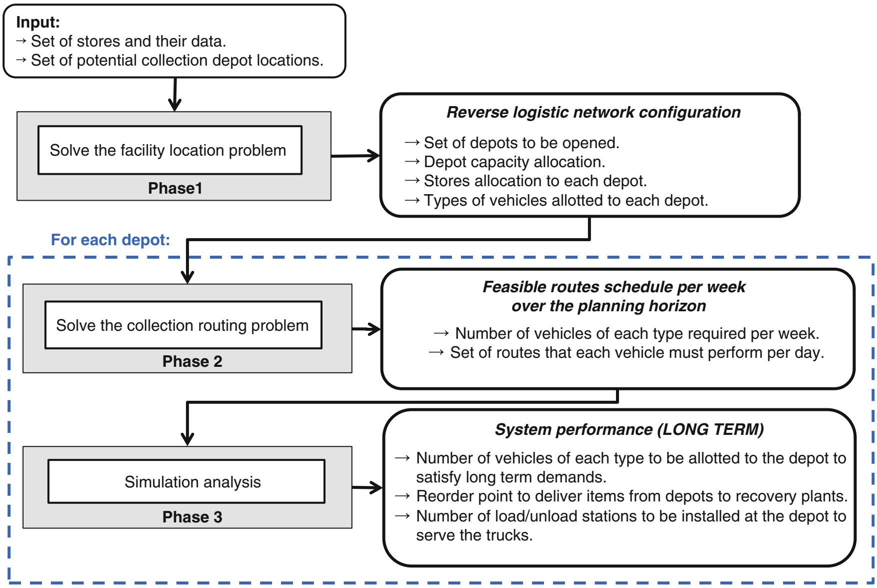

Fig. 2 Hierarchy of decision in the problem of WEEE logistics network (Mar-Ortiz et al. 2011)

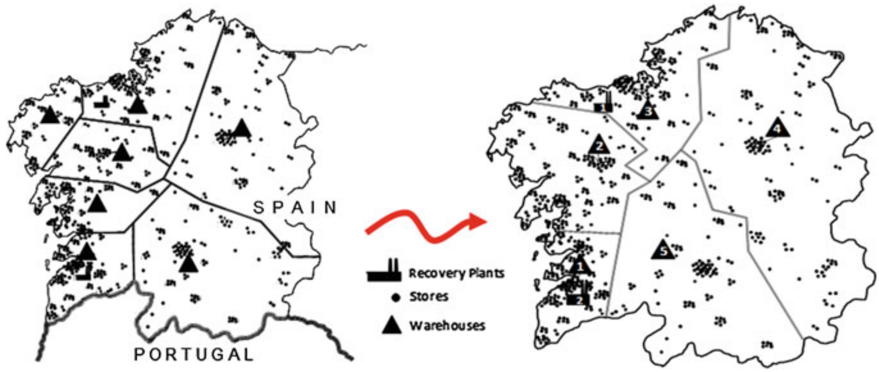

Fig. 3 Re-assignation of the depots and the collection points assigned to each one (Mar-Ortiz et al. 2011)

Since no optimal solution could be obtained in this instance, they developed a heuristic based on the Clarke and Wright's Savings Algorithm, which will provide the daily routes and the final number of required vehicles. Finally, a third phase is required to check the good performance of the depot, considering the number of truckloads, and all other operational aspects, avoiding facility saturation.

They validate the models and analyzed the results obtained, comparing with previous situation. Total saving could be as high as a fifth, mainly due to reduction in the fixed costs.

A different situation was tackled by Gamberini et al. (2010), considering a bi-objective approach, in this case applied in Northern Italy. Taking at the end about an environmental problem, they optimize the WEEE transportation network but considering at the same time both the technical and the environmental perspective. So, they deal with the costs and the impact of the transportation and operations of recycling (measured using LCA for the different scenarios: routes, vehicles, containers). Although this was not the first time in WEEE literature to consider both objectives (they provide a review of previous papers), they provide a whole study of the problem, from the forecasting of the generated WEEE (what is a relevant problem when defining the logistics network given its uncertainty, see Gutiérrez et al. 2010) to the routing, capacity, etc.

Therefore, they use a broad range of techniques for all the design: simulation to test the operative performance such as capacity and working saturation; a heurist approach based on Clarke and Wright's Savings Algorithm for the vehicle routing; for dealing with both technical and environmental objectives, they use the fuzzy optimization method proposed by Fu (2008) selecting one of the solutions previously generated. Achillas et al. (2012) also consider a multiobjective linear programming including total costs and emissions, but they perform a weighted optimization for tackling with both objectives. They claim their model that allows yearly savings of half a million euros in the Greek region where they tested it.

Many others papers can be found, but in most cases with the characteristics already mentioned. For instance, Melacini et al. (2010) propose an interesting approach through the producers' consortia as source of cost reduction. They use a MILP model for assigning flows to consortiums, minimizing the global logistics and administrative costs. Out of Europe, Liu et al. (2010) propose a DSS for the RL network design for WEEE collection. They consider the classical p-hub location problem in a Chinese region, using Lingo for optimization. Later on, they use simulation and qualitative techniques for manual tuning of the solution.

4 Decision Regarding Treatment of WEEE

Once the material is collected and the best design for performing all the related logistics was decided, the next step is to organize what to do with the returned appliances and how. Initially, we could identify two main issues regarding the final phase: when to do all those operations and how the treatment should be performed.

The first of those questions is quite related to the logistics decisions previously commented. Defining the location of processing plants, recycling and storage in a pre-defined geographic area involves both the government and the society. That means that political, social, environmental, and of course economic aspects (the required technology implies high expenditures) must be balanced to a less impacting and more efficient decision. Therefore, usually multiobjective models are taken into account, looking for a ranking of the best alternatives.

To identify the most important criteria to consider, Queiruga et al. (2008) preselected a bunch of 17 aspects that a team of experts reduced to 10. Then, using PROMETHEE, they identify not the optimal alternative but a ranking of the best. In the Spanish case they considered, they found out that the "agglomeration effect" (being close to suppliers and metallic plants) was especially important.

A similar work but using ELECTRE III (a technique that we can find in many papers dealing with location in waste management) is due to Achillas et al. (2010b). They focused on two criteria, namely local acceptance and financial viability, applied to the Greek case. They define the steps followed by many DSS dealing with the best locations for waste facilities as the following:

- Defining alternative potential locations
- Choose the decision criteria (depending on the stakeholders' philosophy) and weightings
- Normalization of quantified values of the criteria for every alternative
- Model run
- Sensitivity analysis
- Repeat and run again if more locations are needed.

A more recent work, in this case applied to the Turkish case, is due to Banar et al. (2014). They consider different MCDM techniques, including AHP, ANP, PROMETHEE, and ELECTRE, for seven criteria and 16 alternatives. They finally offer the best five locations considering those techniques. Again, the decision tool chooses criteria and alternatives and offers a selection of good location, to be later considered.

Many more papers dealt with what to do once in the treatment facility. Here, we can again identify two main streams of researches. A first one helps in the decision of what to do with the recovered material (reuse, shred, landfill, etc.) considering different objectives; also, many others describe the design of products thinking of disassembling the EOL electronic products, given that except for shredding and landfill, disassembly is the previous step to perform.

Regarding the first issue, Fig. 4 shows which are the most commonly considered final alternatives for returned WEEE. We can see them like a hierarchy of alternatives, according to the environmental impact (Zussman et al. 1994). The best options would be the reuse and repairing in order to extend the appliance life; remanufacturing implies some changes in components; shredding for later recycling takes advantages of the materials but all the functionality is lost; lately, disposing of in landfills is the less preferred (being incompatible for poisonous materials). For most of these alternatives, previous disassembly is required (in some cases to extract hazardous materials).

As full disassembly is not usually the ideal solution due to high disassembly costs due to the intensive manual operations needed for this task, many researches deal with the disassembly depth. Usually, the bill of materials (BOM) of the product is necessary to analyze all the structure of the product to decide what to do exactly. For instance, it is possible that a component is decided to be disassembled, but its subcomponents could have each one a different final use (see Fig. 5). Achillas (2013) present a model based on cost-benefit analysis to determine the parts that should be recovered (for reuse or recycling). The maximum depth is four levels

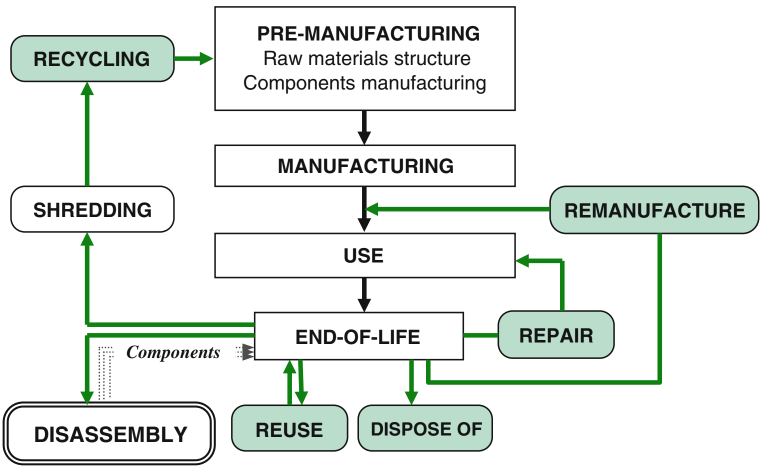

Fig. 4 Life cycle and final alternatives for EOL electrical appliances (González and Adenso-Diaz 2005)

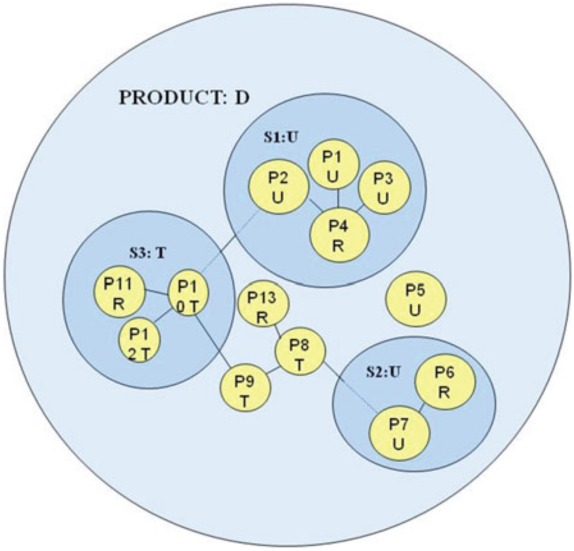

Fig. 5 Example of how every component of a product can have a different final destination. *Key* *D* disassembly; *T* landfill; *U* reuse; *R* recycle; *Sx* components; *Px* subcomponents; *lines* means joints among components (González and Adenso-Diaz 2005)

(what they consider components easy to disassemble) based on the BOM and the value of the components. Their case is ISDN network terminal, being the output what is extracted at each of the four levels studied.

Rentería et al. (2011) present a DSS for selection of operations of recycled WEEE (TV sets and LCDs). The economic viability (considering the income obtained with the sale of the materials) is the main goal pursued, determining which should be the automation level of recycling and the level of material recovered.

To better capture the nature of the problem, again multicriteria environments could be considered. Ravi et al. (2005) present a holistic framework for the selection of alternatives for EOL computers, using ANP and considering four dimensions (customer, internal business, innovation and learning, and finance) inherited from the balanced scorecard. So determine the best operations applied to a small PC manufacturing company.

When talking about multicriteria in this context, usually environmental impact and cost are recurrently considered. Lee et al. (2001) consider both to define the best EOL disassembly level. Their output includes two different EOL charts, one for assisting in product design and the other for determining the optimal level of disassembling, showing the evolving of impact and profit as the time of disassembling increases (disassembly depth). The example considered is a coffee maker machine. A similar work by Yu et al. (2000) considers three objectives (impact, cost, and percentage of recovered material) instead of two, using AHP and fuzzy logic.

Three are also the criteria considered by Kiritsis et al. (2003), namely environmental, economic, and social impact. Given a product with m components, for them an scenario is a m-tuple $\{\langle comp_1; \text{EOL option}\rangle;\ldots;\langle comp_m; \text{EOL option}\rangle\}$ where "EOL option" is one of the six following options: remanufacturing, component reclamation, recycling, incineration with/without energy recovery, and landfill. Therefore, the number of scenarios is quit big (m^6) and a previous filtering is performed to reduce the cardinality. The best scenario is selected based on the scores obtained for each of the three criteria. The methodology is tested with the case of a simple telephone.

