Stochastic Analysis in Production Process and Ecology Under Uncertainty

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Bogusław Bieda
AGH University of Science and Technology
Faculty of Management
Al. Mickiewicza 30
30–059 Kraków
Poland

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Summary

The monograph addresses a problem of stochastic analysis based on the uncertainty assessment by simulation and application of this method in ecology and steel industry under uncertainty. The first chapter defines the Monte Carlo (MC) method and random variables in stochastic models. Chapter 2 deals with the contamination transport in porous media. Stochastic approach for Municipal Solid Waste transit time of contaminants modelling, using MC simulation, has been worked out as well. The third chapter describes the risk analysis of the waste to energy facility proposal for the city of Konin, including its financial aspects. Environmental impact assessment of the Mittal Steel Poland (MSP) S.A. Power Plant, in Kraków is given in the fourth chapter. Thus, four scenarios of the energy mix production processes are studied. Chapter 5 contains examples of using Ecological Life Cycle Assessment (LCA) – a relatively new method of environmental impact assessment – which helps in preparing pro-ecological strategies, and which can lead to the reduction of the amount of waste produced in the MSP production processes. Moreover, real input and output data of selected processes under uncertainty, mainly used in the LCA technique, are examined. The last chapter of this monograph contains the final summary.

Log-normal probability distribution, widely used in risk analysis and environmental management with the aim of developing stochastic analyses of the LCA, as well as uniform distribution for stochastic approach of pollution transport in porous media have been proposed.

In order to determine the uncertainty of parameters using MC simulation, two software packages, SimLab® from the European Union's Joint Research Centre (Italy) and Crystal Ball® (an add-on to Excel) from Decisioneering (USA), are employed. Sensitivity analysis is another function of these computer programs and it refers to the amount of uncertainty in a forecast that is caused by both the uncertainty of an assumption and by the model itself.

The distributions employed in this monograph are assembled from site-specific data as well as from data existing in the most current literature, and are based on professional judgment.

Introduction

The aim of this project is to discuss the stochastic analysis, based on the theory of probability and statistical mechanics, using Monte Carlo (MC) simulation, focusing especially on the chosen aspects of ecology management and on the examples of manufacturing processes in the steel industry under uncertainty. The paper includes the identification, the assessment, and the evaluation of uncertainty in the probabilistic analysis of: (1) the diffusion (transport) of polluting substances in homogeneous porous media, (2) the project investment risk in the waste to energy facility in the City of Konin, Poland, (3) the assessment of the environmental impact of the energy production processes in Mittal Steel Poland (MSP) Power Plant S.A. Unit in Kraków, Poland, as well as (4) the life cycle of waste management in MSP. Despite the interdisciplinary nature of the monograph, MC simulation is the common feature across the fields and, consequently, the methodology employed in MC computer simulations, the sensitivity analysis, and the data uncertainty assessment, are all discussed.

In order to conduct all the necessary calculations, two professional software packages are used in this project: SimLab®, developed by the European Commission Joint Research Centre (JRC) in Italy, and Crystal Ball® (CB), a spreadsheet-based application, used for modelling, forecasting, simulation, and optimisation. Due to its wide application in research publications (Evans and Olson 1998; Sonnemann et al. 2004; Bradley, Warith et al. 1999), and its verification in practice (see Sonnemann et al. 2004), more emphasis is placed on CB software. However, both programs offer a large number of statistical distributions that can be applied in the modelling of stochastic systems, and allow for MC simulation, as well as sensitivity and uncertainty analysis, to be performed.

The monograph is comprised of an introduction, five chapters, and a conclusion. The introduction illustrates the origin of the problem and the outline of the relevant subject matter, whereas the conclusion summarises and generalises the final results. Each of the five chapters also ends with a brief conclusion.

The first chapter defines the chosen terms from the scope of probability, concentrating on MC method and random variables. The log-normal probability distribution of continuous random variables is discussed here in greater detail, as it is widely applied in environmental risk analyses and environmental management, in particular in the research on the ecological Life Cycle Assessment (LCA) and uncertainty.

