IIASA-PC-9

International Institute
for
Applied Systems Analysis

PROCEEDINGS
OF
IIASA PLANNING CONFERENCE
ON
OPTIMIZATION AND CONTROL OF COMPLEX DYNAMIC SYSTEMS

October 3 - 5, 1973

Schloss Laxenburg
2361 Laxenburg
Austria

The views expressed are those of the contributors and not necessarily those of the Institute.

The Institute assumes full responsibility for minor editorial changes made in grammar, syntax, or wording, and trusts that these modifications have not abused the sense of the writers' ideas.

TABLE OF CONTENTS

List of Participants

Chairman:

Prof. G. Dantzig
Department of Operations Research
Stanford University
Stanford, California 94305
USA

AUSTRIA

D.F.J. Firneis
Institut fuer Informations-
verarbeitung der
Oesterreichischen Akademie
der Wissenschaften
Fleischmarkt 20
1010 Wien

Dr. Helmut Strasser
Institut fuer sozio-
oekonomische Entwicklungs-
forschung der
Oesterreichischen Akademie
der Wissenschaften
Fleischmarkt 22
1010 Wien

Fr. Doz. Dr. Inge Troch
I. Institut fuer Mathematik
der Technischen Hochschule
Wien
Karlsplatz 13
1040 Wien

CANADA

Dr. Michael L. Kirby
Principal Assistant
to the Premier
Premier's Office
Halifax, Nova Scotia

CZECHOSLOVAKIA

Vice-Minister Tibor Vaško
Committee for IIASA of CSSR
Slezska 9, Vinohrady
Prague 2

Doz. Dr. Ing. Antonin Ter-
Manuelianc
Institut fuer Wirtschafts-
fuehrung
Reznicka 4
Prague

FEDERAL REPUBLIC OF GERMANY

Dr. H. Bossel
Institut fuer Systemtechnik
und Innovationsforschung
Breslauerstrasse 48
75 Karlsruhe 1 - Waldstadt

FRANCE

Prof. Jean Abadie
29, Blvd. Edgar Quinet
75016 Paris

Prof. M. Breton
E.D.F.
2, Rue Louis Murat
75008 Paris

FRANCE

Dr. Michel Cramer
CESMAP
94112 Arcueil

Prof. George Nissen
IRIA
Domaine de Voluceau
78 Rocquencourt

Prof. B. Roy
S.E.M.A.
16-20 Rue Barbes
92 Montrouge

GERMAN DEMOCRATIC REPUBLIC

Dr. Bruder
Academy of Sciences of the GDR
Leipziger Str. 5
108 Berlin

Prof. H. Koziolek
same address as above

Prof. Peschel
same address as above

HUNGARY

Mr. Istvan Dancs
Head of Department
Research Institute for
Economic Planning
Oktober 6 utca
Budapest V

ITALY

Prof. Guido Guardabassi
Istituto di Elettrotecnica
ed Elettronica del Politecnico
Piazza Leonardo da Vinci 32
20133 Milano

Prof. Luigi Mariani
Istituto di Elettrotecnica
ed Elettronica
Via Gradenigo 6/A
35100 Padua

ITALY

Dr. Claudio Bonivento
Istituto di Automatica
Facoltá di Ingegnieria
Viale Risorgimento, 2
40135 Bologna

JAPAN

Prof. Akira Nomoto
University of Tokyo
Bunkyo-ku
Tokyo

POLAND

Prof. Roman Kulikowski
Institute for Applied Cybernetics
c/o Polish Academy of Sciences
00-818 Warsaw K.R.N. 55

UNITED KINGDOM

Prof. E.M.L. Beale
Scientific Control Systems, Ltd.
Milton Court
Ropemaker Street
Moorgate
London EC2Y 9BH

U.S.A.

Prof. Arthur M. Geoffrion
Graduate School of Business
University of California (UCLA)
Los Angeles, California 90024

Prof. S.K. Mitter
Department of Electrical
Engineering
Massachusetts Institute of
Technology
Cambridge, Massachusetts 02139

U.S.A.

Dr. William Orchard-Hays
National Bureau of Economic
Research, Inc.
Computer Research Center for
Economics and Management Science
575 Technology Square
Cambridge, Massachusetts 02139

Dr. Philip Wolfe
IBM - T.J. Watson Research
Center
P.O.Box 218
Yorktown Heights, NY 10598

U.S.S.R.