Li et al. (2013) also present a multicriteria approach capturing the multiple stakeholders requirements, based on particle swarm optimization (PSO). The geometry and other technical constraints of the product (a LCD in their case) are also considered as that affects the feasible operations during disassembly.

Another multicriteria work is by Bereketli et al. (2011) who use a fuzzy version of LINMAP, a linear model for multiattribute group decision-making, for selecting the best WEEE treatment strategies (among reuse, recycling, and disposal) considering eight criteria. After performing the pairwise comparison by experts, they generate a compromise alternative, ranking the best options using the Copeland's function.

Regarding how disassembly is affected by the product design, the number of papers is quite numerous, starting with a number of works that try to measure the efficiency of the product design thinking of the moment when it must be disassembled [design for disassembly (DFD)]. One of the first is by Das et al. (2000) who define the Disassembly Effort Index (DEI) as a function of seven factors (ease of access, tools used, hazard, etc.) estimating a composed total cost that can be compared with the market value of the disassembled parts. They use a DeskJet printer to test the calculations they propose. In the same line, Kuo (2010) defines a Recyclability Index to measure during the phase of design, the ability of a material to recover its value at the end of its life. An AHP procedure combined with case-based reasoning (CBR) is the methodologies used there.

Hula et al. (2003) also study the robustness of design, analyzing how it affects the best EOL option (shredding, landfill, disassembly, etc.), when the objective is minimizing cost and environmental impact, for varying the EOL scenarios (market changes, variable regulation, etc.). For finding the Pareto set, they use a multiobjective genetic algorithm, comparing results in USA and Germany for the known case of a coffee maker. Santochi et al. (2002) describe the typical modules and steps for the software dealing with disassembly planning.

5 Conclusion

One aspect of capital importance in waste management operations is defining the location of processing plants, recycling, and storage in a pre-defined geographic area. This type of decision involves both the government and the society and the companies involved. To do so, political, social, environmental, and economic aspects must be balanced to a less impacting and more efficient decision.

Another method that may be considered in the evaluation of a set of criteria for decision-making is the definition of the dimension of the decision process. Thus, in

Table 4 Categories of DSS tools for WEEE management

Dimension	Tool	Author(s)
Technical and operational	Simulation MILP MOLP ELECTRE III ELECTRE and PROMETHEE Mathematical formulation	Renteria et al. (2011) Mar-Ortiz et al. (2011) Achillas et al. (2010a, b) Achillas et al. (2012) Sodhi and Reimer (2001) Achillas et al. (2010a, b) Herva and Roca (2013) Achillas et al. (2013)
Management	AHP MILP Delphi–AHP Multicriteria-based AHP	Das et al. (2012) Shi et al. (2014) Melacini et al. (2010) Kim et al. (2013) Rezaei and Ortt (2013)
Modeling	Simulation model Fuzzy–AHP and TOPSIS SWOT–AHP	Liu et al. (2010) Gumus (2009) Seker and Özgürler (2012)

a brief literature review on WEEE solutions, it is possible to classify the alternatives according to its focus, as presented in Table 4.

According to this classification proposed on Table 4, it is possible to observe some examples of DSS applied to WEEE management according to some authors. Different approaches are suggested in several areas such as operational, management, or modeling. In this context, previous studies seem to be important in the choice of the best tool for decision-making process, especially when they are applied in the same area of study.

In this review were presented main articles on e-waste management and policy decision-making tools. Some related issues were highlighted and analyzed in order to provide information and improve the decision-making process.

References

Achillas C, Vlachokostas C, Moussiopoulos T, Banias G (2010a) Decision support system for the optimal location of electrical and electronic waste treatment plants: a case study in Greece. Waste Manage 30(5):870–879

Achillas C, Vlachokostas C, Aidonis D, Moussiopoulos N, Iakovou E, Banias G (2010b) Optimising reverse logistics network to support policy-making in the case of electrical and electronic equipment. Waste Manage 30(12):2592–2600

Achillas Ch, Aidonis D, Vlachokostas Ch, Moussiopoulos N, Banias G, Triantafillou D (2012) A multi-objective decision-making model to select waste electrical and electronic equipment transportation media. Resour Conserv Recycl 66:76–84

Achillas C, Aidonis D, Vlachokostas C, Karagiannidis A, Moussiopoulos N, Loulos V (2013) Depth of manual dismantling analysis: a cost-benefit approach. Waste Manage 33(4):948–956

Adenso-Díaz B, Tuya J, Goitia M (2005) EDSS for the evaluation of alternatives in waste water collecting systems design. Environ Model Softw 20(5):639–649

Araújo MG, Magrini A, Mahler CF, Bilitewski B (2012) A model for estimation of potential generation of waste of electric and electronic equipment in Brazil. Waste Manage 2(2): 335–342

Aucott M, McLindenb M, Winkac M (2004) Release of mercury from broken fluorescent bulbs. In: Environmental assessment and risk analysis element. Research Project Summary. Available at http://www.state.nj.us/dep/dsr/research/mercury-bulbs.pdf. Accessed Aug 2014

Bamontia S, Bonolia A, Tondellib S (2011) Sustainable waste management criteria for local urban plans. Procedia Eng 21:221–228

Banar M, Tulger G, Özkan A (2014) Plant site selection for recycling plants of waste electrical and electronic equipment in Turkey by using multi criteria decision making methods. Environ Eng Manage J 13(1):163–172

Bereketli I, Erol Genevois M, Esra Albayrak Y, Ozyol M (2011) WEEE treatment strategies' evaluation using fuzzy LINMAP method. Expert Syst Appl 38(1):71–79

Brazil. Presidência da República. Casa Civil (2010) Política Nacional de Resíduos Sólidos—NPSW Lei 12.305 de 02 de agosto de 2010. http://www.planalto.gov.br/ccivil_03/_Ato2007-2010/2010/Lei/L12305.htm. Retrieved 24 Feb 2011

Claassen THL (2007) Experiences with DSS in ecologically based water management in the province of Friesland, The Netherlands. Ecol Eng 30(2):176–186

Das SK, Yedlarajiah P, Narendra R (2000) An approach for estimating the end-of-life product disassembly effort and cost. Int J Prod Res 38(3):657–673

Das MC, Sarkar B, Ray S (2012) A framework to measure relative performance of Indian technical institutions using integrated AHP and COPRAS methodology. Socio-Econ Plann 46:230–241

Delden H, Seppelt R, White R, Jakeman AJ (2011) A methodology for the design and development of integrated models for policy support. Environ Model Softw 26(3):266–279

Desa A, Kadir NBA, Yusooff F (2012) Waste education and awareness strategy: towards solid waste management (SWM) program at UKM. Procedia Soc Behav Sci 59:47–50

Dimitrakakis E, Janz A, Bilitewski B, Gidarakos E (2009) Small WEEE: determining recyclables and hazardous substances in plastics. J Hazard Mater 161:913–919

Directive 2012/19/EU on waste electrical and electronic equipment (WEEE) (Recast). http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:197:0038:0071:en:PDF. Retrieved 12 Feb 2014

Dong J, Chi Y, Zou D, Fu C, Juang Q, Ni M (2014) Energy-environment-economy assessment of waste management systems from a life cycle perspective: model development and case study. Appl Energy 11:400–408

Emmanouila MC, Stiakakisa E, Vlachopouloua M, Manthoua V (2013) An analysis of waste and information flows in an ICT waste management system. Procedia Technol 8:157–164

Eriksson O, Bisaillon M, Haraldsson M, Sundberg J (2014) Integrated waste management as a mean to promote renewable energy. Renew Energy 61:38–42

Fleischmann M, Bloemhof-Ruwaard J, Dekker R, van der Laan E, van Nunen J, Van Wassenhove L (1997) Quantitative models for reverse logistics: a review. Eur J Oper Res 103:1–17

Fu G (2008) A fuzzy optimization method for multicriteria decision making: An application to reservoir flood control operation. Expert Syst Appl 34:145–149

Gamberini R, Gebennini E, Grassi A, Mora C, Rimini B (2008) An innovative model for WEEE recovery network management in accordance with the EU directives. Int J Environ Technol Manage 8(4):348–368

Gamberini R, Gebennini E, Manzini R, Ziveri A (2010) On the integration of planning and environmental impact assessment for a WEEE transportation network—a case study. Resour Conserv Recycl 54(11):937–951

Geethan KVA, Jose S, Manikandan VK, Muthuswamy V, Jude SL (2012) Assessment of electronic waste inventory and management model. Int J Appl Environ Sci 7(1):77–92

Gomes MI, Barbosa-Povo AP, Novais AQ (2011) Modelling a recovery network for WEEE: a case study in Portugal. Waste Manage 31(2011):1645–1660

González B, Adenso-Díaz B (2005) A bill of materials-based approach for end-of-life decision making in design for the environment. Int J Prod Res 43(10):2071–2099

Grunow M, Gobbi C (2009) Designing the reverse network for WEEE in Denmark. CIRP Ann Manufact Technol 58(1):391–394

Guerrero LA, Maas G, Hogland W (2013) Solid waste management challenges for cities in developing countries. Waste Manage 33(1):220–232

Gumus AT (2009) Evaluation of hazardous waste transportation firms by using a two step fuzzy-AHP and TOPSIS methodology. Expert Syst Appl 36:4067–4074

Gutiérrez E, Adenso-Díaz B, Lozano S, González-Torre P (2010) A competing risks approach for time estimation of household WEEE disposal. Waste Manage 30(8–9):1643–1652

Herva M, Roca E (2013) Ranking municipal solid waste treatment alternatives based on ecological footprint and multi-criteria analysis. Ecol Ind 25:77–84

Hula A, Jalali K, Hamza K, Skerlos SJ, Saitou K (2003) Multi-criteria decision-making for optimization of product disassembly under multiple situations. Environ Sci Technol 37 (23):5303–5313

Iona I, Gheorgheb FF (2014) The innovator role of technologies in waste management towards the sustainable development. Procedia Econ Finan 8:420–428

Kaynak R, Koçoglu I, Akgün AE (2014) The role of reverse logistics in the concept of logistics centers. Procedia—Soc Behav Sci 109:438–442

Kim M, Jang Y-C, Lee S (2013) Application of Delphi-AHP methods to select the priorities of WEEE for recycling in a waste management decision-making tool. J Environ Manage 128:941–948

Kiritsis D, Bufardi A, Xirouchakis P (2003) Multi-criteria decision aid for product end of life options selection. In: Proceedings of the IEEE international symposium on electronics and the environment, pp 48–53

Kuo TC (2010) Combination of case-based reasoning and analytical hierarchy process for providing intelligent decision support for product recycling strategies. Expert Syst Appl 37 (8):5558–5563

Lee SG, Lye SW, Khoo MK (2001) A multi-objective methodology for evaluating product end-of-life options and disassembly. Int J Adv Manuf Technol 18(2):148–156

Li WD, Xia K, Gao L, Chao K-M (2013) Selective disassembly planning for waste electrical and electronic equipment with case studies on liquid crystal displays. Rob Comput-Integr Manuf 29 (4):248–260

Lin C-H, Wen L, Tsai Y-M (2010) Applying decision-making tools to national e-waste recycling policy: an example of analytic hierarchy process. Waste Manage 30:863–869

Liu X, Qiu J, Liu M (2010) Design and simulation WEEE reverse logistics network in Guangxi. In: Proceedings—2010 international conference on optoelectronics and image processing (ICOIP 2010), vol 1, pp 403–408. Article number 5663025

Lohri CR, Camenzind EJ, Zurbrügg C (2014) Financial sustainability in municipal solid waste management—Costs and revenues in Bahir Dar, Ethiopia. Waste Manage 34:542–552

Mar-Ortiz J, Adenso-Diaz B, González-Velarde JL (2011) Design of a recovery network for WEEE collection: the case of Galicia, Spain. J Oper Res Soc 62(8):1471–1484

Mar-Ortiz J, Adenso-Díaz B, González JL (2013) Designing routes for WEEE collection: the vehicle routing problem with split loads and date windows. J Heuristics 19(2):103–127

Marshal RE, Farahbakhsh K (2013) Systems approaches to integrated solid waste management in developing countries. Waste Manage 33(4):988–1003

McIntosh BS, Ascough JC II, Twery M, Chew J, Elmahdi A, Hasse D, Harou JJ, Hepting D, Cuddy S, Jakeman AJ, Chen S, Kassahun A, Lautenbach S, Matthews K, Merritt W, Quinn NWT, Rodriguez-Roda I, Sieber S, Stavenga M, Sulis A, Ticehurst J (2011) Environmental decision support systems (EDSS) development–Challenges and best practices. Environ Model Softw 26(12):1389–1402