The second chapter focuses on the stochastic model of the diffusion (transport) of polluting substances in homogeneous porous media, with the help of CB computer software. Thanks to its wide range of statistical tools, CB makes it possible to perform sensitivity analyses, among other tasks, and is able to generate tornado charts and spider charts. In addition, the program allows the user to express uncertainty as a probability, which makes it a useful tool in environmental forecasting and management. In the third chapter the emphasis is on the employability of MC simulation, a problem which is analysed with the help of SimLab® professional computer software that performs risk assessments of investment costs management, illustrated with the case study of the waste gasification project in the City of Konin.

The possible applications of stochastic analysis in the LCA studies that determine the potential environmental impact of the energy production processes in MSP Power Plant are discussed in the fourth chapter. The opening paragraphs of the chapter deal with the basic terms used in the LCA method, a method used in environmental management, and defined in the ISO 1404x standard series (Environmental Management – Life Cycle Assessment), published by the International Organisation for Standardisation (ISO). The application of Life Cycle Assessment is recommended in a number of official documents issued by the EU, among which is the Directive 2008/98/EC of the European Parliament and of the Council (of 19 November 2008) on waste (Kulczycka and Henclik 2009). According to the provisions outlined in the standard, the Life Cycle Assessment method can be adopted by identifying and determining the amount of materials and energy used, as well as the quantity of waste discharged into the environment. This is followed by the assessment of the environmental impact of such processes and the interpretation of the obtained results. It is vital to establish both the aim and scope of the analysis, as well as its functional unit and its boundary system. The detailed description of the LCA method can be found in the subsequent chapters of this monograph.

In LCA studies, the emphasis is on a more detailed characterisation of uncertainty, which leads to concentration on uncertainty of source data. The quantitative data analysis, based on MC simulation, is performed, as exemplified by the comparative analysis of the environmental impact of the four scenarios of the energy production processes in the Power Plant, in its annual cycle in 2005. Each of these scenarios is different, due to the change of proportioning ratios of the two types of fuels: hard coal and blast furnace gas. The levels of other fuels, such as natural gas and coke oven gas, are left unchanged. The life cycle processes of energy production in the Power Plant and the existing connections between these processes are illustrated with the help of resources "trees" and processes "trees" generated by SimaPro 7.1 computer software.

The fifth chapter focuses on the LCA methodology with a view to presenting the problem of stochastic analysis of the waste management life cycle in MSP Power

Plant and its impact on the quality of the environment. The uncertainty and sensitivity analyses are performed by looking at the Human Health damage category, measured in Disability Adjusted Life Years (DALY) that help determine the relative amount of time by which human life is shortened as a result of damaging waste management effects of MSP, recognising the category as the most representative type of analysis possible. Other categories, namely Consumption of Resources and Ecosystem Quality, were omitted, since, as is indicated in the Eco-indicator 99 method, the uncertainly analysis is not conducted in the Resources category.

All four chapters (Chaps. 2–5) focus on the application of the MC method in stochastic models.

Both the material balance and the waste management balance in MSP are composed on the basis of information received from MSP and the data obtained from a document about the application for an integrated permit for the fuel combustion for energy production facility in the Mittal Steel Poland S.A. Unit in Kraków – the summary (in non-specialist language), drafted in June 2006 (Wniosek 2006).

All the simulations and recorded findings, which result from these simulations and are presented in the fourth and fifth chapter of this monograph, are performed using the data acquired from the calculations made for the thesis by the Mineral and Energy Economy Research Institute of the Polish Academy of Sciences in Kraków, as part of the order for the papers entitled "Life cycle assessment in the energy production process in MSP Power Plant S.A. in Kraków, Poland" (Ocena 2008) and "Life cycle assessment in the generation processes – the case study of MSP Power Plant S.A. in Kraków, Poland" (Ocena 2009), financed by the research project resources (post doctoral research grant number N115 084 32/4279), allocated for foreign services. All the calculations are made using the SimaPro 7.1 software and its implemented databases (mostly Ecoivnet), and the analysis is based on the Eco-indicator 99 method, a typical example of final element method (Kowalski et al. 2007).

