

Review of optimization models in the pollution prevention and control

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Abstract

The objective of the present work is to investigate the extent and effectiveness of the implementation of optimization methods for the solution of environmental problems. In order to fulfill its objective, the present work reviews a significant number of scientific / research papers dealing with the application of optimization approaches for the solution of environmental problems, in the areas of air pollution, solid, liquid and industrial waste management, and production integrated pollution control. The review focuses its attention to the identification of the basic problem parameters, the type of the optimization model for each particular problem category and the results obtained. Amongst its various other conclusions, the present work exhibits the contribution of the optimization modeling to the identification of all the characteristics of the environmental problems and their integrated approach.

Keywords: Optimization, Modeling, Pollution Prevention, Mathematical Programming

1. Introduction

In many cases the solution of problems related to the environment require decision-making and selection between a number of alternatives that need to satisfy a number of technical and regulation constraints. Therefore, in parallel to various other efforts for the solution of the environmental problems, a significant number of scientific works have appeared in the literature, approaching the environmental issues through the development of optimization models and their implementation in practical cases. The objective of the present work is to investigate the extent and effectiveness of the implementation of optimization methods for the solution of environmental problems. In order to fulfill its objective, the present work reviews a significant number of scientific / research papers dealing with the application of optimization approaches for the solution of environmental problems. The review focuses its attention to the identification of the basic problem parameters, the development of the optimization model, i.e. the identification of the optimization criteria that drive the problem solution, the various different constraints that need to be taken into account in each specific type of problem, the algorithms being used for the solution of the optimization models and the results obtained.

2. Optimisation methods and tools

Optimisation methods and algorithms have lately become very valuable tools for the solution of a wide variety of complex engineering problems. Two recent excellent review papers of Biegler and Grossmann (2004) and Grossmann and Biegler (2004) analyse and classify the current situation and future prospects of optimisation methods and tools, as well as their applicability to the solution of various practical problems. Mathematical programming and optimization in general have also found extensive use in various types of environmental problems. The reason is that, in these problems, there is very often a need for decision making under conflicting objectives, since there is a number of alternative solutions and the optimal one needs to be chosen. Therefore, a list of mathematical and decision support techniques have been deployed in the past years to aid in forming policies or solving various environment-related design, operation, planning, scheduling and routing problems.

The optimization techniques being implemented in the reviewed literature are deterministic and stochastic programming models. The deterministic optimization models range from simple Linear Programming, Mixed Integer Linear Programming, Non-Linear Programming, Dynamic Programming models, as well as multi-objective optimization models, depending on the specific characteristics of the problem under consideration. For problems including uncertainty stochastic programming models, such as Fuzzy linear programming, fuzzy integer programming, Interval linear Programming, are used.

The use of multicriteria decision methods in a number of real environmental problems is described by Ladhema et. al (2000). The authors describe the methodology for approaching environmental problems with multicriteria analysis, supporting the view that this formulation provides a comprehensive framework for storing all relevant problem information, makes the requirement for new information explicit and thus supports the most efficient allocation of resources.

3. Optimisation methods in various environmental problems

3.1 General considerations

A wide spectrum of environmental problems is solved with optimization methods, such as the environmental process synthesis and design, waste management and minimization, water resources management, energy management with environmental considerations. However, the present work only deals with a rather limited area of environmental problems, focusing its attention to the problems with most interest for the CAPE community (Table 1).

Table 1. Environmental problems included in the present work

Air pollution
Waste minimisation
Environmental synthesis and design
Facility location
Supply chain with environmental considerations
Solid waste management

3.2 Air pollution

Mathematical programming models are extensively used in air pollution management literature. Generally, the objective of these models is to optimise the cost of policy decisions with the great majority oriented to minimising the cost of control and removal methods. The main possibilities are the minimisation of the pollutants, the minimisation of the pollutants reduction cost and the minimisation of the pollutants concentration in the most sensitive receptors. The constraints being developed express the conformity to pollution standards. A very comprehensive survey of mathematical programming models in air pollution management is presented by Cooper et al (1996). However, since then, various papers have appeared in the literature, dealing with a number of interesting aspects of air pollution management. For example, Shaban, Elkamel and Gharbi (1996) have developed a Mixed Integer Linear Programming model for the selection of the best pollution control strategy to achieve a given pollution reduction level. The objective of the model is to minimise the total control cost, consisting of operating and investment costs. Various constraints are imposed on the model, including a prescribed pollution reduction level and maximum budget available for investment. The model gives the optimum set of control options along with their optimum set-up times.

3.3 Waste minimisation

Wu and Chang (2003) have developed a method and procedure for the optimisation of a textile dyeing manufacturing process in response to the designated waste minimisation alternatives, the new environmental regulations and the limitations of production resources. They use a nonlinear integer optimisation framework. The objective function is the profit maximisation, including benefits from product sales as well as the emission/effluent charge and water resources fees required by new environmental regulations. The constraint set includes capital and labour limitations, equipment availability, demand requirements, water balances and capacity limitations. The optimisation method that is used is based on the Genetic Algorithm and uncertainties are dealt with via an interval analysis.

