

**"A GUIDED TOUR THROUGH APPLICATIONS OF
OR-TECHNIQUES TO ENVIRONMENTAL
PROBLEMS"**

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A guided tour through applications of OR-techniques to environmental problems

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Abstract:

This paper discusses how Operational Research (OR) techniques can be used in environmental problem solving. It is based on a restricted literature search and subsequent analysis of some 50 papers. We did not have the time nor the resources to perform an exhaustive literature study. Neither did we have the inclination to do so. Our only intentions were to roughly divide the field into topical areas, to provide an example problem for each and to point to some references for further reading. In short, the sole ambition of this paper is to give the reader a guided tour (some would say a random walk) through "OR and Environment" land. We would be very pleased if it would contribute to making the "environmental world" interested in OR or the "OR world" interested in environmental problems.

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Introduction

In the last few decades there has been increasing concern about pollution and other threats to our environment. Nowadays, protection of the environment has even become a major political issue. In fact, for the first time in history, a government (the Dutch) fell over an environmental issue. Almost daily, newspapers carry reports on the greenhouse effect, acid rain, smog in big cities and industrial areas, polluted rivers and oceans, etc. Unfortunately, industry, preoccupied by short run profitability, views measures to prevent or fight pollution too often as just another operating cost undermining competitiveness. However, a clean environment is beneficial to industry in the long run (consider, e.g., a plant which requires clean water for production). Together with all the obvious arguments this point can be used to convince managers that it is necessary to take environmental concerns seriously (even without strict enforcement laws).

The biggest difficulties with environmental problems are, however, their frequently international nature and their immense complexity. It is therefore necessary to have a clear formulation of the problem and of the impact that specific measures will have. This is where Operations Research (OR) can be an invaluable tool. OR is primarily concerned with the efficiency and effectiveness of decision processes in a wide range of fields. It mostly uses mathematical (optimization) models to find an appropriate course of action in a given situation. Apart from evaluating and comparing alternatives, OR can also easily perform sensitivity analysis to answer "what-if" questions. All in all, there seems to be ample reason to use OR modelling in environmental problems, since a clear insight in the relative ranking of alternatives and their consequences might give managers an impulse to improve their actions in terms of pollution control.

The purpose of this paper is not to develop models for given problems, but to provide a kind of guided tour through the use of OR in environmental problem solving and to suggest opportunities for further research wherever possible. To do this (a small subset of) the literature was studied and a classification of environmental problems was made. This classification yields the following fields:

1. Water Quality Control
2. Air Quality Control
3. Chemical Pollution
4. Nuclear Pollution
5. Transportation of Hazardous Materials
6. Location of Industries or Disposal Sites
7. Pollution Control versus Economic Growth
8. New and/or Related Fields

It will be obvious that this classification is quite arbitrary in that the fields are not at all mutually exclusive and the list is not exhaustive. Many classifications are conceivable but the one above is convenient for our purposes.

Each section of this paper is devoted to a specific field and starts with a general description of that field. Then, a specific example is discussed in some detail to illustrate the potential of OR and finally further references are given. If possible we indicate which sub-fields have been adequately addressed, what techniques have been used and what the opportunities for further research are. It should be noted that the problems discussed constitute a random sample. There is no intention to be complete. We close the paper with a brief conclusion.

Throughout the paper it is assumed that the reader is somewhat familiar with the terminology and basic techniques of Operations Research. However, one can skip the rather technical parts of the paper and still obtain a good idea about the potential of using OR in environmental problem solving.

1. WATER QUALITY CONTROL

The field of water quality control is quite comprehensive and covers many different problems. Think of the quality of ground water, which is affected by the use of products to boost agricultural production (e.g. pesticides). These are, by their nature, non-point polluters, meaning that it is difficult to track down responsibility for the pollution. Problems become even worse if the pollution is transboundary. An example is the river Rhine, polluted by France and Germany to such an extent that Rotterdam had to build especially sealed sumps. Situations like this can easily lead to international conflicts. Different is the one-point pollution by, for example, certain plants at a river or a lake (although the same

river or lake may also be polluted by mass tourism). Since it is difficult and costly to clean ground, river or sea water, attention is mainly focused on the act of polluting itself: the use and disposal of hazardous materials.

Before reviewing some literature and techniques used in this field we discuss the paper by Bouzaher et al. [7] on non-point source pollution. The problem considered is sediment deposition, i.e., modelling soil movements through a watershed. It is important to observe that the objective is not to minimize pollution, but to minimize costs while not violating an imposed maximum level of pollution. The problem is modelled as follows.

The area under consideration is divided into land units (with specific characteristics of slope, ownership and delivery of soil particles to the ground water streams). For each land unit u a set of alternatives p are identified, each characterized by a cost r_{pu} and an amount of sediment s_{pu} . The objective is to minimize the cost of the alternatives selected for each unit so as not to violate the maximum allowable pollution level. In mathematical terms this yields the following integer linear programming model:

$$\begin{aligned} & \text{Min } \sum_p \sum_u r_{pu} x_{pu} \\ & \text{s.t. } \sum_p \sum_u s_{pu} x_{pu} \leq S \\ & \sum_p x_{pu} = 1 \quad \forall u \\ & x_{pu} \in \{0,1\} \quad \forall p,u \end{aligned}$$

Where

p denotes the alternative

u denotes the land unit

r_{pu} = the incremental cost if alternative p is chosen in land unit u

s_{pu} = amount of sediment delivered by alternative p in land unit u

S = maximum allowable sediment load in the stream channel

$x_{pu} = 1$, if alternative p is selected for unit u

0, otherwise

The role of the sediment deliveries s_{pu} should be stressed. Not only are they crucial for the outcome of the model, they also form the severest limitation of the validity of the model. When they are determined (which involves a fair amount

of experimental guessing), the model can be solved using dynamic programming. This is an obvious choice if one considers the fact that the sediment load in a land unit depends only on its own delivery and on the sediment loads in upstream units, since water always flows downstream. The model yields the cheapest alternative which stays within the bounds of the prespecified pollution standards. Note that because of the conflicting interests of cost and pollution, minimizing costs will force any upper bound on sediment delivery to be binding.

This is just one example of the use of a mathematical optimization model to solve a problem in water pollution. A considerable amount of research has been done in this field. Somlyódy and Wets [38] discuss the eutrophication of lakes, taking Lake Balaton as an example. They use chance-constrained programming to model the stochastic problem, and quadratic programming to solve it. Burn and McBean [9] also stress the stochastic nature of water quality problems, and use chance-constrained programming to derive an easily solved linear programming model for a given water body. Their model is modified by Fujiwara et al. [18] who consider various river parameters as random variables and optimize wastewater treatment efficiencies at source points using Monte Carlo simulation. Das and Haimes [11] consider multiobjective optimization models, in which the main target is not to strictly enforce pollution standards (which may be infeasible) but to set fines on failing to meet standards. This leads to more realistic models, since in general it will be difficult to obtain exact results in practical situations.

Loucks and Bell [30] review the early literature on systems analysis and water quality, considering optimization as well as simulation. Galya [20] presents an overview of ground water modelling techniques in the last decade. Rosa [35] discusses a model for estimating potential economic damages resulting from contamination of groundwater. Hassan [23] addresses the water quality in streams, using the DO BOD dynamic simulation approach. Fontane, Labadie and Lofties [17] consider the combination of a stochastic simulation approach and a dynamic programming optimization algorithm to obtain control of reservoir discharge quality through selective withdrawal. Bishop and Grenney [4] use integer programming to solve a treatment cost minimization model which is linked to a stream water quality simulation model to capitalize on the unique advantages of both OR techniques in managing river basin water quality.

Many papers have been written on specific problems. See, for example, Kuo et al. [27] for a discussion on an Illinois urban watershed, or Nemetz and Margolick [33] who turn their attention on municipally generated water pollution in British Columbia.