Melacini M, Salgaro A, Brognoli D (2010) A model for the management of WEEE reverse logistics. Inter J Logistics Syst Manage 7(1):1–18

Milovantseva N, Saphores J-D (2013) E-waste bans and U.S. households' preferences for disposing of their e-waste. J Environ Manage 124:8–16

Mladineo N, Lozic I, Stosic S, Mlinaric D, Radica T (1992) An evaluation of multicriteria analysis for DSS in public policy decision. Eur J Oper Res 61(1):219–229

Morrissey AJ, Browne J (2004) Waste management models and their application to sustainable waste management. Waste Manage 24(3):297–308

Ojha A, Reuben AC, Sharma D (2012) Solid waste management in developing countries through plasma arc gasification—an alternative approach. APCBEE Procedia 1:193–198

Ongondo FO, Williams ID, Cherrett TJ (2011) How are WEEE doing? A global review of the management of electrical and electronic wastes. Waste Manage 31(4):714–730

Park JY, Cherlow MR (2014) Establishing and testing the "reuse potential" indicator for managing wastes as resources. J Environ Manage 137:45–53

Plata-Díaz AM, Zafra-Gómez JL, López P, López-Hernández AM (2014) Alternative management structures for municipal waste collection services: The influence of economic and political factors. Waste manage 34(11):1967–1976

Queiruga D, Walther G, González-Benito J, Spengler T (2008) Evaluation of sites for the location of WEEE recycling plants in Spain. Waste Manage 28(1):181–190

Ravi V, Shankar R, Tiwari MK (2005) Analyzing alternatives in reverse logistics for end-of-life computers: ANP and balanced scorecard approach. Comput Ind Eng 48(2):327–356

RELAC (2014) Plataforma regional de residuos electrónicos en latinoamérica y el caribe. Available at http://www.residuoselectronicos.net/. Accessed on Nov 2014

Renteria A, Alvarez E, Perez J, Del Pozo D (2011) A methodology to optimize the recycling process of WEEE: Case of television sets and monitors. Int J Adv Manuf Technol 54 (5–8):789–800

Rezaei J, Ortt R (2013) Multi-criteria supplier segmentation using a fuzzy preference relations based AHP. Eur J Oper Res 225(1):75–84

Santochi M, Dini G, Failli F (2002) Computer aided disassembly planning: state of the art and perspectives. CIRP Ann—Manuf Technol 51(2):507–529

Seker S, Özgürler M (2012) Analysis of the Turkish consumer electronics firm using SWOT-AHP method. Procedia Soc Behav Sci 58:1544–1554

Shi S, Cao J, Feng L, Liang W, Zhang L (2014) Construction of a technique plan repository and evaluation system based on AHP group decision-making for emergency treatment and disposal in chemical pollution accidents. J Hazard Mater 276:200–206

Shih L-H (2001) Reverse logistics system planning for recycling electrical appliances and computers in Taiwan. Resour Conserv Recycl 32(1):55–72

Slavik J, Pavel J (2013) Do the variable charges really increase the effectiveness and economy of waste management? a case study of the Czech Republic. Resourcer Conserv Recycl 70:68–77

Sodhi MS, Reimer B (2001) Models for recycling electronics end-of-life products. OR Spektrum 23(1):97–115

STEP (2014) Solving the e-waste problem. Available at http://www.step-initiative.org/index.php/WorldMap.html. Accessed on Sep 2014

Tavares G, Zsigraiová Z, Semiao V (2011) Multi-criteria GIS-based siting of an incineration plant for municipal solid waste. Waste Manage 31(9–10):1960–1972

Wilson CD, Velis CA, Rodic L (2013) Integrated sustainable waste management in developing countries. Waste Resour Manage 166 (WR2)

Yu Y, Jin K, Zhang HC, Ling FF, Barnes D (2000) A decision-making model for materials management of end-of-life electronic products. J Manuf Sys 19(2):94–107

Zussman E, Kriwet A, Seliger G (1994) Disassembly-oriented assessment methodology to support design for recycling. CIRP Annals - Manuf Technol 43(1):9–14

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Part VIII
Decision Model in Agribusiness

The Impact of Environmental Regulation and Some Strategies for Improving the Eco-Efficiency of Brazilian Agriculture

Carlos Rosano-Peña and Cecílio Elias Daher

Abstract The decision on who will pay for environmental damage to Brazilian agriculture and how this will be done looks like a zero-sum game between environmentalists and farmers. Their different interests, however, do not prevent the development of strategies that maximize social welfare. This work shows that it is possible to produce more with fewer resources and less environmental impact. Following Färe et al. (Rev Econ Stat 71:90–98, 1989) and Picazo-Tadeo et al. (Eur J Oper Res 220:798–809, 2012), we use data envelopment analysis (DEA) and directional distance functions (DDF) to evaluate the impact of environmental regulations on the drop in the productivity and eco-efficiency of Brazilian agriculture. The methodology is applied to the data from 33 decision-making units (DMUs): 27 States of the Federation of Brazil as a whole, and the five geographical regions taken in their entirety—relating to three inputs and three outputs, one of which is desirable and the other two undesirable. The results show that when DMUs face environmental rules preventing free disposal of undesirable output, their potential to increase desirable output is affected. Also an estimate was made of a set of eco-efficiency indicators that, satisfying the Pareto optimality concept, can support the formulation of strategies consistent with the simultaneous optimization of economic and environmental goals. Comparing the results with the commitments made by Brazil to reduce emissions in agriculture by 2020, it is concluded that the country can surpass the goal with technology given only improving the emissions, however, maintaining the level of resource consumption, production, and degraded lands. On the other hand, while trying to maximize production while minimizing land degradation and CO_2

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emissions, a maximum of two years is needed to attain this goal. Additional measures may be used, such as adopting international best practices and developing clean technology innovation. Accordingly, it is recommended that a high priority be given to strategies aimed at improving eco-efficiency and eliminating institutional barriers to transferring and spreading knowledge of best national and international technologies. These strategies can generate greater results in productivity and environmental conservation than other actions aimed at fostering technological innovation. While the cost of imitation of existing clean technology is lower than the cost of innovation, eco-inefficient units can approach the leaders, thus creating the conditions to sustain the convergence of economic and environmental development.

Keywords Brazilian agriculture • Data envelopment analysis • DEA • Eco-efficiency

1 Introduction

Recently, there was heated debate in the Brazilian National Congress and Senate over environment legislation, including a new Forest Law. Two opposing groups stood out: agro-business representatives and environmentalists. Although they do not express a monolithic thought, each of them has its own economic and political agenda on the subject.

Agro-business has been experiencing a boom in recent years. Not only is the internal market growing steadily, but so too is the external demand for agricultural products, mainly from China, the Middle East, and Russia, which has turned it into a buyer market. At the same time, the new Forest Law increased the amount of land farmers must preserve as forest. Brazil has one of the strictest forms of environmental legislation in the world, which stipulates that landowners must conserve a percentage of their land as forest. This ranges from 20 to 80 %, depending on the region. However, environmentalists are demanding an even stricter law. The consequence is lost of sowing fields, which has led the whole of agro-business industry to a new battlefront on combating losses in productivity.

Environmentalists argue that the expansion of Brazilian agriculture has a heavy environmental cost. It is seen as the main reason for deforestation, the loss of biodiversity, pollution, and the exhaustion of hydroresources. Another point put by the environmentalists is that agriculture is one of the principal contributors to greenhouse gases (GHG) emission, while being highly susceptible to climate change. Therefore, environmentalists affirm that legislation and rules that punish polluters, by correcting marketing imperfections through the internalization of externalities, are needed in order to ensure sustainable development, and the search for cleaner technologies.

Having these antagonistic positions in mind, legislators should try to write new laws that not only maximize social well-being and meet environmental demand, but also aid the attainment of economic objectives.

One of the instruments used to solve this dilemma is called an eco-efficiency concept, that of environmental and economic efficiency (EEC). The EEC shows the capacity that a company or the economy has to produce more while using fewer natural resources and causing minimum environmental impact. In other words, eco-efficiency can be improved by reducing the environmental impact and natural resources while maintaining or increasing the value of the output produced, and thus, this concept can be viewed from many perspectives such as at the macroeconomic (national economy), the mesoeconomic (regional), and the microeconomic (company) levels (Mickwitz et al. 2006).

Considering how important eco-efficiency is for agriculture, and, on the other hand, the lack of empirical research studies on the subject in Brazil, our main contribution is to estimate the impact of environmental regulation on agricultural productivity and to develop a set of eco-efficiency indicators that, satisfying the Pareto optimality concept, can be used by ecologists and farmers when pursuing their objectives. In addition, it can support policy makers who seek to maximize social welfare provisions. In order to estimate these results, we use directional distance functions (DDF), combined with data envelopment analysis (DEA).

Apart from this introduction, this work is divided into six sections. In the following two sections, a review of the literature on estimating eco-efficiency is made and the method of DDF, combined with DEA, is discussed. In Sect. 4, the parameters used to measure eco-efficiency in Brazilian agriculture are described. In Sect. 5, we present the results of our research, and we draw conclusions in Sect. 6.

2 Review of the Literature

According to Zhang et al. (2008), eco-efficiency was first used in the 1970s, being referred to by Freeman (1973) as environmental efficiency. In the 1980s, Pittman (1983) proposed a revision of the traditional methodology including undesirable products and using their shadow prices, when calculating productivity. In the 1990s, Schaltegger (1996) used the concept of eco-efficiency as an empirical estimate of sustainability. Afterward, the concept was popularized by OECD (1998) and Elkington (1999) as a practice to be followed by companies who seek greater competitiveness and environmental responsibility. As Porter and Van Der Linde (1995) stated, eco-efficiency is an established practice and is even used as a competitive tool, as demonstrated by the number of researchers, politicians, and managers who believe that it can be important for companies and even countries.

The work of Verfaillie and Bidwell (2000) developed a framework with eight indicators to be used as a measure of “progress toward economic and environmental sustainability”. For them, eco-efficiency may be represented as a ratio between the product or service value and its environmental influence.

Based on a similar understanding, other methods have been developed, of which two stand out: stochastic frontier analysis (SFA) and DEA. They differ from each other in terms of their data requirements, their behavioral assumptions, and the performance measurement they produce (Lampe and Hilgers 2015).

SFA is an analytical approach that uses parametric methods whose models of production recognize technical inefficiency and the fact that unexpected events beyond the producers' control may affect productivity. Given the specification of a suitable functional form for the production frontier, SFA enables unknown parameters of the frontier to be estimated. An important extension of this framework is that it allows for more than one type of output and can deal with situations where an individual decision-making unit produces undesirable outputs such as pollution (Fernandaz et al. 2002). These techniques have been used for many purposes in agribusiness. For example, they have enabled a firm level of technical efficiency to be measured, productivity growth over time to be decomposed, and the substitutability of outputs and the shadow prices of pollutants to be investigated (Brümmer et al. 2002; O'Donnell 2010).

DEA is a nonparametric method for estimating production frontiers (so-called deterministic frontiers) and has the advantage that there is no need to specify a functional form for the boundary of the production technology. Rather, the frontier is constructed using the subset of the feasible production set (efficient units), identified by solving a sequence of linear programming problems (LPP). This technique also enables multiple outputs to be dealt with and economic efficiency to be assessed without knowledge of prices (Coelli et al. 2005). This is the main reason for its use here.

The paper of Färe et al. (1986)was the first which used DEA, by taking desirable and undesirable outputs into consideration, thereby adapting the so-called hyperbolical efficiency measures. Among the various models to estimate eco-efficiency using DEA, Tyteca (1996) cites two, giving the following relations: (1) (desirable outputs–inputs)/undesirable outputs; (2) desirable outputs/(inputs + undesirable outputs). Using an example, Scheel (2001) compares other different methods used to model environment-polluting subproducts. In the last few years, Zhang et al. (2008), Picazo-Tadeo and Prior (2009) and Picazo-Tadeo et al. (2012) suggested that using DDF, as proposed by Chung et al. (1997), Färe and Grosskopf (2000, 2005), is one of the most flexible methods to determine eco-efficiency. Both DDF and hyperbolic efficiency measures have emerged as powerful empirical tools to incorporate environmental externalities into traditional production theory, and in assessing the eco-efficiency and the opportunity cost of reducing pollution.