Chakraborty et. al. (2003) introduce a systematic planning methodology for obtaining a long-term waste management strategies for entire batch manufacturing sites. Their work introduces a dynamic view of designing optimal waste management strategies for a planning horizon of 5-10 years. The objective function minimises the net present cost that includes the operating cost, the annualised capital investment and the maintenance costs. The operating cost is obtained as the probabilistic average of the operating cost in the individual waste forecast scenarios. This term takes into account penalties for capacity constraint violations. The problem constraints include corporate-wide budget limitations, special permit constraints, emission trading opportunities, emission limitations. The resulting model is an MILP model.

Alidi (1996) proposes a multiobjective optimisation model based on the goal programming approach to assist in the proper management of hazardous waste generated by the petrochemical industry. The analytic hierarchy process (AHP), a decision making approach, incorporating qualitative and quantitative aspects of a problem is incorporated in the problem to prioritise the conflicting goals usually

encountered when addressing the waste management problems of the petrochemical industry.

3.4 Environmental Synthesis and Design

Brett et al (2000) believe that the incorporation of environmental sensitivity into process models has not been very satisfactory, mainly because of the difficulty in translating process information to environmental objectives. In their work they propose a methodology according to which the Life Cycle Analysis (LCA) assists in the development of environmental objectives in process design and they use a multiobjective formulation of the process that combines economic objectives with the LCA environmental objectives. A case study of a nitric acid plant has been undertaken to demonstrate their approach. The process is modelled in Hysys to obtain mass and energy information. Goal programming, a multiobjective optimisation technique, has been used to solve the problem. In conclusion, they believe that LCA linked to rigorous process analysis tools allow for explicit considerations to the design decisions.

Linninger and Chakraborty (1999) proposed a hybrid methodology for the synthesis of waste treatment flowsheets through a search based superstructure generation step using a linear planning algorithm. Next, a rigorous plant specific policy optimisation is carried out, with a desired performance function, such as treatment cost, and a set of site specific environmental capacity and logistics constraints.

3.5 Facility location

Rakas et al. (2004) have developed a model for determining locations of undesirable facilities. It is formulated as multiobjective model, since the problem of locating undesirable facilities faces many conflicting criteria. Mathematical models for the location of undesirable facilities are designed to address key questions, such as how many facilities should be located and how large each facility should be. In general, such problems are multiobjective. The objective functions of the optimisation model express the total cost minimisation and the minimisation of the population opposition to the construction of the landfill in their area. This paper also proposes another way to treat uncertainties in locating undesirable facilities, which is based on Fuzzy Mathematical Programming.

Chang and Wei (2000) illustrate a new approach with a view to optimising siting and routing aspects using a fuzzy multiobjective nonlinear integer programming model as a means that is particularly solved by a genetic algorithm. The effective planning of solid waste recycling programs is a very important challenge in many solid waste management systems. One of such efforts is how to effectively allocate the recycling drop-off stations with appropriate size in the solid waste collection network to maximise the recycling achievement with minimum expense.

3.6 Supply chain with environmental considerations

Hu et al (2002) present a cost-minimisation model for a multi-step, multi-type hazardous waste reverse logistics system. They develop a discrete-time linear analytical model that minimises total reverse logistics operating costs subject to constraints that take into account such internal and external factors as business operating strategies and environmental regulations. The model that is developed consists of four critical activities: collection, storage, treatment and distribution. The objective of the proposed

model is to maximise the total reverse logistics cost for a given multi-step period, including total collection cost, total storage, treatment, transportation cost for reusing processed wastes and total transportation costs for disposing processed wastes.

Turkay et al (2003) address the multicompany collaborative supply chain management problem. The proposed approach consists of modelling process units using fundamentals of thermodynamics, conservation of mass and energy and process data, development of an MILP model for the supply chain integration of different process systems and comparative analysis of the results. The problem is solved using ILOG system.

3.7 Solid Waste Management

Various deterministic mathematical programming models have been used for planning solid waste management systems. Nema and Gupta (1999) have dealt with the planning and design of a regional hazardous waste management system that involves the selection of treatment and disposal facilities, allocation of hazardous wastes and waste residues from generator to treatment and disposal sites and selection of the transportation routes. They present an improved formulation based upon multi-objective integer programming approach to arrive at the optimal configuration. The objectives addressed are the minimisation of the total cost, which includes treatment and disposal costs and transportation cost, minimisation of the total risk, which includes waste treatment and disposal risk as well as risk involved in waste transportation. The problem constraints are mass balances of wastes, allowable capacities for treatment and disposal technologies, waste-treatment technology compatibility constraints and waste-waste compatibility constraints. The resulting model is an MILP problem.