From this rather eclectic list it will become clear that a lot of work has been done in applying Operation Research techniques to water quality problems. Techniques used include linear, integer, quadratic, dynamic and chance-constrained programming. Many model formulations are overly simplified and a lot of problems could perhaps better be tackled by using more advanced OR techniques. This field is still quite open for further research.

2. AIR QUALITY CONTROL

It will be obvious that this field also covers a wide range of topics. The Greenhouse Effect and Acid Rain are just two examples covered almost daily in the newspapers. The focus of attention in this field is upon the emission of polluting gases by industries, cars and the like. An estimation is made of the releases into the air and how they will spread out in the atmosphere. The main difficulty here is the unpredictability of weather, which has a large influence on the dispersion of hazardous gases. Therefore, a stochastic approach has to be used in most research and in the corresponding optimization models. Even more than in water quality control, transboundary effects play an important role here. One example are the British Isles, which 'export' much more air pollution than they receive from other countries. The -generally favoured- polluter pays principle would imply that the UK and Ireland should pay much more to an international fund or specific governments than they are willing to. Companies themselves can take measures as well ; for example Drax, Western Europe's largest coalfired power station, is being equipped with a Flue Gas Desulphurisation (FGD) plant, which will remove over 90 % of the sulphurdioxide usually emitted.

The paper we use to provide an example in this field is by Ellis [13]. It considers multiobjective programming models for acid rain control. The land area considered corresponds to the United States of America. The basic framework is a linear programming (LP) model:

$$\begin{aligned}
 & \text{Min } \sum_j C_j R_j \\
 & \text{s.t. } \sum_j CE_j (1-R_j) t_{ij} + \sum_k NE_k J_{ik} + BG_i \leq D_i \quad \forall i \\
 & \quad R_j \geq 0 \quad \forall j
 \end{aligned}$$

where

C_j = removal cost function for controlled source j

R_j = SO_2 removal level for source j

CE_j = existing emission rate for source j

t_{ij} = transfer coefficient for source j and receptor i

NE_k = non controlled SO_2 emission rate for source k

t_{ik} = transfer coefficient for noncontrolled source k and receptor i

BG_i = background wet sulfate deposition rate for receptor i

D_i = maximum allowable wet sulfate deposition rate for receptor i

In this basic model framework the objective is to minimize the cost of SO_2 removal at the sources so as not to exceed maximum allowable deposition rates at various receptors.

It is clear that the maximum allowable deposition limits D_i play a critically important role. It is crucial to have a reasonable estimate of what is safe in order for the model to be of reasonable validity. It could well be that for some pollution receptors a relaxation of the limit will result in a large cost saving. One can introduce slack variables S_i that are incorporated in the objective function with a penalty weight. Note that the pollution standards have now become more of a target than a necessity. The results given in the paper show that multiobjective models can considerably reduce costs by allowing some restrictions to be slightly relaxed, as was to be expected.

Another change in the model could be to make the source removal cost dependent on the specific receptors, and on other sources. It might be a (politically) unretainable situation if a source is removing much more emission than it is receiving. Since it is quite cumbersome to model this concept we do not discuss it here. The interested reader is referred to the original paper.

Considerable research was done on the use of OR for air quality control. One example of this is the Regional Acidification INformation and Simulation (RAINS) model, which is able to predict SO_2 and NO_x depositions in Europe if locations and sizes of the sources of pollution are known. It shows that geographic reallocation of the budget to reduce emissions may lead to a significant decrease in maximum deposit levels. A short description of the RAINS model is given in, e.g., Van Beek, Fortuin and Van Wassenhove [3]. The paper also briefly discusses the Integrated

Model for the Assessment of the Greenhouse Effect (IMAGE), developed by the Dutch National Institute of the Public Health and Environmental Protection, which combines knowledge from different scientific disciplines to model the effect of many potentially dangerous emissions into the atmosphere. Operations Research techniques can then be used in conjunction with the IMAGE model to find the minimum budget required to satisfy imposed (legal) standards.

Gulman [21] introduces a chance-constrained dynamic air quality model which determines least cost time-linked air pollution emission controls while accounting for the dynamic and stochastic character of meteorological conditions. Ellis, McBean and Farquhar [14] also use a stochastic model to study acid rain abatement. Nakamori and Sawagari [32] and Darby, Gregory and Ossenbruggen [10] describe air quality monitoring networks in urban areas, and Szepesi [40] discusses a receptor oriented model simulating the transmission of air pollutants, which is validated using field measurement data and which optimizes meteorological parameters. Kemner and Tomes [26] develop a computerized optimization model to examine the cost effectiveness of alternative emission control strategies for coke plants, while Youston [43] does the same for power plants in Ontario.

A more general discussion is found in Balatskiy [1] which examines the economic aspects of establishing a standard for maximum permissible substances in the atmosphere, using an optimization method to determine an economic criterion. This completes our discussion on the field of air quality control. As in water quality, many topics have been covered by previous research. The techniques employed vary again from linear to chance-constrained programming. Modifications and generalizations of the methodology could be helpful in many of the specific situations discussed in the papers.

Almost all pollution ends up in water or air. This means in fact, that the majority of problems should be covered by the fields discussed above. The reason that there are six fields still to be discussed below, is that many aspects of pollution can perhaps better be classified on grounds other than its recipient. In this way fields of research can better be matched and specific characteristics of those fields can be highlighted.

3. CHEMICAL POLLUTION

The main issue in this field is the release of hazardous chemicals that can sometimes contaminate consumer products. Pesticides used for agricultural purposes are one example for which many legal measures are being taken currently. Another example is given by packaging materials which often contain large amounts of Vinyl Chloride Monomer

(V.C.M), causing so much trouble in the atmosphere (Greenhouse Effect). The focus here is on the alternatives industry has to fight V.C.M emission into the atmosphere.

Siskos, Lombard and Oudiz [37] use multicriteria outranking methods in the comparison of control options against such a chemical pollutant. Their framework allows for three emission alternatives: canalized (known, at given locations in a plant), fugitive (in all kinds of processes) and accidental. For these emissions five prevention systems are distinguished: recycling, burning, absorption by other materials, fugitive control by airtight equipment, and storage improvement.

These systems are said to bring forth three levels of consequences:

1. normal or disrupted plant operations,
2. type of impact: health or economic,
3. do/do not affect the production system and concern the public or the workers

The model considers six independent evaluation criteria: annualized cost, V.C.M released, V.C.M recovered, co-pollutant releases recovered, variation of shop content (workers' exposure), impact on operating security.

The multicriteria method works as follows. For each criterion a function is specified that can represent the performance of every management alternative on that criterion. There are several steps involved in the outranking procedure .

1. *Monocriteria outranking relations*: the introduction of a function that represents the intensity of the outranking of one alternative by another alternative.
2. *Concordance analysis*: to each criterion an importance index (weight) is assigned. The weighted sum of the outranking intensity functions gives the degree of concordance of all criteria to the proposition of "global" outranking of one alternative by another alternative.
3. *Discordance analysis*: this takes into consideration that, even if there is global outranking, there can be incomparability between two alternatives if there are some criteria on which alternative A outperforms alternative B, but others where the opposite is the case.

4. *Fuzzy outranking*: this concept combines the previous two steps in that it forms a degree of credibility of the global outranking of one alternative by another one.
5. A final step is a classic ranking of all alternatives, based on the fuzzy outranking relations.

Although one can argue whether it is possible to make a comparison between very different criteria, the method surely provides a logical basis for comparing all important aspects of a pollution problem.

Other examples of chemical pollution problems often concern specific industries or plants, such as the coke plant discussed by Kemner and Tomes [26] and the power plants discussed by Youston [43]. There are some papers that discuss the impact of legal measures concerning the use of pesticides, often considering regional situations only. Landner et al. [28] describe some systems for testing and hazard evaluation of chemicals in an aquatic environment.

From the above it is clear that this field has not received much attention. The most important reason for this is that much more attention is paid to different ways of modelling air or water pollution than to focussing on the industrial processes that cause the pollution. Future work should concentrate more on processes and ways to reduce the release of hazardous chemical materials.