The large number of articles published proves the rapid evolution of DEA efficiency studies that consider environmental externalities. One of its prominent applications is in agriculture. Some examples of the extensive application of DDF in agriculture are found in Färe et al. (2006), Kjærsgaard et al. (2009), Azad and Ancev (2010) and Picazo-Tadeo et al. (2012).

Despite the importance that agriculture has in the Brazilian economy, there are only a few studies that use DEA applied to it. Reviewing the state of the art on the use of the DEA approach in Brazilian agriculture, Gomes (2008) found no more than 20 papers. Most of them adopted DEA classic models, and none of them considered either undesirable outputs or environmental variables. An extensive review by the authors found, also, that the use of DEA in the study of eco-efficiency in Brazilian agriculture is still incipient.

3 Theoretical Framework

Traditionally, the study of efficiency begins with the definition of the production technology that the industry takes as a benchmark, i.e., the generic form by which a vector of inputs is combined and transformed into a vector of goods and services (outputs). This process is characterized by a production possibility set (PPS), which is the set of all input–output combinations that are feasible. In other words, it joins all p nonnegative outputs $(y \in R_{+}^{p})$ that can feasibly be produced with the input nonnegative n-vector $\left(x \in R_{+}^{n}\right)$ in the k decision-maker units (DMUs) observed. Formally, $\text{PPS} = \{(x, y) : x \text{ can produce } y; x, y \geq 0\}$ and must meet the classic axioms formulated by Grosskopf (1986). Graphically bounding the PPS, the production possibilities frontier (PPF) shows either the minimum amount of input needed to produce a given output vector or the maximum possible production to be obtained from a given input vector. That means the frontier is formed by the efficient DMUs. The inefficient ones lie below the frontier, and the inefficient ratios are obtained by comparing the productive units with the efficient ones. The distance a DMU is from the efficient frontier is a measure of its inefficiency.

A tool used to estimate efficiency is one for distance functions developed independently by Shephard (1953) and Malmquist (1953), that is, the reciprocal of the efficiency measures of Farrell (1957), estimated by using the linear programming method of DEA. Distance functions describe a multi-input, multi-output technology using input and output sets. The distance function oriented to outputs can be determined as shown in Eq. 1, considering that $\theta \in (0,\ 1]$

$$D_{\text{o}}(x, y) = \text{Min}\{\theta : (x, y/\theta) \in P(x)\} \tag{1}$$

where $P(x)$ is the output set or the output space with fixed amounts of inputs.

This function measures the distance that separates a productive process from the frontier.

The distance function oriented to inputs is defined as shown in Eq. 2, considering $\delta \geq 1$.

$$D_{\text{i}}(x, y) = \text{Max}\{\delta : (x/\delta, y) \in L(y)\} \tag{2}$$

Equation 2 shows in what proportion inputs can be reduced in the input space, $L(y)$. When $\theta = \delta = 1$, the unit being estimated is efficient. On the other hand, if $\theta < 1$ and $\delta > 1$, it is inefficient.

Therefore, the relationship between the distance function and the Farrell index is represented in Eqs. 3 and 4.

$$D_{\mathrm{o}}(x,y) = [F_0(x,y)]^{-1} \tag{3}$$

$$D_{\mathrm{i}}(x,y) = [F_{\mathrm{i}}(x,y)]^{-1} \tag{4}$$

On adding up the environment-polluting and environment-contaminating subproducts, the new output vector $\left(u \in R_{+}^{m}\right)$ is split into desirable and undesirable subvectors as shown in Eq. 5.

$$u = (y,\ b) \tag{5}$$

where $y \in R_{+}^{q}$ is the desirable subvector; $b \in R_{+}^{q}$ is the undesirable one; and $m = p + q$.

Therefore, $\text{PPS} = \left\{(x,y,b) \in R_{+}^{n+p+q}\right\}$ must assume two additional axioms:

$\forall y \in R_{+}^{p}, \forall b \in R_{+}^{q}, y = 0 \Rightarrow b = 0$ (null-jointness), indicating that production of desirable outputs involves generating undesirable ones. For example, the only way to avoid producing environment-polluting subproducts is to not produce desirable outputs; and

$\forall y \in R_{+}^{p}, \forall b \in R_{+}^{q}, (x,y,b) \in \text{PPS} \Rightarrow (x, \alpha y, \alpha b) \in \text{PPS},\ 0 \leq \alpha \leq 1$ [weak disposability of outputs (WDO)], suggesting that the proportional reduction of both types of outputs is possible, but the isolated elimination of unwanted ones is impossible.

The strict or strong version of this property [strong disposability of outputs (SDO)] states that $\forall y \in R_{+}^{p}, \forall b \in R_{+}^{q}, (x,y,b) \in \text{PPS}, b \leq b' \Rightarrow \left(x, y, b'\right) \in \text{PPS}$, indicating that it is possible to produce a larger amount of b using the same amount of y and x. In other words, reducing the undesirable output does not imply reducing the desirable one, the opportunity cost of reducing the environmental impact being nil.

These properties are used by Färe et al. (1986, 1989) in order to distinguish regulated productive processes (where the environmental impact is restricted by legal norms) from free ones, in the absence of environmental restrictions. Regulated PPS may be represented by the axiom of the weak (restricted) disposability of undesirable outputs (WDO). Under this axiom, the elimination of polluting elements involves a trade-off, a cost measured in terms of opportunities such as the value at which outputs must be reduced, given the available resources. The free PPS is characterized by the axiom of the strong (free) disposability of undesirable outputs (SDO), which allows the free reduction or increase in contamination.

Formally, supposing constant returns to scale and strong disposability of desirable outputs, the PPS that satisfies the weak disposability of undesirable outputs is shown in Eq. 6:

$$\text{PPS}^{w} = \left\{(x,y,b) \in R_{+}^{n+p+q} : Xz \leq x, Yz \geq y, Bz = b, z \in R_{+}^{k}\right\} \tag{6}$$

where z is the intensity vector for every DMU, defining the reference hyperplane and as a result of linear combinations of best practices; $x = (x_1, x_2, \ldots, x_n)$ is the input vector used to produce vector $y = \left(y_1, y_2, \ldots, y_p\right)$ and vector $b = \left(b_1, b_2, \ldots, b_q\right)$;

and $X_{(nxk)}, Y_{(pxk)}$ and $B_{(qxk)}$ represent the desirable inputs and outputs, and undesirable output matrices, respectively, of the sample of the k DMUs analyzed.

The PPS that meets the axioms of the strong disposability of undesirable outputs and strong disposability of desirable outputs is demonstrated in Eq. 7.

$$\text{PPS}^S = \left\{(x, y, b) \in R_+^{n+p+q} : Xz \leq x, Yz \geq y, Bz \geq b, z \in R_+^k\right\} \quad (7)$$

To calculate the ecological efficiency of a DMU, Chung et al. (1997), following Luenberger (1992), introduced the concept of function directional distance which is an extension of Shephard's distance function as shown in Eq. 8.

$$\vec{D} = \left(x, y, b; -g_x, g_y, -g_b\right) = \text{Sup}\left\{\beta : (x - \beta g_x, y + \beta g_y, b - \beta g_b \in \text{PPS}\right\} \quad (8)$$

The β optimum value must be greater or equal to zero. If $\beta = 0$, the unit evaluated is eco-efficient; if $\beta > 0$, it is eco-inefficient. β indicates, in percentage terms, how much the evaluated DMU could increase all desirable outputs while, simultaneously, decreasing the undesirable inputs and subproducts, when the a priori direction, defined by the researcher/decision maker, from the direction vector, is $\left(g_x = 1, g_y = 1, g_b = 1\right)$. For each DMU$^{\text{i}}$, β and z are calculated by solving the LPP, as presented in Eq. 9, assuming constant returns to scale.

$$\begin{array}{llll} & \vec{D}^W = \left(x, y, b, -g_x, g_y, -g_b\right) & = & \text{Max}\,\beta \\ \text{Subject to:} & & & \\ & \left(1 + \beta g_y\right) \times y^{\text{i}} & \leq & Yz \quad (i) \\ & \left(1 - \beta g_b\right) \times b^{\text{i}} & = & Bz \quad (ii) \\ & \left(1 - \beta g_x\right) \times x^{\text{i}} & \geq & Xz \quad (iii) \\ & z & \geq & 0 \quad (iv) \end{array} \quad (9)$$

The efficiency measure (9) considers the existence of rules governing environmental impact, assuming the weak disposal of undesirable outputs and the strong disposal of desirable outputs. It can be adapted to the supposed strict or strong disposal of undesirable outputs by exchanging equality (ii) for inequality $(1 - \beta g_b) \times b \leq Bz$, thus obtaining $\vec{D}^s = \left(x,\ y,\ b;\ -g_x, g_y, -g_b\right)$. For example, the calculation of eco-efficiency of each DMU$^{\text{i}}$, assuming strong disposal of undesirable and desirable outputs, with a fixed vector of inputs, from the direction vector $\left(-g_x = 0, g_y = 1, -g_b = 1\right)$ is represented in Eq. 10.

$$\begin{array}{llll} & \vec{D}^S = \left(x, y, b, -g_x, g_y, -g_b\right) & = & \text{Max}\,\beta \\ \text{Subject to:} & & & \\ & \left(1 + \beta g_y\right) \times y^{\text{i}} & \leq & Yz \quad (i) \\ & \left(1 - \beta g_b\right) \times b^{\text{i}} & = & Bz \quad (ii) \\ & \left(1 - \beta g_x\right) \times x^{\text{i}} & \geq & Xz \quad (iii) \\ & z & \geq & 0 \quad (iv) \end{array} \quad (10)$$

The relationship between the concepts of strong disposal $\vec{D}^S$ and weak disposal $\vec{D}^W$ can be illustrated graphically. To facilitate comprehension, assume that the assessed DMUs (B, C, D, E and F), using a given number of inputs, produce a desirable output and an undesirable byproduct. Thus, in Fig. 1, the area OABCDH represents the PPS^s, whose efficient frontier is formed by the segment $\overline{\text{AB}}$. The OEBCDH area represents the PPS^w, whose efficient frontier (OEB) comprises the DMUs with $\vec{D}^W = 0 : \text{E and B}$.

Thus, F as C, D, and H are eco-inefficient. The level of inefficiency will depend on the direction vector defined a priori. For example, if one wishes to know how much of the desired output of F can be added in, while maintaining the same level of environmental impact and inputs, determining $g = (g_x = 0, g_y = 1, g_b = 0)$, LPP (9) will project F onto $F' = [b^{\text{F}}, y^{\text{F}}(1 + \beta^w g_y)]$ and LPP (10) onto $F'' = [b^F, y^F(1 + \beta^S g_y)]$. The fact that F' assumes a desired output less than attainable with F'' is explained by the presence of stringent regulations regarding undesirable byproducts which require lower production, thereby diverting production inputs in order to reduce their environmental impact. However, since it is technologically unfeasible to reach F'' in real terms, the benchmark unit of F is B (note that $[y^{\text{F}}(1 + \beta^S g_y)] = y^{\text{B}}$), since the lack of environmental regulations allows an increasing release of the undesirable by-product b (in $\Delta b = b^{\text{B}} - b^{\text{F}}$).

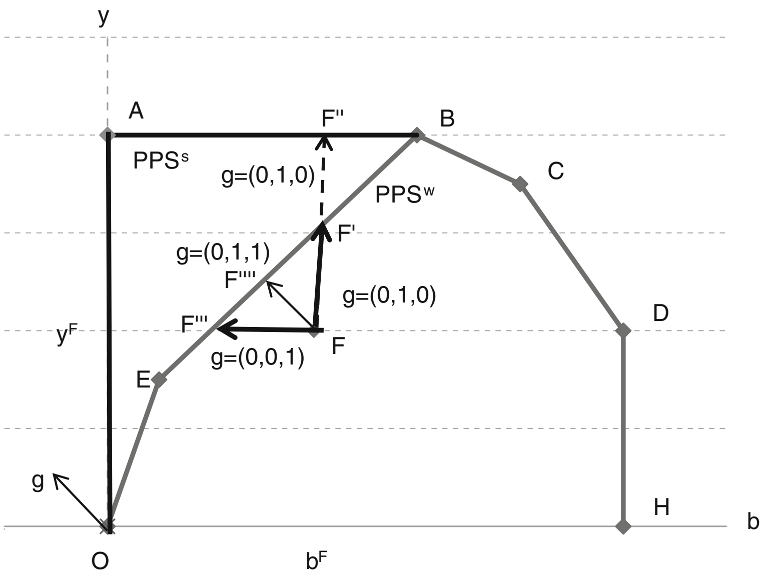

Fig. 1 Set of production possibilities, assuming weak and strong disposals of undesirable outputs (PPS^w and PPS^s), and eco-efficiency indicators

The difference between the values of DDF oriented to maximize the desired output vector $\left(\vec{D}_y^S - \vec{D}_y^W\right)$ is used to estimate the effects of environmental regulation on each DMU[i], evaluated in terms of lost potential product. According to Picazo-Tadeo et al. 2005, for each producer, this measure is obtained as shown in Eq. 11.

$$\text{Opportunity Cost} = y \times \left[\vec{D}_y^S - \vec{D}_y^W\right] \tag{11}$$

Equation 11 estimates the indirect or opportunity cost in terms of desirable output lost because resources must be used in compliance with regulations. It will be greater than zero if environmental legislation restricts the production of desirable outputs, and it will be zero when legislation has a neutral effect on the ability of the DMU[i] to maximize production.