Costi et. al (2003) have developed a Decision Support System (DSS) designed to help decision makers of a municipality in the development of incineration, disposal, treatment and recycling integrated programs. The main goal of the proposed DSS is to plan the MSW management, defining the refuse flows that have to be sent to recycling or to different treatment or disposal plants and suggesting the optimal number, the kinds and the localisation of the plants that have to be active. The DSS is based on a decision model that requires the solution of a constrained non-linear optimisation model where some variables are binary and other ones are continuous. The objective function takes into account all possible economic costs, whereas constraints arise from technical, normative and environmental issues.

Huang et. al (2001) have applied an integrated solid waste management system based on inexact fuzzy stochastic mixed integer linear programming to the long term planning of waste management activities in the city of Regina. Their model can effectively reflect dynamic, interactive and uncertain characteristics of the solid waste management system in the city. Their approach is able to answer questions like the appropriate reduction goals, the waste flow allocation pattern, level of reliability and ways to handle rapid increase of waste generation.

4. Summary and conclusions

The need for effective optimisation methods that incorporate concepts of efficient resource use and environmental concern is becoming more and more urgent as the

environmental situation deteriorates. This paper offers a review on optimisation methods that have been used for the solution of environmental problems and reviews a number of papers in specific environmental problems. Depending on the characteristics of the treated problem, different optimization models and optimization algorithms are used. Critical success factors are the problem size and the reliability of various process models that are used. In any case, one of the most significant contributions of the optimization modeling is the identification of all the characteristics of the environmental problems and their integrated approach.

References

- Alidi Abdulaziz S., 1996, A multiobjective optimization model for the waste management of the petrochemical industry, *Appl. Math. Modelling*, Vol. 20
- Biegler, L. T., Grossmann, I. E., 2004, Retrospective on Optimisation, *Computers and Chemical Engineering* 28, 1169-1192
- Brett A., Barton G., Petrie J., Romagnoli J., 2000, Process synthesis and optimisation tools for environmental design: methodology and structure, *Comp. and Chemical Engng* 24, 1195-1200
- Chakraborty A., A.Malcolm, R. D. Colberg, A. Linninger, 2003, Optimal waste reduction and investment planning under uncertainty, *Computers and Chemical Engineering* 2003
- Chang N-Bin, Y.L. Wei, 2000, Siting recycling drop-off stations in urban area by genetic algorithm-based fuzzy multiobjective nonlinear integer programming modelling, *Fuzzy Sets and Systems* 114, 133-149
- Cheng S., C.W. Chan, G.H. Huang, 2003, An integrated multi-criteria decision analysis and inexact mixed integer linear programming approach for solid waste management, *Engineering Applications of Artificial Intelligence* 16, 543-554
- Cooper, W.W., Hemphill, H., Huang, S.L., Lelas, V., Sullivan D.W., 1997, Survey of Mathematical Programming models in air pollution management, 96, 1, 1-35.
- Costi P., Minciardi, R., Robba, M., Rovatti, M., Sacile R., 2003, An environmentally sustainable decision model for urban solid waste management, *Waste Management* 24, Issue 3, 277-295
- Grossmann, I. E., Biegler, L. T., 2004, Part II. Future Perspective on Optimisation, *Computers and Chemical Engineering* 28, 1193-1218
- Hu Tung-Lai, Jiu-Biing Sheu, Kuan-Hsiung Huang, 2002, A reverse logistics cost minimization model for the treatment of hazardous wastes, *Transportation Research, Part E*, 38 457-473
- Huang G.H., N. Sae-Lim, Z. Chen and L. Liu, 2001, Long-term planning of waste management system in the City of Regina – An integrated inexact optimisation approach, *Environmental Modelling and Assessment* 6, 285-296
- Ladhema R., Salminen P., Hokkanen J., 2000, Using Multicriteria Methods in Environmental Planning and Management, *Environmental Management*, 26, 595-605
- Linninger A. A., Aninda Chakraborty, 1999, Synthesis and optimisation of waste treatment flowsheets, *Computers and Chemical Engineering* 23, 1415-1425
- Nema Arvind K, S.K. Gupta, 1999, Optimization of regional hazardous waste management systems: an improved formulation, *Waste Management* 19, 441-451
- Rakas J., Theodorovic D., Kim, T., 2004, Multi-objective modeling for determining location of undesirable facilities, *Transportation Research Part D* 9, 125-138
- Shaban H. I., A. Elkamel, R. Gharbi, 1997, An optimization model for air pollution control decision making, *Environmental Modeling & Software*, Vol. 12, No. 1, pp. 51-58
- Türkay Metin, Cihan Oruç, Kaoru Fujita, Tatsuyuki Asakura, 2003, Multi-company collaborative supply chain management with economical and environmental considerations, *Comp. and Chemical Engineering*
- Wu C.C., N.B. Chang, 2003, Global strategy for optimising textile dyeing manufacturing process via GA-based grey nonlinear integer programming, *Comp. and Chemical Engng* 27, 833-854