4. NUCLEAR POLLUTION

Perhaps this is one of the best known fields of pollution, especially since small mistakes in the handling of nuclear materials can have dramatic consequences (e.g. Chernobyl). There are two main subfields here. First, there is the organization and control of processes in which nuclear radiation can be released, thereby endangering the health of workers and nearby population. OR can be used in different ways here, from selecting the best equipment and organization of a plant to determining the best location of those plants. Second, there is the management of nuclear waste, which has to be stocked somewhere for years or even for decades. There are many possibilities, from ocean dumping or storing in salt-mines to building special containers for storage. All of those possibilities have their pros and cons. By modelling these, OR can help in choosing an appropriate alternative. From the section on chemical pollution one could expect that in these problems multicriteria outranking methods might also be appropriate.

An example of this is given by Briggs, Kunsch and Mareschal [8]. They concentrate on interim storage of radioactive waste, which is the period between the cooling of irradiated used fuel and its final disposal into geological formations. Three types of questions must be answered: how long should it be stored, where should it be stored, and how should the storage be financed? For all these questions a set of alternatives is formed, leading to an even bigger set of scenarios. Each scenario is then evaluated on three different criteria:

1. *The total financial cost*: all expenses necessary to cover technical costs before, during and after the dumping of radioactive waste.
2. *The "Pollutor Pays Principle"*, attempting to measure the societal implications of each of the financing methods, considering present as well as future consumers.
3. *Financial risk due to a wrong assessment of future costs*, related to long term uncertainties in determining cost.

The same procedure as described earlier is used to obtain a ranking of scenarios.

Apart from a paper by Hill and Mitchell [24], discussing the impact of radionuclide releases to the environment and establishing release limits, we did not come across much in this field. The International Atomic Energy Agency publishes a large number of reports but these do not often discuss mathematical models or OR techniques (for an example, see Farges and Daw [15]).

5. TRANSPORTATION OF HAZARDOUS MATERIALS

Routing (or transportation) is a major topic of interest in Operations Research. A lot of attention has been paid to the basic travelling salesman problem as well as to many extensions: multiple depots, time-windows, pick-up and delivery, overtime, natural barriers, and so on. It is quite natural to extend these basic routing problems to the case of hazardous materials by taking environmental restrictions into account (hazardous materials are not allowed to be transported everywhere, e.g., in tunnels) or by incorporating expected costs of accidents into the analysis. These additional considerations might lead to completely different optimal routes.

An interesting paper in this field is Batta and Chiu [2], which also includes a literature review of most work performed before 1987. The basis of the Batta and Chiu model is given by a connected, undirected, planar transportation network with links (i,j) between nodes i and j , whose distances are measured by the (quite realistic) Euclidean metric.

The problem can be written as

$$\text{Min } \gamma(p) = \sum_{(i,j) \in p} R(i,j)$$

where p is a certain path between an origin and a destination node. $R(i,j)$ represents the desirability of link (i,j) and can be considered as a kind of link length. It is a function of the real link length and the undesirability of routing a vehicle through node i or j or link (i,j) . This undesirability is connected to the so-called threshold distance, within which transportation is considered to be dangerous. When the $R(i,j)$ have been established, the problem can be solved by means of a suitable shortest path algorithm. It is obvious that the optimal path p^* depends crucially on the threshold distance.

A first extension of the model described so far is to incorporate the probability of accidental leakage. This can be done by introducing a function that represents the probability of an accident at node i or link (i,j) . The impact of an accident is supposed to be exogeneous to the model. It is now straightforward to adjust the objective function by adjusting the desirability (risk) of travelling through node i or j or link (i,j) .

Thus $R(i,j)$ can be updated, and the objective changes to finding a path that minimizes the expected damage when accidental leakage of hazardous materials can inflict damage within a threshold distance λ of the accident site. Further extensions of the model can be made by restricting the number of nodes to be visited, considering multiple shipments or origins/destinations, or taking into account wind speed and other meteorological influences.

From the rather technical discussion above it can be deduced that it is not always obvious how to adjust existing OR models and techniques to incorporate environmental issues. It will also be clear, though, that actually going through the effort of adjusting them can be of great help in supporting environmental decision making.

We would like to mention two other papers here. The first one is by Derwent [12], and describes the long range transport of air pollutants. Quantitative information is obtained via simulated annealing, a heuristic technique which uses a stochastic element to escape from 'local' optima. The second paper, by Sharma [36], discusses a completely different sub-field. Pollution in a city is tackled by optimizing an intraurban bus operating system to reduce automobile traffic. This is an interesting area which deserves a lot more attention.

6. LOCATION OF INDUSTRIES OR DISPOSAL SITES

Just as routing, location theory is a well-known and major research area in Operations Research. It is often linked to the problem of distribution in that it tries to find an optimal location for a plant or depot which has to serve a number of customers. In this way it is also highly connected with transportation problems.

The environmental issues enter in two places. First, there is the transportation side : hazardous waste has to be transported from producers to disposal sites. The environmental restrictions that arise have been discussed before. Second, there is the location issue. Plants and disposal sites may pollute air and/or ground (water) in the proximity of their location. Since pollution standards are mostly regional, they have to be taken into consideration in the location problems. It should be noted that it is often very difficult to design appropriate standards.

Bötcher and Rembold [6] consider an optimization model for a regional system of solid waste disposal which considers legal pollution standards. The solution procedure uses a branch and bound method and a flow-graph algorithm. There are three phases to be distinguished in planning a waste disposal system:

1. selection of suitable potential locations
2. determination of all potential lines of transport between waste producers and waste disposal sites
3. selection of the facility locations and the optimal transportation routes

The objective is to minimize transportation costs and operating costs at the disposal sites, given a set of legal pollution standards that may not be violated.

Since the mathematical formulation of the problem is quite cumbersome, only a description will be given. Four different types of disposal facilities for solid waste are considered: reloading stations for waste compaction, incineration plants, composting plants and dumps/sinks. Given are the locations of the waste producers, the potential locations for all of the disposal facilities and all the transportation lines. Furthermore, each location is characterized by specific technical and economic parameters. The objective function is then formulated as described above, and restrictions considering flow conservation, capacity limits and prescribed legal emission boundary rates are specified. All possible locations of facilities involve a binary variable, and it is this that makes the problem hard to solve.

A graph is introduced on which all necessary locations, transportation links and parameters can be defined easily, and the optimal solution is determined via a branch-and-bound procedure. This procedure can easily be extended to incorporate bonuses for lower emission levels or many of the extensions mentioned in the section on transportation.

Gulman and Schefer [22] develop a cost-effective optimization approach to industrial location planning and air quality measurement. The optimization criterion to be used is a welfare function, containing the following types of costs:

1. pollution related costs, costs of reducing pollution flows at the source, stack costs at the sources, cost of the pipes, costs at the treatment plants,
2. production costs, taking account of scale effects,
3. locational costs for the industrial units, related to land development costs,
4. commuting and goods transportation costs.

The specification of all these cost functions determines the difficulty of solving the problem. The authors suggest to use simplified linear programming formulations to delineate, as a first approximation, general solution patterns, upon which more refined and complex models can then be applied.

Erkut and Neuman [44] present a survey of location models in the OR literature which use a distance maximization criterion which is appropriate in locating undesirable facilities.

Again it can be concluded that existing OR techniques can be adjusted, although not trivially, to incorporate environmental issues. The fact that we did not find many examples in literature is probably due to the complexity of the

required solution techniques. It seems that many opportunities for further study remain here.