Additionally, in Fig. 1, we see that for every directional vector established a priori, depending on the objectives that the decision maker must pursue, the DDF can be used to calculate different eco-efficiency measures, which satisfy the Pareto optimality concept. This flexibility is particularly important for the purpose of this study, since it identifies the maximum objectives of farmers, environmentalists, or both (or society as a whole). Table 1 records eight possible combinations of the directional vector with its different objectives and key stakeholders.

According to Picazo-Tadeo et al. (2012), a particular case of vector minimization of undesirable by-products (b) can arise when the decision maker is interested only in reducing a particular undesirable output, thus keeping all other undesirable outputs, as well as other variables, fixed. Calling the undesirable output to be minimized b_1, and the other environmental impact b_2, the directional vector is $\left(-g_x = 0,\, g_y = 0, -g_{b1} = 1, -g_{b2} = 0\right)$, and the LPP used to calculate the directional DMU[i] function is defined as (12).

Table 1 Directional vectors, economic and/or environmental objectives, and main stakeholders

No	Combinations	Objectives	Stakeholder
1	$\overrightarrow{D_{\text{u}}^W} = (0,1,1)$	Maximize y and minimize b, with fixed vectors of x	Both
2	$\overrightarrow{D_y^W} = (0,1,0)$	Maximize y, with fixed vectors of x and b	Farmers
3	$\overrightarrow{D_b^W} = (0,0,1)$	Minimize b, with fixed vectors of x and y	Ecologists
4	$\overrightarrow{D^w} = (0,0,0)$	Maintain the status quo	None
5	$\overrightarrow{D_{\text{iu}}^W} = (1,1,1)$	Maximize y and minimize simultaneously x and b	Both
6	$\overrightarrow{D_{\text{iy}}^W} = (1,1,0)$	Maximize y and minimize x, with fixed vectors of b	Farmers
7	$\overrightarrow{D_{\text{i}b}^W} = (1,0,1)$	Minimize b and x, with fixed vectors of y	Both
8	$\overrightarrow{D_{\text{i}}^W} = (1,0,0)$	Minimize x, with fixed vectors of y and b	Farmers

$$
\begin{array}{llcll}
 & \vec{D}^{w} = \left(x, y, b, -g_x = 0, g_y = 0, (-g_{b1} = 1, -g_{b1} = 0\right) & = & \text{Max}\,\beta & \\
\text{Sub. to}: & (1 - \beta g_{b1}) \times b_1^{\mathrm{i}} & = & b_1 z & (i) \\
 & \left(1 + \beta g_y\right) \times y^{\mathrm{i}} & \leq & Yz & (ii) \\
 & (1 - \beta g_{b2}) \times b_2^{\mathrm{i}} & = & b_2 z & (iii) \\
 & (1 - \beta g_x) \times x^{\mathrm{i}} & \geq & Xz & (iv) \\
 & z & \geq & 0 & (v)
\end{array}
\tag{12}
$$

4 Object and Research Variables

Some key features of our object of study (Brazilian agriculture) are the diversified climate, regular rainfall, abundant solar energy, vast and dense river network (13 % of all available freshwater on the planet lies in Brazil), and millions of hectares of fertile and highly productive lands (22 % of arable land in the world). These characteristics make Brazilian agriculture a thriving business that has reached successive production records, but still has immense potential for growth. According to IBGE (2011), in 2011, agriculture represented 4.6 % of Brazil's gross domestic product (GDP), reaching, at current values, R$192.7 billion, or nearly US $ 100 billion. But this sector is the basis of a more comprehensive set called agribusiness, which accounts for about 30 % of GDP, 40 % of total exports, and 37 % of jobs in Brazil (Mendes and Padilha 2007).

Agriculture made Brazil the largest producer and exporter of coffee, sugar, alcohol, and fruit juices. Brazil also ranks first on external sales of soybeans, beef, chicken, tobacco, leather, and leather footwear. According to projections made by the United Nations Food and Agriculture Organization (FAO) and the Organization for Economic Cooperation and Development (OECD), Brazil should become the largest agricultural producer in the world this decade, thus collaborating in reducing food shortages worldwide (OECD 2010).

However, the rapid growth of this industry has also significantly increased its pressure on the environment. The work of Brasil (2010) shows that between 1990 and 2005, GHG emissions in Brazil increased by 62 %–2.2 billion tons of CO_2 equivalent. Of these gases emitted in 2005, approximately 58 % corresponded to activities related to changes in land and forest use, which include deforestation and slash and burn, and 22 %[1] to agriculture and livestock. Regarding this last ratio, 55 % of emissions originate from livestock, from which the enteric fermentation of organic waste generated by nearly 200 million heads of Brazilian cattle produces methane, a greenhouse gas. The other part—45 %—originates from agricultural practices, such as cultivating rice, burning biomass to clear land prior to planting, and excessive use of nitrogenous fertilizers, which lead to producing N_2O, another greenhouse gas (McKinsey 2009).

[1] This ratio shall increase to 30 % by 2030, according to McKinsey (2009).

It is important, therefore, on modeling the performance evaluation of Brazilian agriculture, to consider not only the inputs and traded goods, but also undesirable products, thus internalizing externalities. Moreover, the growing recognition of the environment as a global public good and the existence of different environmental legislation in different Brazilian states have made traditional methods inappropriate, since they consider only inputs and marketed products.

For this research, we used data from 33 DMUs: the 27 States of the Federation plus the Federal District, Brazil, as a whole, and the five geographic regions taken in their entirety, relating to three inputs, one desirable output and two undesirable, all estimated as a ratio, where the basis used was the total area (100 km^2) of farms.

As Gomes (2008) used in most cases, the inputs used in the modeling were as follows:

- x_1—Employees;
- x_2—Agricultural inputs (fertilizers, seeds and seedlings, packaging, pesticides, and animal medicines and feed, electricity, fuels, raw materials, etc.) at R $1,000;
- x_3—Capital estimated by 10 % depreciation of fixed capital assets (machinery, implements, buildings, facilities, etc.) at R$1,000.

As outputs:

- Y—Desirable: Value of total production at R$1,000;
- b_1—Undesirable: Degraded land (eroded, desertified, salinized, etc.) at 1/100 (km^2) scale;
- b_2—Undesirable: Values of emissions of GHG in tons of CO_2 equivalent in 2006.

The first five variables were obtained from the (IBGE 2010).

The variable b_2 was estimated based on four reports of GHG emissions from the agricultural sector, developed by the Brazilian Agricultural Research Corporation (EMBRAPA) for the Second Brazilian Inventory: (a) methane emissions from enteric fermentation and manure management of animals; (b) methane emissions from cultivating rice; (c) GHG emissions from the burning of agricultural waste; and (d) nitrous oxide emissions from agricultural soils and manure management Brasil (2010a, b, c, d).

These reports estimated GHG emissions by region and states in 2006, except for the emissions of nitrous oxide (N_2O) from agricultural soils and manure management. Brasil (2010) reports N_2O emissions, from 1990 to 2006, for the country as a whole. Therefore, considering the rate of growth of these emissions in the last ten years in Brazil and records by States in 1995 reported by Brasil (2006), we estimated the values of N_2O for 2006. From GHG data, we calculated tons of CO_2 equivalent, based on the global temperature potential (GTP) scale.

Table 2 shows the data and descriptive statistics of selected variables that DMUs provided. Notice that the Federal District, which has the smallest land area, is not only the most productive unit of the Federation, but also the one that most pollutes and uses agricultural inputs and capital per km^2 most intensively.

Table 2 DMUs' data, and descriptive statistics of the variables, year 2006

DMU	$x_{1\ \text{personnel}}$	$x_{2\ \text{inputs}}$	$x_{3\ \text{capital}}$	$b_{1\ \text{degraded land}}$	$b_{2\ \text{GHG}}$	$y_{\ \text{production}}$
Rondônia	3.335	7.831	3.864	0.081	0.071	10.214
Acre	2.852	3.121	2.886	0.092	0.031	9.964
Amazonas	7.337	3.973	1.284	0.150	0.023	17.899
Roraima	1.736	2.989	1.187	0.051	0.024	5.819
Pará	3.526	5.087	1.797	0.215	0.048	14.847
Amapá	1.499	0.385	0.549	0.191	0.025	11.470
Tocantins	1.237	7.372	2.271	0.231	0.039	5.352
Maranhão	7.633	7.245	1.526	0.315	0.037	24.027
Piauí	8.750	6.254	2.010	0.865	0.035	13.968
Ceará	14.465	10.535	3.471	0.475	0.041	48.575
Rio Grande do Norte	7.764	6.435	3.795	0.602	0.033	35.164
Paraíba	12.961	13.699	4.068	0.836	0.038	37.592
Pernambuco	17.389	34.700	4.434	0.469	0.055	88.685
Alagoas	21.426	46.460	5.787	0.188	0.077	155.247
Sergipe	18.157	58.566	4.866	0.152	0.063	71.954
Bahia	7.971	18.735	2.474	0.432	0.042	28.838
Mato Grosso do Sul	0.703	12.961	3.592	0.111	0.070	11.855
Mato Grosso	0.750	22.577	3.316	0.142	0.020	20.085
Goiás	1.628	20.363	4.950	0.174	0.028	24.304
Distrito Federal	8.883	85.391	34.947	0.324	5.502	172.222
Minas Gerais	5.810	35.085	6.731	0.301	0.050	57.705
Espírito Santo	11.189	32.192	12.024	0.147	0.148	82.563
Rio de Janeiro	7.695	22.640	10.170	0.155	0.845	60.903
São Paulo	5.453	81.020	14.419	0.097	0.229	152.821
Paraná	7.308	55.061	5.506	0.090	0.085	103.999
Santa Catarina	9.462	58.259	22.835	0.179	0.204	146.911
Rio Grande do Sul	6.098	46.899	15.074	0.137	0.024	82.644
Sum	203.016	705.838	179.834	7.202	7.887	1,495.629
Average	7.519	26.142	6.661	0.267	0.292	55.394
Maximum	21.426	85.391	34.947	0.865	5.502	172.222
Minimum	0.703	0.385	0.549	0.051	0.020	5.352
North	3.022	5.761	2.231	0.181	0.045	11.223
Northeast	10.184	16.262	2.773	0.489	0.042	37.587
Center-West	0.973	19.397	3.876	0.141	0.050	19.114
Southeast	6.053	8.609	9.505	0.225	0.080	88.417
South	7.033	51.556	12.681	0.126	0.053	99.853
Brazil	5.021	25.264	5.384	0.239	0.059	43.590

5 Results and Discussion

Using the data set and the theoretical methodology, described in the previous sections, first, we calculated the DDF with a view to maximizing the desired output vector for each of the analyzed units, taking the existence or absence of legal environmental regulations into consideration. By doing so, we were able to measure the effects of environmental regulation on the decrease in productivity. Secondly, we estimated other eco-efficiency indicators.

In Table 3, the values of D_y^w showed the highest level of output-oriented eco-inefficiency. Only 13 out of the 27 states of the Federation are eco-efficient. The average desirable potential necessary to increase production, while maintaining the level of inputs and undesirable outputs constant, is 0.232. This means that under eco-efficient management, producers could increase their absolute results from R $1,495,629.00 (see Table 2) to R$1,645,240.96 per 100 km^2 of land (see Table 3); that is, they could increase the overall production of the sector by 10 %. This increase would be higher in the absence of environmental regulation: The values of D_y^s confirm an average of 0.576.