Prof. Nikita N. Moiseev
Deputy Director
Computing Center of the USSR
Academy of Sciences
Vavilov Str. 40
Moscow B-333

Dr. Vladislav V. Tokarev
Institute for Control Problems
c/o The USSR Academy of Sciences
State Committee for Science
and Technology
11 Gorky Street
Moscow

IIASA Staff

Professor Howard Raiffa
Director

Professor Alexandr Letov
Deputy Director

Dr. Andrei Bykov
Secretary to IIASA

Research Scholars

Dr. Rudolf Avenhaus
Energy Project

Professor Gerhard Bruckmann

Professor Jerome Feldman
Artificial Intelligence

Professor Wolf Haefele
Energy Project

Professor P. Koryavov
Water Resources Project

Professor Alan Manne
Energy Project

Professor Yuri Rozanov
Water Resources Project

Doz. Ing. Dr. Robert Trappl
Biomedical Systems

Dr. Robert Winkler
Methodology

Dr. David Bell
Rapporteur

Dr. Jean-Pierre Ponssard
Rapporteur

Minutes of the Research Planning Conference on The Optimization and Control of Complex Dynamic Systems*

October 3-5, 1973

The conference opened with a welcome and introduction to IIASA by the Director, Professor Howard Raiffa. He mentioned that this was the ninth in a series of conferences to discuss possible research strategies for IIASA both in the long and short terms. The scientific staff was expected to number about thirty by the end of this year rising to eighty or so by the end of next year. The hope was that IIASA could cooperate with other institutions, universities as well as the various United Nations organizations around the world. Activities at IIASA might fall into four main categories:

1) In-house research involving small groups of up to half a dozen scientists having only loose outside contacts.

2) A labor intensive study of a concrete problem involving data collection, the writing of software, for example in the study of an inland Alpine lake.

3) Acting as a clearinghouse for information in the area of systems analysis with a view to improving communication between fields. IIASA might act as a catalyst for inter-disciplinary and international work. This would require IIASA to hire some scientists with administrative abilities.

4) Convening conferences on special topics as a need arises.

Scientific services available at IIASA included a library network to supply books and papers as required. It is felt that a library of archive form would be too large. The computing services were not yet finalized, the Institute at present having a computer link with Cleveland, Ohio in the United States.

The Director then outlined some of the main points of discussion from the previous eight conferences, ending with his hope that the present conference would provide a useful

*These Minutes were prepared by D. Bell and J-P. Ponssard.

basis on which a research strategy could be devised to present to the Council in November.