7. POLLUTION CONTROL VERSUS ECONOMIC GROWTH

Perhaps the title of this section is a little vague, but it basically covers the field of environmental economics (see e.g., Pearce, Markandya and Barbier [45]). The problems in this class consider the conflicting interests between economic growth and pollution control. Economic growth means increasing profits, production and factories, often with an embedded cost minimization objective. This can easily lead to more pollution. The target now is to find a compromise between the two conflicting interests. Most papers in this area are not very technical or detailed, but generally describe all important factors to come to a conclusive framework (upon which more advanced OR techniques could be used). An example of such approach is given by Parvin and Grammas [34]. The starting point is an input-output model of economic activities in which the social costs of pollution associated with each unit of consumption (its 'negative price') are generated as outputs. These social costs are then used as coefficients in the objective function of mathematical programming models which optimize the (net) value of bill of goods (and bads) produced and consumed. Since the input-output model covers all economic activity, it is quite an extensive model. It can, however, be nicely represented as in figure 1.

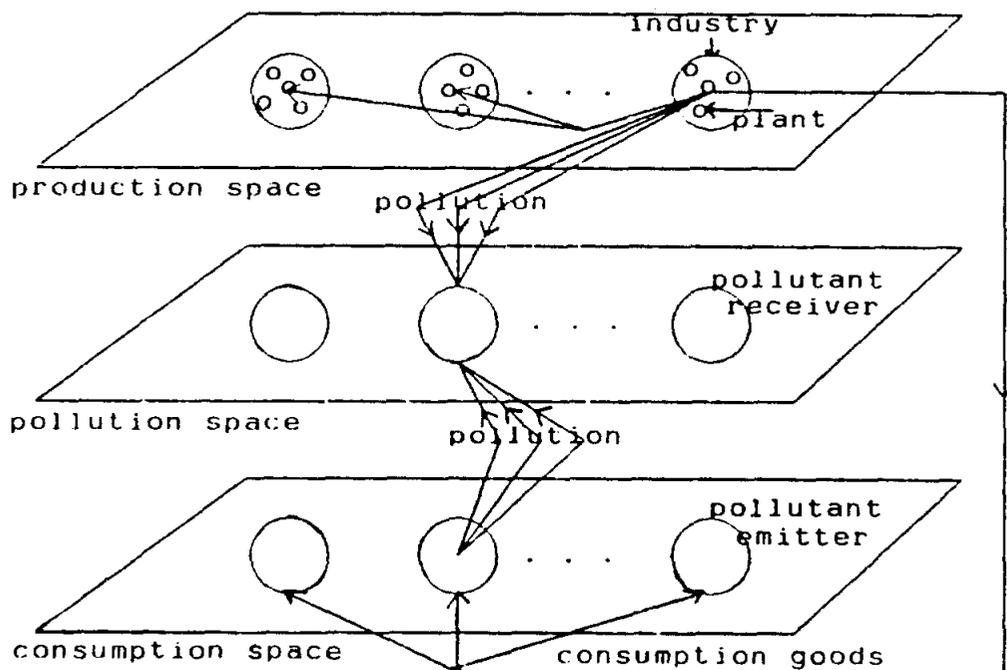


Figure 1: Hypothetical production, consumption and pollution spaces

The production space is formed by a number of industries, each containing a maximum number of plants (characterized by a method of production and location site), which produce certain commodities by using a number of different resources. All production alternatives have their own specific pollution effects. The outputs of the plants are used as inputs for other plants or are distributed to the consumption locations. Every consumer good can be consumed in a number of ways, each resulting in a particular pollution effect. The structural model formulated in this manner can be used to compute the social costs (negative prices) mentioned before.

There are several mathematical optimization models conceivable to determine the optimum level and composition of economic activities.

1. Maximize the value of final demand for a given price vector while a set of authorized pollutant-location specific standards is observed and the resource availability is not exceeded. This yields a linear programming model. The disadvantages of this model for policy control are the problems of setting standards and determining costs associated with pollution level measurement, general supervision and legal enforcement.
2. Minimize the total pollution damage cost, subject to relative lower bounds for consumption levels (which might be appropriate for planned or social economies). In this model the standards need not to be set beforehand, but on the other hand a damage function must be constructed. The model is nonlinear, in the best case quadratic.
3. Maximize the net value of final demand, recognizing that associated with each and every consumption activity there is a social cost. Here, the shadow prices of resources can take into account the pollution cost per unit of final demand. Again, the model is nonlinear.

Suggested further areas of research are the construction of pollution attenuation and damage cost functions, the role of location and distance, and the introduction of dynamic models.

There are numerous other papers in this field. Muschett [31] discusses conflicts between economic development of a society and clean air. A linear programming optimization model is used along with an interactive solution procedure to determine which economic development systems involve only limited air pollution. A highly specialized paper by Ferullo [16] describes how the government of Poland made an effort to solve a pollution

problem by concentrating all available resources in a model area selected in the most densely populated and highly industrialized part of Katowice. Spifford [39] concentrates on a conceptual framework for analyzing regional environmental quality management problems; some simulation and optimization modelling approaches that could be used for ranking alternative management strategies are discussed.

A completely different approach is given by Fujii [19], who adopts entropy as a rough index for environmental pollution, and then formulates the problems of economic growth as they relate to pollution as an optimization problem.

As this field is quite vaguely defined, a lot of opportunities are still open. The most interesting, however, are the development of dynamic (instead of steady-state) models and the use of (advanced) OR optimization techniques on the models that are described (but often left unsolved) in many of the papers.

8. NEW AND/OR RELATED FIELDS

This section is included to enable us to mention some interesting papers which do not easily fit into the fields mentioned before.

One possible area of future research is the identification of the source of pollution. Whitehead, Williams and Hornberger [41] consider a technique based on dispersion theory to identify the source of a pollutant. It is clear that it might become important to be able to trace every point or non-point pollutor. Here OR can also be of considerable help.

Another area of interest is resource planning. Lonergan [29] discusses how a simulation/optimization model can aid in the resolution of conflicts between natural and human systems. The same is done by Jameson and Gross [25]. The message in those papers is that it is necessary for a healthy environment to be very careful with natural resources. Related to this is the field of land use (and water supply). An example of poor land and resource management is given by the destruction of rain forests in South-America for cultivation reasons.

One final field to be mentioned here that deserves more attention in the future is the handling of (specific kinds of) industrial waste (see for an example of OR in this area Wold, Carlson and Skagerberg [42]).

CONCLUDING REMARKS

This paper discusses a set of publications on the use of Operations Research techniques in solving environmental problems. Since environmental problems are numerous and mutually very different, a problem classification into eight fields was suggested.

As was to be expected, it turns out that some areas have received a lot more attention than others. However, basic research has been done almost everywhere, often resulting in either descriptive models or in very simple optimization models. These models often incorporate environmental issues as a side constraint rather than as an objective. This implies that those issues are still considered to be externally imposed rather than an intrinsic part of policy making. Experiments have pointed out that OR might help to significantly reduce costs or pollution levels. It must be noted that there will always remain difficulties in applying those models to real-life. They are often built on many simplifications and assumptions hard to meet in practice. Nevertheless these models often provide unique insights in very complex problems. It is therefore especially important to concentrate on convincing managers, who have an increased responsibility in managing environmental resources (see e.g. Bodily and Gabel [5]), that it is recommendable to give OR models and techniques a chance.

We hope to have given the reader a clear picture of the use of OR in environmental problem solving and to have indicated opportunities for future research, many of which involve the further refinement of existing work.

REFERENCES

- [1] Balastskiy, O.F., Economic Aspects in Establishing the Maximum Permissible Substances in the Atmosphere, presented at Doc. First US/USSR Environmental Economics Symposium, 1977, pp. 134-142.
- [2] Batta, R. & S.S. Chiu, Optimal Obnoxious Paths on a Network: Transportation of Hazardous Materials, *Operations Research*, 1988, Vol. 36, No. 1, pp. 84-92.
- [3] Beek, P. van, L. Fortuin & L.N. Van Wassenhove, Operationele Research en Milieu, *De Ingenieur*, 1990, No. 4, pp. 7-13. Also available as Operational Research and Environment, Working Paper 91/02/TM/SM, INSEAD, Fontainebleau, France.
- [4] Bishop, A.B. & W.J. Grenney, Coupled Optimization-Simulation Water Quality Model, *Journal of Environmental Engineering - ASCE*, 1976, Vol. 102, No. 5, pp. 1071-1086.
- [5] Bodily, S.E. & H.L. Gabel, A New Job for Businessmen: Managing the Company's Environmental Resources, *Sloan Management Review*, Summer 1982, pp. 3-18.
- [6] Böttcher, H. & G.H. Rembold, Optimization Model for a Regional System of Solid Waste and Wastewater Disposal which Considers Legal Pollution Standards, *Environment and Planning A*, 1977, Vol. 9, pp. 771-786.
- [7] Bouzaher, A., J.B. Braden & G.V. Johnson, A Dynamic Programming Approach to a Class of Nonpoint Source Pollution Control problems, *Management Science*, 1990, Vol. 36, No. 1, pp. 1-15.
- [8] Briggs, Th., P.L. Kunsch & B. Mareschal, Nuclear Waste Management: an Application of the Multicriteria PROMETHEE Methods, *European Journal of Operational Research*, 1990, No. 44, pp. 1-10.