In order to compare both results (D_y^w and D_y^s) estimated under alternative scenarios of strong and weak disposal, we used Eq. 11. From this equation, we calculated the opportunity cost for each unit in terms of lost desirable output due to the use of resources in compliance with legislation. From Table 3, we see that the sum of the losses reaches a value of R$311,450.78 per 100 km^2 of land. We also see that in only nine units of the Federation (i.e., states), the impact of environmental legislation is null. Therefore, in 66.6 % of Brazilian states, the existence of environmental constraints has negative results.

The values of the other seven eco-efficiency indicators and improvement strategies for each of the analyzed units are reported in Tables 4, 5, 6, and 7.

In Table 4, the indicator D_{yb}^w, which suggests what percentage the States of the Federation could increase desirable output while simultaneously reducing undesirable by-products at the same level of inputs, reaches an average of 0.195. This means that an effective strategy with environmental responsibility could increase the global production of the sector by 6.7 %, while decreasing the percentage of degraded lands and emissions of GHG by 12.6 and 3.67 %, respectively. This potential, desired by society, is possible in the 15 states located mainly in the north and northeast of Brazil, where $D_{yb}^w > 0$.

D_b^w, alluding to the rate at which the States of the Federation could reduce undesirable outputs with the same level of inputs and outputs, reaches an average of 0.341, as shown in Table 4. This allowed us to estimate the possibilities of reducing both degraded land and emissions of GHG: 23 and 11 %, respectively. This result, of paramount importance to ecologists, can serve as a reference when drawing up environmental legislation and environmental responsibility goals, especially for the 15 eco-inefficient units.

Table 3 Eco-efficiency measures with strong disposal D_y^s and weak disposal D_y^w, output oriented, improvement potential $[y(1 + \overrightarrow{D_y^w})]$, and the opportunity cost of environmental regulation in R $1,000

DMU[i]	$\overrightarrow{D_y^s}$	$\overrightarrow{D_y^w}$	$\overrightarrow{D_y^s} - \overrightarrow{D_y^w}$	$[y(1+\overrightarrow{D_y^w})]$ (R$'000s)	Opportunity cost (R$'000s)
Rondônia	2.450	1.633	0.817	26.89	8.345
Acre	1.525	0.442	1.083	14.37	10.791
Amazonas	0.638	0.130	0.508	20.23	9.093
Roraima	1.893	1.025	0.868	11.78	5.051
Pará	1.163	0.812	0.351	26.90	5.211
Amapá	0.000	0.000	0.000	11.47	0.000
Tocantins	0.000	0.000	0.000	5.35	0.000
Maranhão	0.496	0.344	0.152	32.29	3.652
Piauí	0.000	0.000	0.000	13.97	0.000
Ceará	0.628	0.000	0.628	48.58	30.505
Rio Grande do Norte	0.866	0.000	0.866	35.16	30.452
Paraíba	1.495	0.000	1.495	37.59	56.200
Pernambuco	0.272	0.029	0.243	91.26	21.550
Alagoas	0.000	0.000	0.000	155.25	0.000
Sergipe	0.814	0.751	0.063	125.99	4.533
Bahia	1.060	0.537	0.523	44.32	15.082
Mato Grosso do Sul	0.130	0.130	0.000	13.40	0.000
Mato Grosso	0.000	0.000	0.000	20.09	0.000
Goiás	0.281	0.106	0.175	26.88	4.253
Distrito Federal	0.000	0.000	0.000	172.22	0.000
Minas Gerais	0.530	0.115	0.415	64.34	23.948
Espírito Santo	0.532	0.189	0.343	98.17	28.319
Rio de Janeiro	0.415	0.024	0.391	62.36	23.813
São Paulo	0.000	0.000	0.000	152.82	0.000
Paraná	0.000	0.000	0.000	104.00	0.000
Santa Catarina	0.023	0.000	0.023	146.91	3.379
Rio Grande do Sul	0.330	0.000	0.330	82.64	27.272
Average	0.576	0.232			11.535
Sum				1645.241	311.451
North	1.680	1.293	0.387	25.73	4.343
Northeast	0.779	0.380	0.399	51.87	14.997
Center-West	0.119	0.119	0.000	21.39	0.000
Southeast	0.264	0.030	0.234	91.07	20.689
South	0.234	0.000	0.234	99.85	23.366
Brazil	0.627	0.390	0.237	60.59	10.331

Table 4 Eco-efficiency indicators D_{yb}^{w} and D_{b}^{w}, and improvement targets for each of the analyzed units

DMU^{i}	$\overrightarrow{D_{yb}^{w}}$	$y^{i}(1+\vec{D}_{yb}^{w})$	$b_1^{i}(1-\vec{D}_{yb}^{w})$	$b_2^{i}(1-\vec{D}_{yb}^{w})$	$\overrightarrow{D_{b}^{w}}$	$b_1^{i}(1-\vec{D}_{b}^{w})$	$b_2^{i}(1-\vec{D}_{b}^{w})$
Rondônia	0.784	18.222	0.018	0.015	0.887	0.009	0.008
Acre	0.304	12.993	0.064	0.021	0.842	0.014	0.005
Amazonas	0.086	19.438	0.138	0.021	0.253	0.112	0.017
Roraima	0.728	10.055	0.014	0.007	0.868	0.007	0.003
Pará	0.473	21.870	0.113	0.025	0.851	0.032	0.007
Amapá	0.000	11.470	0.191	0.025	0.000	0.191	0.025
Tocantins	0.923	10.292	0.018	0.003	0.960	0.009	0.002
Maranhão	0.250	30.034	0.236	0.028	0.623	0.119	0.014
Piauí	0.000	13.968	0.865	0.035	0.000	0.865	0.035
Ceará	0.000	48.575	0.475	0.041	0.000	0.475	0.041
Rio G. do Norte	0.000	35.164	0.602	0.033	0.000	0.602	0.033
Paraíba	0.000	37.592	0.836	0.038	0.000	0.836	0.038
Pernambuco	0.018	90.281	0.461	0.054	0.048	0.447	0.052
Alagoas	0.000	155.247	0.188	0.077	0.000	0.188	0.077
Sergipe	0.273	91.597	0.111	0.046	0.429	0.087	0.036
Bahia	0.409	40.633	0.255	0.025	0.618	0.165	0.016
Mato Grosso do Sul	0.624	19.252	0.042	0.026	0.870	0.014	0.009
Mato Grosso	0.000	20.085	0.142	0.020	0.000	0.142	0.020
Goiás	0.106	26.881	0.155	0.025	0.632	0.064	0.010
Distrito Federal	0.000	172.222	0.324	5.502	0.000	0.324	5.502
Minas Gerais	0.093	63.072	0.273	0.046	0.387	0.185	0.031
Espírito Santo	0.179	97.342	0.121	0.122	0.445	0.082	0.082
Rio de Janeiro	0.028	62.608	0.150	0.821	0.505	0.077	0.418

(continued)

Table 4 (continued)

DMU^i	$\overrightarrow{D_{yb}^{w}}$	$y^i(1+\vec{D}_{yb}^{w})$	$b_1^i(1-\vec{D}_{yb}^{w})$	$b_2^i(1-\vec{D}_{yb}^{w})$	$\overrightarrow{D_{b}^{w}}$	$b_1^i(1-\vec{D}_{b}^{w})$	$b_2^i(1-\vec{D}_{b}^{w})$
São Paulo	0.000	152.821	0.097	0.229	0.000	0.097	0.229
Paraná	0.000	103.999	0.090	0.085	0.000	0.090	0.085
Santa Catarina	0.000	146.911	0.179	0.204	0.000	0.179	0.204
Rio Grande do Sul	0.000	82.644	0.137	0.024	0.000	0.137	0.024
Average	0.195				0.341		
Sum		1595.270	6.294	7.597		5.548	7.023
Targets in Δ%		6.7	12.6	3.7		23.0	11.0
North	0.766	19.820	0.042	0.011	0.908	0.017	0.004
Northeast	0.261	47.397	0.361	0.031	0.447	0.270	0.023
Center-West	0.296	24.772	0.099	0.035	0.653	0.049	0.017
Southeast	0.026	90.715	0.219	0.077	0.197	0.181	0.064
South	0.000	99.853	0.126	0.053	0.000	0.126	0.053
Brazil	0.302	56.754	0.167	0.041	0.723	0.066	0.016

In order to assess how much one could increase the desirable production while simultaneously reducing inputs and undesirable by-products, we calculated the indicator D^{w}_{iu}. As stated in Table 5, its average value is 0.083, indicating the average potential to increase desirable production is 8.3 % while simultaneously reducing the level of inputs, the ratio of degraded lands, and emissions of GHG. This potential exists in 13 states, where $D^{w}_{\mathrm{iu}} > 0$. If we consider the overall values of the sector, desirable production may increase by 3.8 %, reducing the number of employees may reach 6.7 %, agricultural inputs −5 %, capital −4.1 %, and the decrease in degraded lands and GHG emissions could be 5.2 and 1.6 %, respectively, as shown in Table 5.

These results show that the discussion of environmental legislation is not necessarily a zero-sum game, in which the sum of the utility obtained by all participants is always equal to nil; that is, what a player receives is directly proportional to what the others lose. Therefore, the apparent antagonism between the farmers and environmentalists does not prevent the formulation of policies consistent with maximizing social welfare, with a view to optimizing both the environmental and economic goals.

Another interesting strategy may arise in the event that producers want to increase productivity (products/inputs ratio) keeping the volume of undesirable by-products unchanged. This strategy can be drawn using the indicator $\vec{D}^{w}_{\mathrm{iy}}$, which reached a mean value of 0.089, as shown in Table 6. Thus, at the same level of environmental impact, the sector can increase the desired output by 4 %, and, at the same time, decrease three inputs by 7, 5.1 and 4.3 %, respectively.

Farmers should be the parties most interested in Table 6. $\vec{D}^{w}_{\mathrm{i}}$ as this shows it is possible to reduce human and capital resources by 14.6 %, on average, keeping the same level of production and environmental impact, if eco-efficient management is used. If the 14 eco-inefficient states of the Federation adopted best practices, the saving of human resources would be 11.8 %, of inputs 8.4, and 7.2 % of capital.

From the directional vector, which seeks to minimize undesirable outputs and inputs with a fixed vector of desirable products, the $\vec{D}^{w}_{\mathrm{i}b}$ indicator is drawn. Its average value is 0.132, as shown in Table 7. Farmers and environmentalists should both be interested in this reduction. From Table 7, $\vec{D}^{w}_{\mathrm{i}b}$ shows that degraded land and GHG can be mitigated by 8.5 and 2.6 %, respectively; employees can be reduced by 10.9 %; capital resources by 8.1 %; and agricultural inputs by 6.7 %.

Finally, those involved in defining international commitments to reduce GHG in Brazil should be interested in knowing by how much GHG emissions can be minimized while keeping the other variables constant. From Table 7, we see that the indicator $\vec{D}^{w}_{b2}$ has an average value of 0.33, suggesting that eco-efficient management could reduce GHG emissions by 82.4 %, *ceteris paribus*.