Chairman's Introduction

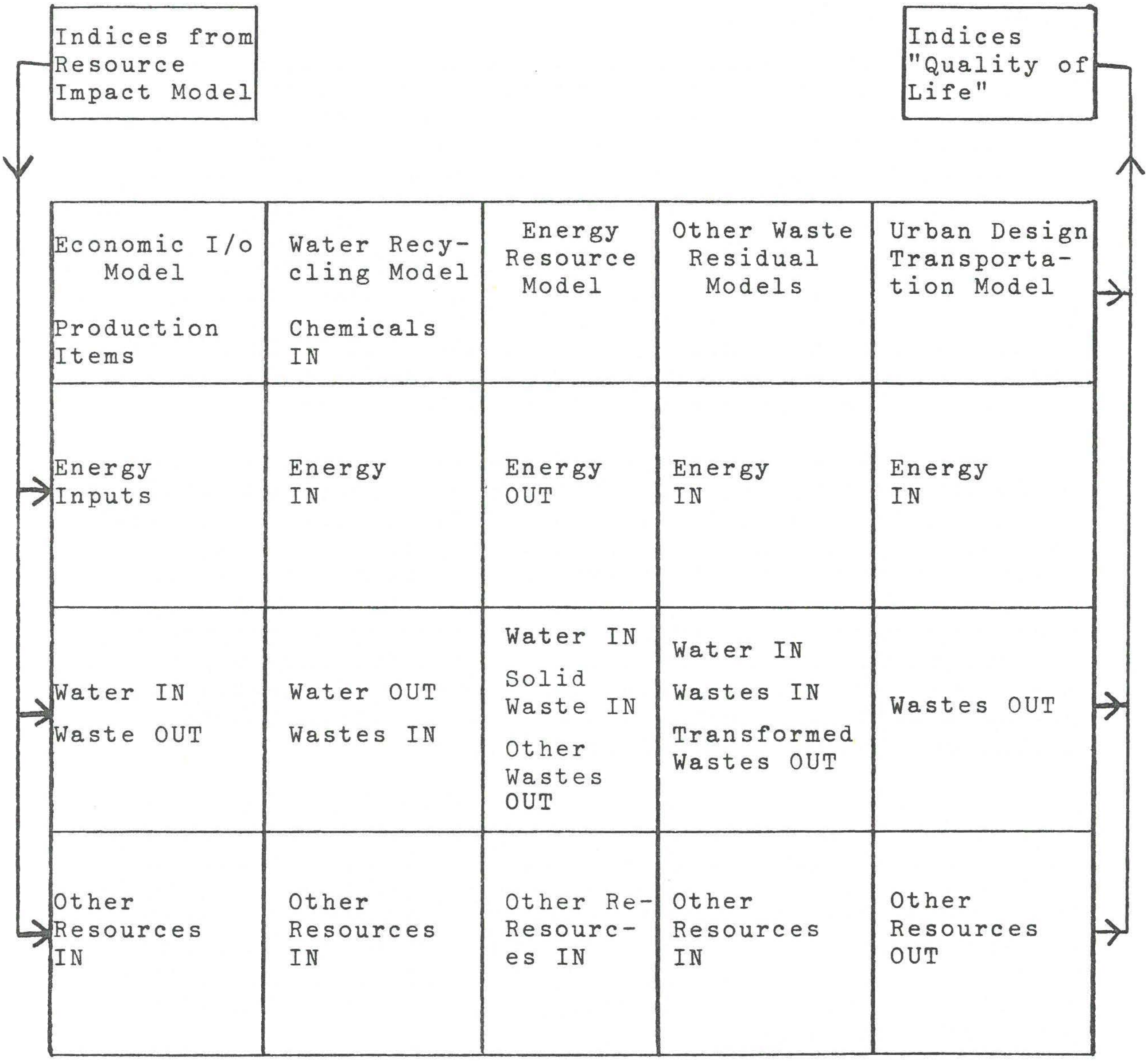
Professor Dantzig asked representatives of the National Member Organizations to be prepared to give a 15-20 minute summary of research going on in their respective countries of interest to the Conference. He urged participants to inform him if they wished to make a separate presentation which could then be included in a revised agenda. As suggestions for discussion, Professor Dantzig went through a list of twelve points which he had prepared before the conference (Appendix A). He then pointed out that Large Scale Systems Theory was an active area both in theoretical and applied areas; priorities would have to be established to define IIASA's role. Another question to treat would be IIASA's role as a clearinghouse for ideas in this area.

There was also an internal problem of what services the Optimization Group should offer other projects and staff within IIASA. Perhaps they could offer advice on software availability, or on how to formulate a model in order ultimately to be able to solve it. A possibility could be the formulation of a large interrelated model involving a hierarchy of models. Figure 1 was shown on a blackboard to illustrate the way in which the various projects might interact. For example, in a municipal problem, a strategy which causes commuters to swap from cars to electric trains influences pollution and energy levels.

Although there is an extensive theory available for finding optimum solutions to large scale system problems, little effort has so far been directed towards developing software systems for solving practical problems. To facilitate the development of such systems, Professor Dantzig recommended the setting up of System Optimization Laboratories. Such labs could compare procedures like the decomposition Principle with alternative methods on representative practical examples.

A participant asked the Chairman to explain better the aim of the Conference: was it about general systems theory or merely about the application of linear programming and other optimization techniques to applied areas? Professor Raiffa answered the question by saying that IIASA's interest was on optimization in general but consideration must be made of actual circumstances. He also stated that Conference 8 had discussed methods of control of operating industrial processes, and he would expect Conference 9 to discuss other types of

Figure 1

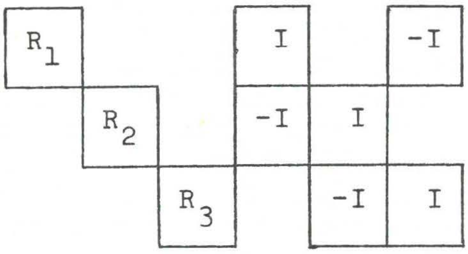


A Systems Group could work on providing software for the study of such interrelated systems.