- [9] Burn, D.H. & E.A. McBean, Optimization Modelling of Water Quality in an Uncertain Environment, *Water Resources Research*, 1985, Vol. 21, No. 7, pp. 934-940.
- [10] Darby, W.P., C.J. Gregory & P.J. Ossenbruggen, Optimization of Urban Air Monitoring Networks, *Journal of Environmental Engineering - ASCE*, 1974, Vol. 100, No. 3, pp. 577-591.
- [11] Das, P. & Y.Y. Haimes, Multiobjective Optimization in Water Quality and Land Management, *Water Resources Research*, 1979, Vol. 15, No. 6, pp. 1313-1322.
- [12] Derwent, D., A Better Way to control Pollution, *Nature*, 1988, Vol. 331, No. 6157, pp. 575-578.
- [13] Ellis, J.H., Multiobjective Mathematical Programming Models for Acid Rain Control, *European Journal of Operational Research*, 1988, vol. 35, pp. 365-377.
- [14] Ellis, J.H., E.A. McBean & G.J. Farquhar, Chance-constrained/Stochastic Linear Programming Model for Acid Rain Abatement - II. Limited Colinearity, *Atmospheric Environment*, 1986, Vol. 20, No. 3, pp. 501-511.
- [15] Farges, L. & T. Daw, Methods for Determining the Release of Radioactive Material into the Environment, *International Atomic Energy Agency B*, 1976, Vol. 18, No. 5-6, pp. 48-52.
- [16] Ferullo, C., An approach to Environmental Quality Management in the Context of Regional Planning in the Province of Katowice, *Poland Public Health in Europe*, 1977, No. 8, pp. 55-68.
- [17] Fontane, D.G., J.W. Labadie & B. Loftis, Optimal Control of Reservoir Discharge Quality through Selective Withdrawal, *Water Resources Research*, 1981, Vol. 17, No. 6, pp. 1594-1604.
- [18] Fujihara, O., W. Puangmaha & K. Hanaki, River Basin Water Quality Management in Stochastic Environment, *Journal of Environmental Engineering - ASCE*, 1988, Vol. 114, No. 4, pp. 864-877.

- [19] Fujii, N., An Entropy Model of Environmental Pollution and Economic Growth, *Applied Mathematical Modelling*, 1982, Vol. 6, pp. 431-435.
- [20] Galya, D. Ground Water Modelling Applications and Advances, *ERT Newsletter*, 1988, No. 4, pp. 1-5.
- [21] Guldman, J.-M., Chance Constrained Dynamic Model of Air Quality Management, *Journal of Environmental Engineering - ASCE*, 1988, Vol. 11, No. 5, pp. 1116-1135.
- [22] Guldman, J.-M. & D. Shefer, Centralized Air Pollution Treatment and the Optimal Location of Industries, *Environment and Planning A*, 1977, Vol. 9, pp. 1121-1142.
- [23] Hassan, M.F., Water Quality Simulation and Control in Streams, *Encyclopedia of Environmental Control Technology: Wastewater Treatment Technology*, 1989, Vol. 3, pp. 77-138.
- [24] Hill, M.D. & N.T. Mitchell, Principles Used in Assessing the Impact of Radionuclide Releases to the Environment and in Establishing Release Limits, *International Atomic Energy Radioactive Waste Management International Conference*, 1983, Vol. 5, pp. 109-125.
- [25] Jameson, D.A. & B.L. Gross, Feedback, an Approach to Natural Resource Management, *NTIS Report PB-287 638*, 1977.
- [26] Kemner, W.F. & S.A. Tomes, Coke Battery Environmental Control Cost-Effectiveness, *Presented at EPA Iron and Steel Pollution Abatement Technology First Symposium*; Chicago, 1979, pp. 143-163.
- [27] Kuo, C.Y., G.V. Loganathan, W.E. Co, S.P. Shrestha & K.J. Ying, Effectiveness of Best Management Practice Structures for Stormwater Management in Urbanized Watershed, Virginia Polytechnic Institute and State University, *Water Resources Research Center*, B 159, 1987.

- [28] Landrer, L., W. Dietrickson, U.B. Fallenius, E. Leppaekoski, R. Nilsson, O. Svanberg & C.A. Wachtmeister, Systems for Testing and Hazard Evaluation of Chemicals in the Aquatic Environment, *Sveriges Naturvaardsverk*, 1982, No. 1631.
- [29] Lonergan, S.C., Simulation/Optimization Model for Natural Resources Planning: The Chesapeake Bay Experience, *Resource Management and Optimization*, 1983, Vol. 2, No. 4, pp. 293-321.
- [30] Loucks, D.P. & J.M. Bell, Administration: Systems Analysis, *Water Pollution Control Federation Journal*, 1978, Vol. 50, No. 6, pp. 1674-1681.
- [31] Muschett, F.D., Clean Air with Economic Growth: Optimization Modelling, *Environmental Management*, 1982, Vol. 6, No. 2, pp. 154-154.
- [32] Nakamori, Y. & Y. Sawaragi, Interactive Design of Urban Level Air Quality Monitoring Network, *Atmospheric Environment*, 1984, Vol. 18, No. 4, pp. 793-799.
- [33] Nemetz, P.N. & M. Margolick, Computer Supported System Analysis for Wastewater Control Cost Minimization, *Water, Air and Soil Pollution*, 1984, Vol. 23, No. 1, pp. 37-49.
- [34] Parvin, M. & G.W. Grammas, Optimization Models for Environmental Pollution Control, *Journal of Environmental Economics and Management*, 1976, Vol. 3, pp. 113-128.
- [35] Rosa, D.J., Modelling of a Marginal Damage Function for Groundwater Contamination, *International Association of Hydrogeologists Groundwater Symposium*, 1984, Vol. 2, pp. 517-527.
- [36] Sharma, S., Intraurban Transport-Optimization Through Operations Research Techniques, *Traffic Quarterly*, 1976, Vol. 30, No. 3, pp. 371-391.

- [37] Siskos, J., J. Lombard & A. Oudiz, The Use of Multicriteria Outranking Methods in the Comparison of Control Options Against a Chemical Pollutant, *Journal of Operational Research Society*, 1986, Vol. 37, No. 4, pp. 357-371.
- [38] Somlyódy, L. & R.J.-B. Wets, Stochastic Optimization Models for Lake Eutrophication Management, *Operations Research*, 1988, Vol. 36, No. 5, pp. 660-681.
- [39] Spifford, W.O., Ecological Modelling in a Resource Management Framework: an Introduction, *Presented at NOAA/Resources from the Future, Symposium on Ecological Modelling*, 1974, pp. 13-47.
- [40] Szepesi, D.J., Sensitivity Analysis on Parameters of Atmospheric Sulfur Transmission, *Science of the Total Environment*, 1983, Vol. 26, No. 2, pp. 183-202.
- [41] Whitehead, P.G., R.J. Williams & G.M. Hornberger, On the Identification of Pollutant or Tracer Sources Using Dispersion Theory, *Journal of Hydrology*, 1986, Vol. 84, pp. 273-286.
- [42] Wold, S., R. Carlson & B. Skagerberg, Statistical Optimization as a Means to Reduce Waste in Industrial Processes, *Environmental Professional*, 1989, Vol. 11, No. 2, pp. 127-132.
- [43] Youston, D.J., Social Effects of Atmospheric Emissions from Fossil-Fired Generating Stations, *Ontario Hydro Research Quarterly*, 1975, Vol. 27, No. 3, pp. 15-18.
- [44] E. Erkut and S. Neuman, Analytical Models for Locating Undesirable Facilities, *European Journal of Operational Research* 40, pp 275-291, 1989.
- [45] Pearce D.W., Markandya A., and E.B. Barbier, *Blueprint for a Green Economy*, Earthscan Publications Ltd, London, 1989.