From the results shown above, we observe a high level of eco-inefficiency in Brazilian agriculture. Only 11 states performed well in all eco-efficiency indicators: São Paulo, Santa Catarina, Paraná, Rio Grande do Sul, Mato Grosso, Rio Grande do

Table 5 Eco-efficiency indicators D_{iu}^{w}, and improvement targets for each of the units analyzed

DMU$^{\mathrm{i}}$	$\vec{D}_{\mathrm{iu}}^{w}$	$x_1^{\mathrm{i}}(1-\vec{D}_{\mathrm{iu}}^{w})$	$x_2^{\mathrm{i}}(1-\vec{D}_{\mathrm{iu}}^{w})$	$x_3^{\mathrm{i}}(1-\vec{D}_{\mathrm{iu}}^{w})$	$b_1^{\mathrm{i}}(1-\vec{D}_{\mathrm{iu}}^{w})$	$b_2^{\mathrm{i}}(1-\vec{D}_{\mathrm{iu}}^{w})$	$y^{\mathrm{i}}(1+\vec{D}_{\mathrm{iu}}^{w})$
Rondônia	0.449	1.837	4.315	2.129	0.045	0.039	14.800
Acre	0.181	2.336	2.556	2.364	0.075	0.025	11.768
Amazonas	0.061	6.890	3.731	1.206	0.141	0.022	18.991
Roraima	0.339	1.147	1.976	0.785	0.034	0.016	7.792
Pará	0.289	2.507	3.617	1.277	0.153	0.034	19.138
Amapá	0.000	1.499	0.385	0.549	0.191	0.025	11.470
Tocantins	0.000	1.237	7.372	2.271	0.231	0.039	5.352
Maranhão	0.147	6.511	6.180	1.302	0.268	0.032	27.559
Piauí	0.000	8.750	6.254	2.010	0.865	0.035	13.968
Ceará	0.000	14.465	10.535	3.471	0.475	0.041	48.575
Rio G. do Norte	0.000	7.764	6.435	3.795	0.602	0.033	35.164
Paraíba	0.000	12.961	13.699	4.068	0.836	0.038	37.592
Pernambuco	0.014	17.145	34.215	4.372	0.463	0.054	89.926
Alagoas	0.000	21.426	46.460	5.787	0.188	0.077	155.247
Sergipe	0.273	13.200	42.578	3.538	0.111	0.046	91.597
Bahia	0.212	6.281	14.763	1.950	0.340	0.033	34.952
Mato G do Sul	0.061	0.660	12.170	3.373	0.104	0.066	12.578
Mato Grosso	0.000	0.750	22.577	3.316	0.142	0.020	20.085
Goiás	0.050	1.546	19.345	4.702	0.165	0.027	25.520
Distrito Federal	0.000	8.883	85.391	34.947	0.324	5.502	172.222
Minas Gerais	0.055	5.491	33.156	6.361	0.285	0.048	60.879
Espírito Santo	0.086	10.227	29.424	10.990	0.135	0.136	89.663
Rio de Janeiro	0.012	7.603	22.369	10.048	0.153	0.835	61.634

(continued)

Table 5 (continued)

DMU^{i}	$\vec{D}^{w}_{iu}$	$x^{i}_{1}(1-\vec{D}^{w}_{iu})$	$x^{i}_{2}(1-\vec{D}^{w}_{iu})$	$x^{i}_{3}(1-\vec{D}^{w}_{iu})$	$b^{i}_{1}(1-\vec{D}^{w}_{iu})$	$b^{i}_{2}(1-\vec{D}^{w}_{iu})$	$y^{i}(1+\vec{D}^{w}_{iu})$
São Paulo	0.000	5.453	81.020	14.419	0.097	0.229	152.821
Paraná	0.000	7.308	55.061	5.506	0.090	0.085	103.999
Santa Catarina	0.000	9.462	58.259	22.835	0.179	0.204	146.911
Rio G. do Sul	0.000	6.098	46.899	15.074	0.137	0.024	82.644
Average	0.083						
Sum		189.437	670.741	172.444	6.828	7.762	1552.848
Targets in Δ%		6.7	5.0	4.1	5.2	1.6	3.8
North	0.393	1.834	3.497	1.354	0.110	0.027	15.634
Northeast	0.160	8.555	13.660	2.329	0.410	0.035	43.601
Center-West	0.056	0.918	18.311	3.659	0.133	0.047	20.185
Southeast	0.015	5.962	47.880	9.363	0.222	0.078	89.743
South	0.000	7.033	51.556	12.681	0.126	0.053	99.853
Brazil	0.163	4.203	21.146	4.506	0.200	0.049	50.695

Table 6 Eco-efficiency indicators $\vec{D}_{iy}^{w}$, $\vec{D}_{i}^{w}$, and improvement targets for each of the units analyzed

DMU^{i}	$\vec{D}_{iy}^{w}$	$x_1^i\left(1-\vec{D}_{iy}^{w}\right)$	$x_2^i\left(1-\vec{D}_{iy}^{w}\right)$	$x_3^i\left(1-\vec{D}_{iy}^{w}\right)$	$y^i\left(1+\vec{D}_{iy}^{w}\right)$	$\vec{D}_{i}^{w}$	$x_1^i(1-\vec{D}_{i}^{w})$	$x_2^i(1-\vec{D}_{i}^{w})$	$x_3^i(1-\vec{D}_{i}^{w})$
Rondônia	0.48	1.73	4.06	2.00	15.14	0.68	1.05	2.47	1.22
Acre	0.22	2.22	2.43	2.24	12.19	0.45	1.57	1.72	1.59
Amazonas	0.08	6.75	3.66	1.18	19.33	0.21	5.82	3.15	1.02
Roraima	0.39	1.06	1.82	0.72	8.10	0.61	0.68	1.17	0.46
Pará	0.34	2.32	3.35	1.18	19.91	0.51	1.75	2.52	0.89
Amapá	0.00	1.50	0.39	0.55	11.47	0.00	1.50	0.39	0.55
Tocantins	0.00	1.24	7.37	2.27	5.35	0.00	1.24	7.37	2.27
Maranhão	0.14	6.58	6.25	1.32	27.34	0.23	5.89	5.59	1.18
Piauí	0.00	8.75	6.25	2.01	13.97	0.00	8.75	6.25	2.01
Ceará	0.00	14.47	10.54	3.47	48.58	0.00	14.47	10.54	3.47
Rio Gr. Norte	0.00	7.76	6.43	3.80	35.16	0.00	7.76	6.43	3.80
Paraíba	0.00	12.96	13.70	4.07	37.59	0.00	12.96	13.70	4.07
Pernambuco	0.02	17.02	33.97	4.34	90.55	0.07	16.15	32.24	4.12
Alagoas	0.00	21.43	46.46	5.79	155.25	0.00	21.43	46.46	5.79
Sergipe	0.28	13.13	42.34	3.52	91.89	0.42	10.57	34.09	2.83
Bahia	0.20	6.36	14.95	1.97	34.66	0.32	5.40	12.68	1.68
Mato Gr. Sul	0.04	0.68	12.49	3.46	12.28	0.05	0.67	12.30	3.41
Mato Grosso	0.00	0.75	22.58	3.32	20.09	0.00	0.75	22.58	3.32
Goiás	0.05	1.55	19.34	4.70	25.52	0.10	1.47	18.43	4.48
DF	0.00	8.88	85.39	34.95	172.22	0.00	8.88	85.39	34.95
Minas Gerais	0.06	5.47	33.02	6.33	61.11	0.12	5.11	30.88	5.92
Espírito Santo	0.09	10.20	29.36	10.97	89.83	0.17	9.33	26.85	10.03
Rio Janeiro	0.01	7.61	22.39	10.06	61.57	0.02	7.53	22.16	9.96

(continued)

Table 6 (continued)

DMU[i]	$\vec{D}_{iy}^{w}$	$x_1^i\left(1-\vec{D}_{iy}^{w}\right)$	$x_2^i\left(1-\vec{D}_{iy}^{w}\right)$	$x_3^i\left(1-\vec{D}_{iy}^{w}\right)$	$y^i\left(1+\vec{D}_{iy}^{w}\right)$	$\vec{D}_{i}^{w}$	$x_1^i(1-\vec{D}_{i}^{w})$	$x_2^i(1-\vec{D}_{i}^{w})$	$x_3^i(1-\vec{D}_{i}^{w})$
São Paulo	0.00	5.45	81.02	14.42	152.82	0.00	5.45	81.02	14.42
Paraná	0.00	7.31	55.06	5.51	104.00	0.00	7.31	55.06	5.51
Sta.Catarina	0.00	9.46	58.26	22.84	146.91	0.00	9.46	58.26	22.84
Rio Gr. Sul	0.00	6.10	46.90	15.07	82.64	0.00	6.10	46.90	15.07
Average	0.089					0.146			
Sum		188.73	669.77	172.05	1555.47		179.06	646.60	166.83
Targets in Δ%		7.04	5.11	4.33	4.00		11.80	8.39	7.23
North	0.46	1.65	3.14	1.22	16.33	0.55	1.37	2.60	1.01
Northeast	0.15	8.68	13.86	2.36	43.15	0.24	7.72	12.33	2.10
Center-West	0.04	0.93	18.54	3.71	19.96	0.07	0.91	18.06	3.61
Southeast	0.02	5.96	47.83	9.35	89.83	0.03	5.85	46.96	9.18
South	0.00	7.03	51.56	12.68	99.85	0.00	7.03	51.56	12.68
Brazil	0.18	4.12	20.72	4.41	51.44	0.33	3.35	16.88	3.60

Table 7 Eco-efficiency indicators $\vec{D}^w_{ib}$, $\vec{D}^w_{b2}$, and improvement targets for each of the units analyzed

DMU^i	$\overrightarrow{D}^w_{ib}$	$x^i_1(1-\overrightarrow{D}^w_{ib})$	$x^i_2(1-\overrightarrow{D}^w_{ib})$	$x^i_3(1-\overrightarrow{D}^w_{ib})$	$b^i_1(1-\overrightarrow{D}^w_{ib})$	$b^i_2(1-\overrightarrow{D}^w_{ib})$	$\overrightarrow{D}^w_{b2}$	$b^i_2(1-\overrightarrow{D}^w_{b2})$
Rondônia	0.62	1.27	2.98	1.47	0.03	0.03	0.93	0.01
Acre	0.31	1.98	2.16	2.00	0.06	0.02	0.79	0.01
Amazonas	0.12	6.49	3.52	1.14	0.13	0.02	0.33	0.02
Roraima	0.51	0.86	1.48	0.59	0.03	0.01	0.87	0.00
Pará	0.45	1.95	2.81	0.99	0.12	0.03	0.76	0.01
Amapá	0.00	1.50	0.39	0.55	0.19	0.02	0.00	0.02
Tocantins	0.00	1.24	7.37	2.27	0.23	0.04	0.00	0.04
Maranhão	0.26	5.68	5.39	1.14	0.23	0.03	0.41	0.02
Piauí	0.00	8.75	6.25	2.01	0.87	0.03	0.00	0.03
Ceará	0.00	14.47	10.54	3.47	0.48	0.04	0.00	0.04
Rio G. do Norte	0.00	7.76	6.43	3.80	0.60	0.03	0.00	0.03
Paraíba	0.00	12.96	13.70	4.07	0.84	0.04	0.00	0.04
Pernambuco	0.03	16.90	33.73	4.31	0.46	0.05	0.03	0.05
Alagoas	0.00	21.43	46.46	5.79	0.19	0.08	0.00	0.08
Sergipe	0.43	10.37	33.44	2.78	0.09	0.04	0.46	0.03
Bahia	0.35	5.19	12.20	1.61	0.28	0.03	0.43	0.02
Mato G. do Sul	0.12	0.62	11.47	3.18	0.10	0.06	0.81	0.01
Mato Grosso	0.00	0.75	22.58	3.32	0.14	0.02	0.00	0.02
Goiás	0.10	1.47	18.41	4.47	0.16	0.03	0.22	0.02
Distrito Federal	0.00	8.88	85.39	34.95	0.32	5.50	0.96	0.22
Minas Gerais	0.10	5.21	31.47	6.04	0.27	0.05	0.21	0.04
Espírito Santo	0.16	9.41	27.07	10.11	0.12	0.12	0.76	0.04
Rio de Janeiro	0.02	7.51	22.10	9.93	0.15	0.82	0.97	0.03

(continued)

Table 7 (continued)

DMU^i	$\overrightarrow{D}^w_{ib}$	$x^i_1(1-\overrightarrow{D}^w_{ib})$	$x^i_2(1-\overrightarrow{D}^w_{ib})$	$x^i_3(1-\overrightarrow{D}^w_{ib})$	$b^i_1(1-\overrightarrow{D}^w_{ib})$	$b^i_2(1-\overrightarrow{D}^w_{ib})$	$\overrightarrow{D}^w_{b2}$	$b^i_2(1-\overrightarrow{D}^w_{b2})$
São Paulo	0.00	5.45	81.02	14.42	0.10	0.23	0.00	0.23
Paraná	0.00	7.31	55.06	5.51	0.09	0.08	0.00	0.08
Santa Catarina	0.00	9.46	58.26	22.84	0.18	0.20	0.00	0.20
Rio G. do Sul	0.00	6.10	46.90	15.07	0.14	0.02	0.00	0.02
Average	0.13						0.33	
Sum		180.96	648.56	167.80	6.59	7.68		1.38
Targets in Δ%		10.86	8.11	6.69	8.55	2.57		82.45
North	0.56	1.32	2.51	0.97	0.08	0.02	0.80	0.01
Northeast	0.28	7.38	11.79	2.01	0.35	0.03	0.28	0.03
Center-West	0.11	0.87	17.34	3.47	0.13	0.04	0.63	0.02
Southeast	0.03	5.88	47.20	9.23	0.22	0.08	0.12	0.07
South	0.00	7.03	51.56	12.68	0.13	0.05	0.00	0.05
Brazil	0.28	3.62	18.19	3.88	0.17	0.04	0.56	0.03

Norte, Alagoas, Paraíba, Ceará, Piauí, and Amapá. The leading region was the southern region. Rondônia and the north had the worst performance.