Figures 2 and 3 show matrix outlines of interacting systems. Figure 4 shows a similar diagram for an investment planning model showing "staircase structure".

Figure 2

Multi-Regional Model



R_i = Matrix for Region i

I = Identity Matrix

Figure 3

Block Angular Model

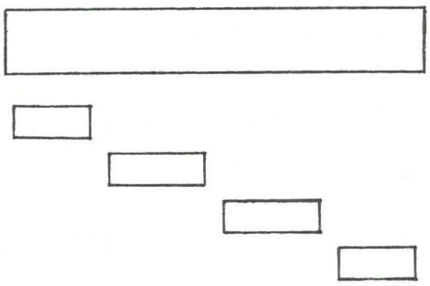
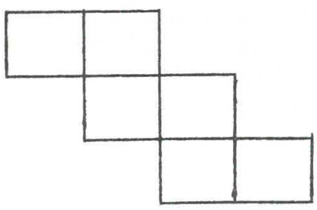


Figure 4

Staircase (Dynamic) Model



planning and appropriate solution methods.

In answer to another question, Professor Raiffa also said that the function of the optimization group would be as a support to other projects as well as being a project doing research to advance the state of the art. To a question about IIASA finances in this area, he said that the effective budget could be made much larger through cooperation with other institutes. In addition, it might be possible to apply for direct funding for special, well-defined subject areas. The point was raised whether systems should be studied, and thus optimized at the micro or macro level. Professor Dantzig said that while it was natural to want to do optimization at the macro level, the historical difficulty has been knowing what detail information to aggregate. Aggregation had not been done too successfully on any complex problem before the solution was known in detail. That is to say, it was very easy to know how to aggregate after inspection of the solution from a study made at the micro level. Aggregation is thus an important research area.

One participant asked if IIASA is able to obtain cheap computer time. Professor Raiffa replied that at the moment although IIASA's computer was free, the rates were very expensive. Professor Dantzig noted that the Systems Group at Stanford University were using large quantities of computing time, and even with very reduced rates, were overspending. A member of the Institute pointed out that IIASA was not planning to have a large computing center. The Chairman suggested that this topic (IIASA's computing facilities) be given more time later in the conference.

Description of Activities in National Member and other Organizations

USSR (Professor Moiseev)

Professor Moiseev said that the main goals of IIASA's project on large scale system optimization were quite clear: this was mainly a mathematical project and no attempt should be made to try to do everything. It was difficult to make specific recommendations, but Professor Dantzig was noted for work on decomposition which, together with the problems of aggregation, constituted an important area.

Existing work with dynamic systems aims to find exact solutions but problems of high dimensions cannot always be reduced (from a practical viewpoint) to these pure formulations. This might be helped however, by improved man-machine dialogue.

1) Professor Moiseev suggested that IIASA hold an annual seminar for intensive work amongst experts on a special topic of narrow scope, and

2) study systems which have many subsystems in common.

With reference to 2) there are many large systems which are too complex for analysis in their entirety but contain subprocesses which can be studied separately. Many examples can be found in agriculture. Problems of this category could be possible topics for the seminars referred to in 1).

Professor Raiffa commented on Moiseev's suggestion about seminars to say that one way to go about developing a successful seminar would be to invite a few people to IIASA beforehand for a short period to organize the seminar to ensure that it would be intensive--the advance preparation was the key point.

The Chairman noted that the discussion of suitable seminar topics might be a useful agenda item to be taken up later on in this conference.

USA (Dr. Wolfe)

Dr. Wolfe said he would confine his remarks to Mathematical Programming in the three main regions of:

- -Linear Programming (LP)
- -Integer Programming (IP)
- -Non Linear Programming (NLP).

He noted a) that most progress had been made in LP but that IP was the most important, b) that handling large NLP problems is important but not crucial, and that c) integer programming was less well understood than LP. For example, it was difficult to know how long the solution to any particular IP would take, whereas an LP is now fairly predictable.

Dr. Wolfe cited work by Tomlin and Harris in LP as important. Most work in IP has been theoretical and has not been properly tested on examples. Computational work has been minor and hard to evaluate. He said all recommendations should be systematically tried as it was a vital area.

Dr. Wolfe discussed the idea of parallelism or netting of computers for solving large-scale systems but said that no real information was available about what its future impact might be.