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90/15 TM	Arnoud DE MEYER, Dirk DESCHOOLMEESTER, Rudy MOENAERT and Jan BARBE	"The Internal Technological Renewal of a Business Unit with a Mature Technology", January 1990.	90/26 OB/BP	Charles KADUSHIN and Michael BRIMM	"Why networking Fails: Double Binds and the Limitations of Shadow Networks", February 1990.
90/16 FIN	Richard LEVICH and Ingo WALTER	"Tax-Driven Regulatory Drag: European Financial Centers in the 1990's", January 1990.	90/27 TM	Abbas FOROUGHFI and Tawfik JELASSI	"NSS Solutions to Major Negotiation Stumbling Blocks", February 1990.
			90/28 TM	Arnoud DE MEYER	"The Manufacturing Contribution to Innovation", February 1990.

90/29 FIN/AC	Nathalie DIERKENS	"A Discussion of Correct Measures of Information Asymmetry", January 1990.	90/40 OB	Manfred KETS DE VRIES	"Leaders on the Couch: The case of Roberto Calvi", April 1990.
90/30 FIN/EP	Lars Tye NIELSEN	"The Expected Utility of Portfolios of Assets", March 1990.	90/41 FIN/EP	Gabriel HAWAWINI, Itzhak SWARY and Ik HWAN JANG	"Capital Market Reaction to the Announcement of Interstate Banking Legislation", March 1990.
90/31 MKT/EP	David GAUTSCHI and Roger BETANCOURT	"What Determines U.S. Retail Margins?", February 1990.	90/42 MKT	Joel STECKEL and Wilfried VANHONACKER	"Cross-Validating Regression Models in Marketing Research", (Revised April 1990).
90/32 SM	Srinivasan BALAK- RISHNAN and Mitchell KOZA	"Information Asymmetry, Adverse Selection and Joint-Ventures: Theory and Evidence", Revised, January 1990.	90/43 FIN	Robert KORAJCZYK and Claude VIALLET	"Equity Risk Premia and the Pricing of Foreign Exchange Risk", May 1990.
90/33 OB	Caren SIEHL, David BOWEN and Christine PEARSON	"The Role of Rites of Integration in Service Delivery", March 1990.	90/44 OB	Gilles AMADO, Claude FAUCHEUX and André LAURENT	"Organisational Change and Cultural Realities: Franco-American Contrasts", April 1990.
90/34 FIN/EP	Jean DERMINE	"The Gains from European Banking Integration, a Call for a Pro-Active Competition Policy", April 1990.	90/45 TM	Soumitra DUTTA and Piero BONISSONE	"Integrating Case Based and Rule Based Reasoning: The Possibilistic Connection", May 1990.
90/35 EP	Jac Won PARK	"Changing Uncertainty and the Time-Varying Risk Premia in the Term Structure of Nominal Interest Rates", December 1988, Revised March 1990.	90/46 TM	Spyros MAKRIDAKIS and Michèle HIBON	"Exponential Smoothing: The Effect of Initial Values and Loss Functions on Post-Sample Forecasting Accuracy".
90/36 TM	Arnoud DE MEYER	"An Empirical Investigation of Manufacturing Strategies in European Industry", April 1990.	90/47 MKT	Lydia PRICE and Wilfried VANHONACKER	"Improper Sampling in Natural Experiments: Limitations on the Use of Meta-Analysis Results in Bayesian Updating", Revised May 1990.
90/37 TM/OB/SM	William CATS-BARIL	"Executive Information Systems: Developing an Approach to Open the Possibles", April 1990.	90/48 EP	Jae WON PARK	"The Information in the Term Structure of Interest Rates: Out-of-Sample Forecasting Performance", June 1990.
90/38 MKT	Wilfried VANHONACKER	"Managerial Decision Behaviour and the Estimation of Dynamic Sales Response Models", (Revised February 1990).	90/49 TM	Soumitra DUTTA	"Approximate Reasoning by Analogy to Answer Null Queries", June 1990.
90/39 TM	Louis LE BLANC and Tawfik JELASSI	"An Evaluation and Selection Methodology for Expert System Shells", May 1990.	90/50 EP	Daniel COHEN and Charles WYPLOSZ	"Price and Trade Effects of Exchange Rates Fluctuations and the Design of Policy Coordination", April 1990.

90/51 EP	Michael BURDA and Charles WYPLOSZ	"Gross Labour Market Flows in Europe: Some Stylized Facts", June 1990.	90/63 SM	Sumantra GHOSHAL and Eleanor WESTNEY	"Organising Competitor Analysis Systems", August 1990
90/52 FIN	Lars Tye NIELSEN	"The Utility of Infinite Menus", June 1990.	90/64 SM	Sumantra GHOSHAL	"Internal Differentiation and Corporate Performance: Case of the Multinational Corporation", August 1990
90/53 EP	Michael Burda	"The Consequences of German Economic and Monetary Union", June 1990.	90/65 EP	Charles WYPLOSZ	"A Note on the Real Exchange Rate Effect of German Unification", August 1990
90/54 EP	Damien NEVEN and Colin MEYER	"European Financial Regulation: A Framework for Policy Analysis", (Revised May 1990).	90/66 TM/SE/FIN	Soumitra DUTTA and Piero BONISSONE	"Computer Support for Strategic and Tactical Planning in Mergers and Acquisitions", September 1990
90/55 EP	Michael BURDA and Stefan GERLACH	"Intertemporal Prices and the US Trade Balance", (Revised July 1990).	90/67 TM/SE/FIN	Soumitra DUTTA and Piero BONISSONE	"Integrating Prior Cases and Expert Knowledge In a Mergers and Acquisitions Reasoning System", September 1990
90/56 EP	Damien NEVEN and Lars-Hendrik RÖLLER	"The Structure and Determinants of East-West Trade: A Preliminary Analysis of the Manufacturing Sector", July 1990	90/68 TM/SE	Soumitra DUTTA	"A Framework and Methodology for Enhancing the Business Impact of Artificial Intelligence Applications", September 1990
90/57 FIN/EP/ TM	Lars Tye NIELSEN	Common Knowledge of a Multivariate Aggregate Statistic", July 1990	90/69 TM	Soumitra DUTTA	"A Model for Temporal Reasoning in Medical Expert Systems", September 1990
90/58 FIN/EP/TM	Lars Tye NIELSEN	"Common Knowledge of Price and Expected Cost in an Oligopolistic Market", August 1990	90/70 TM	Albert ANGEHRN	"Triple C': A Visual Interactive MCDSS", September 1990
90/59 FIN	Jean DERMINE and Lars-Hendrik RÖLLER	"Economies of Scale and Scope in the French Mutual Funds (SICAV) Industry", August 1990	90/71 MKT	Philip PARKER and Hubert GATIGNON	"Competitive Effects in Diffusion Models: An Empirical Analysis", September 1990
90/60 TM	Peri IZ and Tawfik JELASSI	"An Interactive Group Decision Aid for Multiobjective Problems: An Empirical Assessment", September 1990	90/72 TM	Enver YÜCESAN	"Analysis of Markov Chains Using Simulation Graph Models", October 1990
90/61 TM	Pankaj CHANDRA and Mihkel TOMBAK	"Models for the Evaluation of Manufacturing Flexibility", August 1990	90/73 TM	Arnoud DE MEYER and Kasra FERDOWS	"Removing the Barriers in Manufacturing", October 1990
90/62 EP	Damien NEVEN and Menno VAN DIJK	"Public Policy Towards TV Broadcasting in the Netherlands", August 1990	90/74 SM	Sumantra GHOSHAL and Nitin NOHRIA	"Requisite Complexity: Organising Headquarters- Subsidiary Relations in MNCs", October 1990