There may be at least four reasons for this high level of eco-inefficiency: (1) high technical inefficiency: the DEA-CCR model is output oriented, not considering environmental impacts in the analysis, and estimated an average inefficiency index of 1.78, with only four states being considered efficient (Amapá, Alagoas, São Paulo, and Paraná); (2) the environment is only now beginning to be considered a public good; (3) inadequacy and inefficiency of state environmental legislation; and (4) multiple criteria are taken into account by farmers in their decision making, not only economic and environmental ones. However, analysis of the causes of eco-efficient behavior is beyond the scope of this work.

6 Conclusions

By using DDF combined with DEA to assess the eco-efficiency of Brazilian agriculture, this paper contributes to the state of the art on the subject, mainly because we did not find studies on Brazilian agriculture, which deal with asymmetrically desirable and undesirable outputs.

The results show that when DMUs face environmental rules preventing free disposal of wastes, their potential to increase desirable output is affected. The results also enabled us to estimate a set of eco-efficiency indicators that, satisfying the concept of Pareto optimality, represent the goals of both environmentalists and farmers, thus supporting optimal decision making. These indicators reinforce the initial hypothesis that the apparent antagonism between farmers and environmentalists does not prevent formulation of policies consistent with maximizing social welfare, in order to optimize both the economic and environmental objectives. Therefore, it is clear that the discussion of environmental legislation is not necessarily a zero-sum game.

The eco-efficiency indicators, summarized in Table 8, show that it is possible to improve the state of at least one of the variables without adversely affecting the level of the others.

On the other hand, Brazil, at the 15th Conference of the Parties on Climate Change (COP-15) held in December 2009 in Copenhagen, Denmark, made a voluntary commitment to reduce GHG emissions by 36.1 and 38.9 % by 2020, and, therefore, to reduce emissions from agriculture from 4.9 to 6.1 % (Law No. 12.187, of December 29, 2009).

Comparing this commitment in agriculture with the data in Table 8, we can see that Brazil could surpass that goal (achieving 82.4 %), thereby improving its eco-efficiency, while maintaining the level of consumption of inputs, production, and degraded land. The goal of simultaneously maximizing production and minimizing degraded lands and CO_2 emissions is unattainable in a single year, solely by

Table 8 Improvement aggregate indicators as % of variables

Objectives of eco-efficiency indicators	Optimal Δ% of variables for eco-efficiency					
	x_1	x_2	x_3	y	b_1	b_2
Maximize y and minimize b with fixed vectors of x				6.6	12.6	3.67
Maximize y with fixed vectors of x and b				10		
Minimize b with fixed vectors of x and y					23	11
Maximize y and minimize simultaneously x and b	6.7	5	4.1	3.8	5.2	1.6
Maximize y minimize x with fixed vectors of b	7	5.1	4.3	4		
Minimize b and x with fixed vector of y	10.9	8.1	6.7		8.7	2.6
Minimize x with fixed vectors of y and b	11.8	8.4	7.2			
Minimize b_2 with fixed vectors of x, b_1 and y						82.4

adopting national best practices.[2] The results show that to achieve this goal a maximum of two years is necessary. Additional measures may be used, such as adopting international best practices and the development of clean technology innovation. Accordingly, it is recommended that priority is given to strategies aimed at improving eco-efficiency, and eliminating institutional barriers to the transfer and dissemination of best national and international technologies. These strategies can generate greater results in productivity and environmental conservation than other actions exclusively aimed at fostering technological innovation. While the cost of replicating existing clean technology is lower than the cost of innovation, eco-inefficient units can approach industry and political leaders, thereby fostering the conditions needed to sustain the convergence of economic and environmental development.

It is important to note, however, that one must be careful in using the results found here. The DEA, like any other methodology, has its limitations, as noted Sarkis and Weinrach (2001). Being a deterministic technique, and by defining efficiency as a measure relative to the best practices sampled, this tool is very susceptible to observations. The analysis is conditional on the sample units evaluated,[3] on the variables included in the survey, and on the principle that all other factors involved are identical. Adding or deleting variables can affect the results.

Finally, it is worth noting that there is a great potential for research regarding the use of DDF. New studies can model broader concepts such as sustainability, involving not only economic and environmental performance, but also other social dimensions. Similarly, analysis of eco-efficiency indicators developed here is static, since it uses variables and compares units in a given period. The use of time series

[2] If it adopted national best practices, agriculture would achieve only 74 % of what was predicted (3.67/4.9).

[3] That is less relevant in this study, since our sample was the whole population.

will create a dynamic model, which will shift the central issue of eco-efficiency to other very important issues: the evolution of the indicators, and the nature of the temporal trajectory (with or without fluctuations, tending to converge or diverge).

References

Azad MAS, Ancev T (2010) Using ecological indices to measure economic and environmental performance of irrigated agriculture. Ecol Econ 69(8):1731–1739

Brasil (2006) Primeiro Inventário Brasileiro de Emissões Antrópicas de Gases de Efeito Estufa – Relatórios de Referência. Brasília: MCT – Ministério da Ciência e Tecnologia

Brasil (2010) Segundo Inventário Brasileiro de Emissões de Gases de Efeito Estufa. MCT – Ministério da Ciência e Tecnologia, Brasília

Brasil (2010a) Segundo Inventário Brasileiro de Emissões Antrópicas de Gases de Efeito Estufa – Relatórios de Referência: Emissões de óxido de nitroso de solos agrícolas e manejo de dejetos. Brasília: MCT – Ministério da Ciência e Tecnologia

Brasil (2010b) Segundo Inventário Brasileiro de Emissões Antrópicas de Gases de Efeito Estufa – Relatórios de Referência: Emissões de GEE na queima de resíduos agrícolas. Brasília: MCT – Ministério da Ciência e Tecnologia

Brasil (2010c) Segundo Inventário Brasileiro de Emissões Antrópicas de Gases de Efeito Estufa – Relatórios de Referência: Emissões de metano do cultivo de arroz. Brasília: MCT – Ministério da Ciência e Tecnologia

Brasil (2010d) Segundo Inventário Brasileiro de Emissões Antrópicas de Gases de Efeito Estufa – Relatórios de Referência: Emissões de metano por fermentação entérica e manejo de dejetos de animais. Brasília: MCT – Ministério da Ciência e Tecnologia

Brümmer B, Glauben T, Thijssen G (2002) Decomposition of productivity growth using distance functions: the case of dairy farms in three European countries. Am J Agric Econ 84 (3):628–644. http://ajae.oxfordjournals.org/content/84/3/

Chung YH, Färe R, Grosskopf S (1997) Productivity and undesirable outputs: a directional distance function approach. J Environ Manage 51(3):229–240

Coelli TJ, Rao DSP, O'Donnell CJ, Battese GE (2005) An Introduction to efficiency and productivity analysis, 2nd edn. Springer, New York. http://www.springer.com/economics/econometrics/book/978-0-387-24265-1

Elkington J (1999) Cannibals with forks: triple bottom line of 21st century business. Capstone Publishing Ltd, Oxford, ISBN 9781841120843

Färe R, Grosskopf S (2000) Theory and application of directional distance functions. J Prod Anal 13(2):93–103

Färe R, Grosskopf S (2005) New directions: efficiency and productivity. Springer, Berlin, p 183

Färe R, Grosskopf S, Pasurka C (1986) Effects on relative efficiency in electric power generation due to environmental controls. Resour Energy 8(2):167–184

Färe R, Grosskopf S, Lovell CAK, Pasurka C (1989) Multilateral productivity comparisons when some outputs are undesirable: a nonparametric approach. Rev Econ Stat 71(1):90–98

Färe R, Grosskopf S, Weber WL (2006) Shadow prices and pollution costs in U.S. agriculture. Ecol Econ 56(1):89–103

Farrell MJ (1957) The measurement of productive efficiency. J Royal Stat Soc Series A (General) 120(3):253–290

Fernandez C, Koop G, Steel M FJ (2002) Multiple-output production with undesirable outputs: an application to nitrogen surplus in agriculture. J Am Stat Assoc 97:432–442. http://ideas.repec.org/a/bes/jnlasa/v97y2002mjunep432-442.html

Freeman AM, III, Haveman RH, Kneese AV (1973) Economics of environmental policy. Wiley, New York

Gomes EG (2008) Uso de modelos DEA em agricultura: revisão da literatura. ENGEVISTA 10 (1):27–51
Grosskopf S (1986) The role of the reference technology in measuring productive efficiency. Econ J 96(382):499–513
IBGE (2010) Censo Agropecuário 2006. Instituto Brasileiro de Geografia e Estatística, Rio de Janeiro
IBGE (2011) Sistema de Contas Nacionais - Brasil 2005–2009. Instituto Brasileiro de Geografia e Estatística, Rio de Janeiro
Kjærsgaard J, Vestergaard N, Kerstens K (2009) Ecological benchmarking to explore alternative fishing schemes to protect endangered species by substitution: the Danish demersal fishery in the North Sea. Environ Resour Econ 43(4):573–590
Lampe HW, Hilgers D (2015) Trajectories of efficiency measurement: a bibliometric analysis of DEA and SFA. Eu J Oper Res 240(1):1–21, ISSN 0377-2217. http://www.sciencedirect.com/science/article/pii/S037722171400383X
Luenberger DG (1992) New optimality principles for economic efficiency and equilibrium. J Optim Theory Appl 75(2):221–264
Malmquist S (1953) Index numbers and indifference curves. Trabajos de Estatistica 4(1):209–242
McKinsey (2009) Caminhos para uma economia de baixa emissão de carbono no Brasil. McKinsey & Company, São Paulo
Mendes JTG, Padilha Jr J (2007) Agronegócio: uma abordagem econômica: Pearson Prentice Hall, New Jersey, p 369
Mickwitz P, Melanen M, Rosenström U, Seppälä J (2006) Regional eco-efficiency indicators—a participatory approach. J Clean Prod 14(18):1603–1611
O'Donnell CJ (2010) Measuring and decomposing agricultural productivity and profitability change*: agricultural productivity and profitability change. Aust J Agric Resour Econ 54 (4):527–560. http://espace.library.uq.edu.au/view/UQ:223605
OECD (1998) Eco-efficiency. Co-operation O-OfE, Development, editors. OECD Publishing, Paris, p 84
OECD (2010) OECD-FAO Agricultural outlook 2010–2019. OECD Publishing, Paris, p 252
Picazo-Tadeo AJ, Prior D (2009) Environmental externalities and efficiency measurement. J Environ Manage 90(11):3332–3339
Picazo-Tadeo AJ, Reig-Martínez E, Hernández-Sancho F (2005) Directional distance functions and environmental regulation. Resour Energy Econ 27(2):131–142
Picazo-Tadeo AJ, Beltrán-Esteve M, Gómez-Limón JA (2012) Assessing eco-efficiency with directional distance functions. Eur J Oper Res 220(3):798–809
Pittman RW (1983) Multilateral productivity comparisons with undesirable outputs. Econ J 93 (372):883–891
Porter ME, Van Der Linde C (1995) Green and competitive: ending the stalemate. Harvard Bus Rev 73(5):120–134
Sarkis J, Weinrach J (2001) Using data envelopment analysis to evaluate environmentally conscious waste treatment technology. J Clean Prod 9(5):417–27. http://www.sciencedirect.com/science/article/pii/S0959652600000846
Schaltegger S (1996) Corporate environmental accounting, 1st edn. Wiley, New York. p 324
Scheel H (2001) Undesirable outputs in efficiency valuations. Eur J Oper Res 132(2):400–410
Shephard RW(1953) Cost and production functions. Princeton Univ. Press, Princeton
Tyteca D (1996) On the measurement of the environmental performance of firms—a literature review and a productive efficiency perspective. J Environ Manage 46(3):281–308
Verfaillie HA, Bidwell R (2000) Measuring eco-efficiency: a guide to reporting company performance. World Business Council for Sustainable Development—WBCSD, Geneva
Zhang B, Bi J, Fan Z, Yuan Z, Ge J (2008) Eco-efficiency analysis of industrial system in China: a data envelopment analysis approach. Ecol Econ 68(1–2):306–316

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