Interactive computers could have an impact and be a boon to the area of optimization. A graphic display might be a useful aid to man/machine interaction. He raised the possibility that large problems could be studied using small scale examples with similar structure and that we could design small large-scale problems for this purpose.

Dr. Wolfe had not seen much evidence that research on structure was resulting in solutions to linear programs that were computationally any more efficient than general purpose LP software except for Generalized Upper Bounding, which was proving to be a big help. Decomposition (of the DW type) was still being considered as an important tool in large scale systems theory. A deeper understanding was required, however, about rates of convergence. Another question: Is it possible to decide in advance how hard a problem is?

At the conclusion of Dr. Wolfe's presentation, a participant commented that he thought Wolfe's summary of the state of the art in integer programming was overly harsh. Good solutions could be obtained by Branch and Bound methods except in the case where the LP relaxation of an IP problem has little connection with the IP solution in which case the problem can be tough. The commentator also emphasized tnat Large/Easy problems were not the same structurally as Small/Difficult ones.

There was a general feeling amongst participants that more computation was required as a prerequisite to the understanding of integer programming.

A participant mentioned the work of Klingman with respect to optimizing without using traditional extreme point techniques, citing the code NETGEM.

Professor Dantzig said in connection with the remark about visual displays that Chernoff had made some progress with displays of multi-dimensional vectors, and that one of his (Dantzig's) students had applied Chernoff's software package to an eighteen dimensional problem comparing electrocardiograms of normal patients with patients who have had heart damage.

A participant noted the lack of work on optimization problems where the objective function was ill-defined or suffered from the interaction of multiple criteria. Someone else said that in dual ascent methods it was possible, through man/machine interactions, for the decision maker to provide an automatic objective function by providing directions of ascent.

Czechoslovakia (Vice-Minister Vaško)

Dr. Vaško described the current research trends in Czechoslovakia. Methodological research on mathematical programming is actively pursued at the Institute of Information and Automation (with special efforts on problems of estimation and analysis of global economic models) and in general at institutes connected with the Academy of Sciences. Applied research is taking place in the branch institutes with successful application of linear programming in industrial, medical and environmental systems. Most of the models used are rather unsophisticated.

Canada (Dr. Kirby)

Dr. Kirby's presentation on research in Canada put much emphasis on applications of large scale programming in private industries in contrast to government agencies where, so far, it is underdeveloped. Successful applications of linear programming include:

- forest management
- refineries (production scheduling)
- railway engine allocation
- dynamic suboptimization of planning logistics for large equipment.

There has also been some application of integer programming but clearly some more research should be done in this area. Dr. Kirby suggested that the methodological research done at IIASA should be done with a particular practical problem in mind. One such problem which might be of interest concerns fishing rights in an international environment. In this case there are clearly externalities between countries so that a global optimization would be appropriate. The difficulty is of course, that different countries may have quite different objectives. Hence it is always crucial to include all strategic variables in the model. Another participant pointed out that interesting research on applications of APL for simulation is presently being conducted in Canada.

IIASA--Project on Water Resources (Professor Letov)

Before going on to the report of the next country, the chairman asked Professor Letov, Deputy Director and leader of the project on Water Resources, to review his project since it might be a suitable application to focus on as a seminar topic.

Professor Letov presented a summary of the mathematical model.

$$\max \quad Z = \Sigma \Phi_j(X_j)$$

$$\text{subject to} \quad \sum_i W_i - \sum_{i=1}^{j-1} K_i X_i \geq X_j, \; (j = 1, \ldots, n)$$

$$a_j \leq X_j \leq b_j \quad .$$

By users, one should understand industries, transportation, cities and so on. The model is of high dimensionality, hence decomposition techniques would be most helpful. It has also been suggested that vector optimization may be more appropriate in order to deal with the different objectives of the parties involved. Finally, data for the model is available for a number of rivers.

Hungary (Dr. Dancs)

Dr. Dancs presented a report (see appendix B) on the activities on large scale problems in Hungary with particular emphasis on economic planning. Experience with decomposition methods had been rather inconclusive (Kornai and Liptak's methods and the Dantzig-Wolfe Decomposition Principle) so that approximation methods have been developed. Professor Dantzig commented that although economists have shown enthusiasm for decomposition methods, there is little evidence so far that such methods will have practical impact. Much is to be gained from real experimentation; intuition is not worth a lot for large scale problems.