90/75 MKT	Roger BETANCOURT and David GAUTSCHI	"The Outputs of Retail Activities: Concepts, Measurement and Evidence", October 1990	90/87 FIN/EP	Lars Tyge NIELSEN	"Existence of Equilibrium in CAPM: Further Results", December 1990
90/76 MKT	Wilfried VANHONACKER	"Managerial Decision Behaviour and the Estimation of Dynamic Sales Response Models", Revised October 1990	90/88 OB/MKT	Susan C. SCHNEIDER and Reinhard ANGELMAR	"Cognition in Organisational Analysis: Who's Minding the Store?" Revised, December 1990
90/77 MKT	Wilfried VANHONACKER	"Testing the Koyck Scheme of Sales Response to Advertising: An Aggregation-Independent Autocorrelation Test", October 1990	90/89 OB	Manfred F.R. KETS DE VRIES	"The CEO Who Couldn't Talk Straight and Other Tales from the Board Room," December 1990
90/78 EP	Michael BURDA and Stefan GERLACH	"Exchange Rate Dynamics and Currency Unification: The Ostmark - DM Rate", October 1990	90/90 MKT	Philip PARKER	"Price Elasticity Dynamics over the Adoption Lifecycle: An Empirical Study," December 1990
90/79 TM	Anil GABA	"Inferences with an Unknown Noise Level in a Bernoulli Process", October 1990			
90/80 TM	Anil GABA and Robert WINKLER	"Using Survey Data in Inferences about Purchase Behaviour", October 1990	<u>1991</u>		
90/81 TM	Tawfik JELASSI	"Du Présent au Futur: Bilan et Orientations des Systèmes Interactifs d'Aide à la Décision," October 1990	91/01 TM/SM	Luk VAN WASSENHOVE, Leonard FORTUIN and Paul VAN BEEK	"Operational Research Can Do More for Managers Than They Think!," January 1991
90/82 EP	Charles WYPLOSZ	"Monetary Union and Fiscal Policy Discipline," November 1990	91/02 TM/SM	Luk VAN WASSENHOVE, Leonard FORTUIN and Paul VAN BEEK	"Operational Research and Environment," January 1991
90/83 FIN/TM	Nathalie DIERKENS and Bernard SINCLAIR-DESGAGNE	"Information Asymmetry and Corporate Communication: Results of a Pilot Study", November 1990	91/03 FIN	Pekka HIETALA and Timo LÖYTTYNIEMI	"An Implicit Dividend Increase in Rights Issues: Theory and Evidence," January 1991
90/84 MKT	Philip M. PARKER	"The Effect of Advertising on Price and Quality: The Optometric Industry Revisited," December 1990	91/04 FIN	Lars Tyge NIELSEN	"Two-Fund Separation, Factor Structure and Robustness," January 1991
90/85 MKT	Avijit GHOSH and Vikas TIBREWALA	"Optimal Timing and Location in Competitive Markets," November 1990	91/05 OB	Susan SCHNEIDER	"Managing Boundaries in Organisations," January 1991
90/86 EP/TM	Olivier CADOT and Bernard SINCLAIR-DESGAGNE	"Prudence and Success in Politics," November 1990	91/06 OB	Manfred KETS DE VRIES, Danny MILLER and Alain NOEL	"Understanding the Leader-Strategy Interface: Application of the Strategic Relationship Interview Method," January 1990 (89/11, revised April 1990)

91/07 EP	Olivier CADOT	"Lending to Insolvent Countries: A Paradoxical Story," January 1991	91/19 MKT	Vikas TIBREWALA and Bruce BUCHANAN	"An Aggregate Test of Purchase Regularity", March 1991
91/08 EP	Charles WYPLOSZ	"Post-Reform East and West: Capital Accumulation and the Labour Mobility Constraint," January 1991	91/20 MKT	Darius SABAVALA and Vikas TIBREWALA	"Monitoring Short-Run Changes in Purchasing Behaviour", March 1991
91/09 TM	Spyros MAKRIDAKIS	"What can we Learn from Failure?", February 1991	91/21 SM	Sumantra GHOSHAL, Harry KORINE and Gabriel SZULANSKI	"Interunit Communication within MNCs: The Influence of Formal Structure Versus Integrative Processes", April 1991
91/10 TM	Luc Van WASSENHOVE and C. N. POTTS	"Integrating Scheduling with Batching and Lot-Sizing: A Review of Algorithms and Complexity", February 1991	91/22 EP	David GOOD, Lars-Hendrik RÖLLER and Robin SICKLES	"EC Integration and the Structure of the Franco-American Airline Industries: Implications for Efficiency and Welfare", April 1991
91/11 TM	Luc VAN WASSENHOVE et al.	"Multi-Item Lotsizing in Capacitated Multi-Stage Serial Systems", February 1991	91/23 TM	Spyros MAKRIDAKIS and Michèle HIBON	"Exponential Smoothing: The Effect of Initial Values and Loss Functions on Post-Sample Forecasting Accuracy", April 1991 (Revision of 90/46)
91/12 TM	Albert ANGEHRN	"Interpretative Computer Intelligence: A Link between Users, Models and Methods in DSS", February 1991	91/24 TM	Louis LE BLANC and Tawfik JELASSI	"An Empirical Assessment of Choice Models for Software Evaluation and Selection", May 1991
91/13 EP	Michael BURDA	"Labor and Product Markets in Czechoslovakia and the Ex-GDR: A Twin Study", February 1991	91/25 SM/TM	Luk N. VAN WASSENHOVE and Charles J. CORBETT	"Trade-Offs? What Trade-Offs?" April 1991
91/14 MKT	Roger BETANCOURT and David GAUTSCHI	"The Output of Retail Activities: French Evidence", February 1991	91/26 TM	Luk N. VAN WASSENHOVE and C.N. POTTS	"Single Machine Scheduling to Minimize Total Late Work", April 1991
91/15 OB	Manfred F.R. KETS DE VRIES	"Exploding the Myth about Rational Organisations and Executives", March 1991	91/27 FIN	Nathalie DIERKENS	"A Discussion of Correct Measures of Information Asymmetry: The Example of Myers and Majluf's Model or the Importance of the Asset Structure of the Firm", May 1991
91/16 TM	Arnoud DE MEYER and Kasra FERDOWS et.al.	"Factories of the Future: Executive Summary of the 1990 International Manufacturing Futures Survey", March 1991	91/28 MKT	Philip M. PARKER	"A Note on: 'Advertising and the Price and Quality of Optometric Services', June 1991
91/17 TM	Dirk CATTRYSSSE, Roelof KUIK, Marc SALOMON and Luk VAN WASSENHOVE	"Heuristics for the Discrete Lotsizing and Scheduling Problem with Setup Times", March 1991	91/29 TM	Tawfik JELASSI and Abbas FOROUGHJI	"An Empirical Study of an Interactive, Session-Oriented Computerised Negotiation Support System (NSS)", June 1991
91/18 TM	C.N. POTTS and Luk VAN WASSENHOVE	"Approximation Algorithms for Scheduling a Single Machine to Minimize Total Late Work", March 1991			