The data gathered from the Power Plant contains the material-energy balance, with its 48 entries, which is shown in an inventory table for the energy production processes in MSP Power Plant. For the purposes of the analysis, an individual process is established, which includes all the entries between entry eighteen (18) and entry forty-two (42) of the inventory table. This process is called Siłownia-E (E-Power-Plant) and its functional unit is based on the entire life cycle of the Plant, from an annual perspective, with 2005 used as its base year.

The scope of the study dealing with life cycle assessment of waste production by individual MSP facilities includes:

- The coke production facility – Coke Plant,
- The ore sintering facility – Sintering Plant,
- The pig iron melting facilities – Blast Furnaces,
- The steel melting facility – Converter Plant,
- The Continuous Steel Casting facility – CSC,

- The facility for hot rolling of ferrous metals – Hot Strip Mill,
- The fuel combustion facility – Power Plant.

Each of the facilities is a source of different types of pollutant emissions: air, water, and solid waste. This analysis focuses on the waste management aspect of the problem.

The waste production by the abovementioned facilities in an annual cycle (based on 2005) is considered to be the chosen functional unit, and the boundaries of the analysed system are labelled as gate to gate. The carried out analysis is based on the balance of the waste produced.

For the purposes of the analysis, some of the types of waste are grouped; for instance, a "dangerous waste" category was created, in which all of the dangerous types of waste produced by the analysed facilities are placed. However, the results, indicated in the analysis, may not be entirely correct, owing to the chosen sludge generated during the production of steel in electric furnace shops equipped with electric furnaces (as there is no other method of steel production available in the database). At present, there are two dominant steel production methods in the world. The first one is based on the production in, the so-called, integrated mills where pig iron is produced in blast furnaces and then is converted into steel using oxygen converters with the help of scrap metal. The second method of steel making is based on using scrap metal in an electric process in steel plants equipped with arc furnaces. The use of all-European data may further damage the credibility of the results, as this type of data is not always adequate to Polish conditions.

This monograph would have been impossible to complete without the help of, and the fruitful collaboration with, the Department of Environmental Protection and MSP Power Plant that have made some necessary data available for this experimental research. The permission to use the appropriate data needed to complete this project has been given by the Managing Director of ArcelorMittal Poland S.A. Unit in Kraków (the letter no. DN/327/2007 of 25.05.2007). The financial help offered by the Ministry of Science and Higher Education in Warsaw in the form of a postdoctoral research grant (no. N115 084 32/4279) has been very important as well.

Contents

List of Main Symbols

a	Minimum value
MSP	Mittal Steel Poland S.A. unit in Kraków Poland
b	Maximum value
C_E	Exit concentration of a dissolved contaminant (mg/ton)
$C(z,t)$	Concentration of a dissolved contaminant in the direction of the z-axis (mg/m^3)
C_0	Concentration of a dissolved contaminant in the direction of the z-axis on the surface of the liner (mg/m^3)
CB	Crystal ball®
cm	Centimetre
d	Day (from the 1st to the 31st)
D	Diffusion coefficient (m^2/s)
exp	The Napierian base (e = 2.71828…)
E(X)	Expected value
EDC	Diffusion coefficient (m^2/s)
erfc	Error function
f(x)	Density function (for $x > 0$)
g	Hour (from 0 to 23)
HC	Hydraulic conductivity (m/s)
HG	Hydraulic gradient (dimensionless)
LCA	Life cycle assessment
LCI	Life cycle inventory
Ln(X)	Natural logarithm of variable x
m	Metre
mg	Milligram
$M_0(X)$	Modal value (dominant)
MC	Monte Carlo
POROS	Porosity coefficient (dimensionless)
R_d	Retardation coefficient (dimensionless)
t	Time (s)

TH	Design life of landfill (in years)
VS v_s	Seepage velocity (initial condition) (m/s)
X	Random variable
$x_{0,5}$	Median
y(t)	Stochastic process as a function depending on the time parameter *t* whose values always take the form of random variables
z	Coordinate of the accepted reference system – direction of the diffusion of a contaminant (m)
μ	Mean value
μ_g	Geometric value
σ	Standard deviation
σ_g	Geometric standard deviation