France (Professor Roy)

Professor Roy reported on activities in France. The main thrust of effort is directed toward transportation and energy problems.

On transportation problems, applications have been developed at Air France (crew scheduling, rotation of planes), RATP (management of machines and people, assignment of drivers to buses), and at SNCF (the National Railroad).

In spite of the similarities between these problems, it seems that their structures are quite different from one another so that no general methodology can be used. Work is also being done on traffic flow in towns (Institut de Recherche des Transports: descriptive models; also at University of Grenoble in connection with the city planning under the supervision of M. Sakarovitch--see Appendix H).

On energy problems, Electricite de France has developed large models for investment programs. Oil companies have also made some effort for the implementation of large scale optimization.

There are a number of other institutions which also pursue research on optimization: IRIA (special emphasis on systems governed by differential equations), CEPREMAP (economic modelling) Commissariat General du Plan, SEMA (a consulting firm which developed standard LP codes but also special codes for mixed integer investment problems, partitioning problems, job sequencing problems).

Professor Roy also wanted to make some general remarks about large scale problems. It seemed to him that there is a gap between sophisticated methods for solving models and our ability to conceptualize and model a large scale problem. There is a need for the introduction of fuzzy constraints as well as for multiple criteria analysis (the concept of optimization of only one function is not always adequate).

Poland (Professor Kulikowski)

Professor Kulikowski reported on activities in Poland. At the Institute of Applied Cybernetics research is done on control problems, on optimization of industrial and economic models, and on development of dynamic models with emphasis on the theoretical aspects. Applied research is carried on at the Warsaw Polytechnic Institute in cooperation with engineers and economists. Special topics of interest are job sequencing problems, decomposition problems and optimization of organizational structure.

Federal Republic of Germany (Dr. Bossel)

Dr. Bossel outlined the activities which are taking place in his country. A comprehensive review of the current state of systems analysis in the Federal Republic has recently been given in the book by Erich Zahn "Systemforschung in der Bundesrepublik," Wiesbaden, 1973. Hence only a few of the projects which have been, or are being, undertaken will be mentioned here.

At the Nuclear Research Center, Karlsruhe (Kernforschungszentrum Karlsruhe) methodological studies are being undertaken in the field of environmental pollution--the aggregated effects on humans and the ecology--and on damage parameters. In addition, this work is being done on risk factors in nuclear power generation. At the Nuclear Research Center at Juelich (Kernforschungszentrum Juelich), research has a more technological and economic component. One project there focuses on the use of process heat from high temperature reactors in hydrogen generation and coal gasification. The possibilities and alternatives of a proposed "hydrogen economy" are studied in a comprehensive systems analysis. The state-owned coal and power company of the Saar region has optimized its operation in a large linear programming system. Large-scale systems analyses were also undertaken in the study of the high-speed train system proposed to link the cities of Northern and Southern Germany by a 300 mph electro-magnetically suspended train.

At the Zentrum Berlin für Zukunftsforschung (ZBZ Berlin Center for Futures Research), a comprehensive planning system is being developed for the city of West Berlin. This planning system includes the use of dynamic models of the city and its operations and an attempt to formalize the goal structure of the decision making bodies.

In the context of the Mesarovic-Pestel world model project, an effort is under way at the Technical University of Hannover to provide several submodels for the ten world regions. At the Institute for Systems Analysis and Innovation, attempts are made to develop the normative stratum for this project by explicitly including values and goals and their changes in the decision-making processes being simulated. Systems analytic methods are also applied in technology assessment and attempts are being made to develop a cybernetic model of cooperative planning involving governmental bodies, industry, and citizens' groups from the beginning of the planning process.

German Democratic Republic (Professor Peschel)

Professor Peschel reported on activities in the German Democratic Republic. The main trends of research are centered along the following lines: Optimization of systems with vector criteria, optimization of systems with hierarchical structures, and general system theory. This research is carried on in the Institute of Control Theory.

United Kingdom (Professor Beale)

Professor Beale reported on activities in the United

Kingdom where, in contrast with Canada, there have been quite extensive applications in the public sector (in particular for the Ministry of Industry). As particular research topics pursued in universities, the following may be mentioned:

- codes for LP based on simplexes leaving out ineffective constraints
- analysis of matrices before starting algorithms
- formulating discrete problems for integer programming
- decomposition of large scale problems
- solution of problems with continuous functions of one argument.