91/30 MKT	Wilfried R. VANHONACKER and Lydia J. PRICE	"Using Meta-Analysis Results in Bayesian Updating: The Empty Cell Problem", June 1991	91/43 SM	Sumantra GHOSHAL and Christopher BARTLETT	"Building Transnational Capabilities: The Management Challenge", September 1991
91/31 FIN	Rezaul KABIR and Theo VERMAELEN	"Insider Trading Restrictions and the Stock Market", June 1991	91/44 SM	Sumantra GHOSHAL and Nitin NOHRIA	"Distributed Innovation in the 'Differentiated Network' Multinational", September 1991
91/32 OB	Susan C. SCHNEIDER	"Organisational Sensemaking: 1992", June 1991	91/45 MKT	Philip M. PARKER	"The Effect of Advertising on Price and Quality: An Empirical Study of Eye Examinations, Sweet Lemons and Self-Deceivers", September 1991
91/33 EP	Michael C. BURDA and Michael FUNKE	"German Trade Unions after Unification - Third Degree Wage Discriminating Monopolists?", June 1991	91/46 MKT	Philip M. PARKER	"Pricing Strategies in Markets with Dynamic Elasticities", October 1991
91/34 FIN	Jean DERMINE	"The BIS Proposal for the Measurement of Interest Rate Risk, Some Pitfalls", June 1991	91/47 MKT	Philip M. PARKER	"A Study of Price Elasticity Dynamics Using Parsimonious Replacement/Multiple Purchase Diffusion Models", October 1991
91/35 FIN	Jean DERMINE	"The Regulation of Financial Services in the EC, Centralization or National Autonomy?" June 1991	91/48 EP/TM	H. Landis GABEL and Bernard SINCLAIR-DESGAGNE	"Managerial Incentives and Environmental Compliance", October 1991
91/36 TM	Albert ANGEHRN	"Supporting Multicriteria Decision Making: New Perspectives and New Systems", August 1991	91/49 TM	Bernard SINCLAIR-DESGAGNE	"The First-Order Approach to Multi-Task Principal-Agent Problems", October 1991
91/37 EP	Ingo WALTER and Hugh THOMAS	"The Introduction of Universal Banking in Canada: An Event Study", August 1991	91/50 SM/TM	Luk VAN WASSENHOVE and Charles CORBETT	"How Green is Your Manufacturing Strategy?" October 1991
91/38 EP	Ingo WALTER and Anthony SAUNDERS	"National and Global Competitiveness of New York City as a Financial Center", August 1991	91/51 MKT	Philip M. PARKER	"Choosing Among Diffusion Models: Some Empirical Guidelines", October 1991
91/39 EP	Ingo WALTER and Anthony SAUNDERS	"Reconfiguration of Banking and Capital Markets in Eastern Europe", August 1991	91/52 EP	Michael BURDA and Charles WYPLOSZ	"Human Capital, Investment and Migration in an Integrated Europe", October 1991
91/40 TM	Luk VAN WASSENHOVE, Dirk CATTRYSE and Marc SALOMON	"A Set Partitioning Heuristic for the Generalized Assignment Problem", August 1991	91/53 EP	Michael BURDA and Charles WYPLOSZ	"Labour Mobility and German Integration: Some Vignettes", October 1991
91/41 TM	Luk VAN WASSENHOVE, M.Y. KOVALYOU and C.N. POTTS	"A Fully Polynomial Approximation Scheme for Scheduling a Single Machine to Minimize Total Weighted Late Work", August 1991	91/54 TM	Albert ANGEHRN	"Stimulus Agents: An Alternative Framework for Computer-Aided Decision Making", October 1991
91/42 TM	Rob R. WEITZ and Tawfik JELASSI	"Solving A Multi-Criteria Allocation Problem: A Decision Support System Approach", August 1991			

91/55 EP/SM	Robin HOGARTH, Claude MICHAUD, Yves DOZ and Ludo VAN DER HEYDEN	"Longevity of Business Firms: A Four-Stage Framework for Analysis", November 1991	92/03 OB	Manfred F.R. KETS DE VRIES	"The Family Firm: An Owner's Manual", January 1992
91/56 TM/EP	Bernard SINCLAIR-DESGAGNE	"Aspirations and Economic Development", November 1991	92/04 SM	Philippe HASPELAGH and David JEMISON	"Making Acquisitions Work", January 1992
91/57 MKT	Lydia J. PRICE	"The Indirect Effects of Negative Information on Attitude Change", November 1991	92/05 TM	Xavier DE GROOTE	"Flexibility and Product Diversity in Lot-Sizing Models", January 1992 (revised)
91/58 OB	Manfred F. R. KETS DE VRIES	"Leaders Who Go Crazy", November 1991	92/06 FIN	Theo VERMAELEN and Kees COOLS	"Financial Innovation: Self Tender Offers in the U.K.", January 1992
91/59 OB	Paul A. L. EVANS	"Management Development as Glue Technology", November 1991	92/07 TM	Xavier DE GROOTE	"The Flexibility of Production Processes: A General Framework", January 1992 (revised)
91/60 TM	Xavier DE GROOTE	"Flexibility and Marketing/Manufacturing Coordination", November 1991 (revised)	92/08 TM	Luk VAN WASSENHOVE, Leo KROON and Marc SALOMON	"Exact and Approximation Algorithms for the Operational Fixed Interval Scheduling Problem", January 1992
91/61 TM	Arnoud DE MEYER	"Product Development in the Textile Machinery Industry", November 1991	92/09 TM	Luk VAN WASSENHOVE, Roelof KUIK and Marc SALOMON	"Statistical Search Methods for Lotsizing Problems", January 1992
91/62 MKT	Philip PARKER and Hubert GATIGNON	"Specifying Competitive Effects in Diffusion Models: An Empirical Analysis", November 1991	92/10 SM	Yves DOZ and Heinz THANHEISER	"Regaining Competitiveness: A Process of Organisational Renewal", January 1992
91/63 EP	Michael BURDA	"Some New Insights on the Interindustry Wage Structure from the German Socioeconomic Panel", December 1991	92/11 TM	Enver YUCESAN and Sheldon JACOBSON	"On the Intractability of Verifying Structural Properties of Discrete Event Simulation Models", February 1992
91/64 FIN	Jean DERMINE	"Internationalisation of Financial Markets, Efficiency and Stability", December 1991	92/12 FIN	Gabriel HAWAWINI	"Valuation of Cross-Border Mergers and Acquisitions", February 1992
<u>1992</u>			92/13 TM	Spyros MAKRIDAKIS and Michèle HIBON et.al.	"The M2-Competition: A Budget Related Empirical Forecasting Study", February 1992
92/01 MKT/EP/TM	Wilfried VANHONACKER	"CONPRO*DOGIT: A New Brand Choice Model Incorporating a Consideration Set Formation Process", January 1992	92/14 MKT	Lydia PRICE	"Identifying Cluster Overlap with NORMIX Population Membership Probabilities", February 1992
92/02 MKT/EP/TM	Wilfried VANHONACKER	"The Dynamics of the Consideration Set Formation Process: A Rational Modelling Perspective and Some Numerical Results", January 1992			

92/15 MKT	Vikas TIBREWALA, Peter LENK and Ambar RAO	"Nonstationary Conditional Trend Analysis: An Application to Scanner Panel Data", February 1992
92/16 TM	Xavier DE GROOTE and Yu-Sheng ZHENG	"A Sensitivity Analysis of Stochastic Inventory Systems", March 1992
92/17 TM	Xavier DE GROOTE and Evan L. PORTEUS	"An Approach to Single Parameter Process Design", March 1992
92/18 TM	Xavier DE GROOTE	"Information Disclosure and Technology Choice", March 1992
92/19 FIN	Jean DERMINE	"Deposit Insurance, Credit Risk and Capital Adequacy: A Note", March 1992
92/20 TM	Tawfik JELASSI and Michèle SANGLIER	"Information, Systèmes Complexes et Technologies de l'Information", March 1992
92/21 SM	Paul J. VERDIN and Peter J. WILLIAMSON	"From Barriers to Entry to Barriers to Survival", March 1992
92/22 MKT	Christian PINSON	"Semiotics of Marketing", April 1992
92/23 TM	Luk VAN WASSENHOVE, Jacqueline RUWAARD and Marc SALOMON	"On Coordination of Product and Waste Flows in Distribution Networks: Model Formulations and Solution Procedures", April 1992