Italy (Professor Guardabassi)

Professor Guardabassi presented an overview of the activities in his country (see appendix C). Research is carried on in the following topics:

- Observability of discrete decentralized systems
- Identification of large linear systems
- Decomposition techniques and information structures in the numerical solution of complex models
- Optimization of information structures in decentralized systems
- Large scale techniques versus problem solving theory
- Decentralized operating systems
- A combinatorial approach to the stability analysis of a large network
- Coordinator design in a two-level linear control system
- Control strategies based on non-conventional information structures
- Simplified models of complex nonlinear networks.

Austria (Dr. Firneis)

Dr. Firneis reported on activities in Austria. Projects on optimization are done virtually at every university and research institute of this country. Notable examples are done at the faculty of Electrical Engineering of the Technical University of Vienna under the leadership of Prof. Alexander Weinmann on practical evaluation of multiple criteria. A rather application-oriented approach is pursued as actual industrial projects are being solved. This institute has in fact a very strong connection to different industrial branches.

At the University Computer Center, Dr. P. Sint systematically studies available software for optimization problems.

The Institute of Advanced Studies is probably the only place in Austria where optimization of large scale systems in conjunction with operations research problems is studied. Modelling of economic systems is done there.

At the Academy of Sciences, the Institute for Information Processing studies software for optimization in a joint venture with the University Computer Center. Apart from this activity, there is a far broader one not only confined to optimization and systems theory. It is the study of parallel algorithms which are thought to be best suited for the optimization of large scale systems.

Dr. Firneis took this opportunity to let the members of the conference know that the computer installation of the Technical University of Vienna, the University of Vienna, and the Academy of Sciences provides a big system Cyber 74 and Cyber 73, which will also be at the disposal of IIASA. This system is ideally suited for large scale optimization problems. Apart from that immediate application, the Institute for Information Processing seeks out connection via satellite to real, large, parallel processing computers as, for instance, the Illiac IV. In addition to theoretical investigations, experiments along that line must be made.

At the Technical University in Graz, Peter Meissl, Professor of Surveying and Geodesy, who at the same time pursues a career in operations research, studies transport problems with all kinds of nonstandard constraints and also allocation problems and integer programming in a joint venture with the Graz Computer Center. In Linz, Professor Schulz has a project to teach non-mathematical students computer-oriented optimization methods through an interactive approach.

Japan (Professor Nomoto)

Professor Nomoto presented a short report on the activities in Japan. Optimization techniques are extensively used in industry and in particular in the petroleum companies.

This concluded the reports describing current national research.

Computer Availability for IIASA's Needs (Prof. Feldman)

Since the research strategy on large-scale optimization will be strongly interconnected with the activities in the computer area, Professor Dantzig asked Professor Feldman to report on the suggestions made at the Computer Conference and on his own thoughts on a research strategy in computer and artificial intelligence. These suggestions centered on two themes: information services and computer networks. IIASA will perform a clearinghouse function and thus has to be supported by more automated information processes. The research scholars at IIASA will want to run programs on machines at different places (software translations are quite expensive and difficult to do), and they may also want to run programs interactively on different machines.

These two themes may be combined to generate the following research activities:

- survey of what is available at any place
- systematic comparisons of data banks (a semantic problem in Artificial Intelligence)
- heuristic search for looking at large data banks
- uses of extra mathematical knowledge in computer programs.

Given this background and given that IIASA cannot afford to have a large computer, several alternatives for computer facilities are presently under study.

Professor Dantzig urged the participants of the conference to write down their suggestions on what computer facilities IIASA should acquire. Some participants recommended the present trend, namely to work on terminals and build big systems remotely. However, it was remarked that there are strong arguments in favor of in-house facilities: file storage and communication would be very expensive otherwise. It was also pointed out that interactive communication with the computer would be desirable. There is a need for the transfer of subjective information in real decision problems.

Some comments were made on simultaneous use of computers:

- integrated circuits are now developed so that parallel computation is possible,
- however, the reduction in time generally appears to be only of the order of log k for k parallel channels.

At any rate we should expect progress in improved hardware to continue at a rapid rate in the computer industry and we should prepare now to use such hardware as it becomes available.

The following agenda was agreed upon:

- non linear large scale optimization
- integer and mixed integer programming
- energy models
- software for large scale systems
- decomposition and aggregation.

If time allowed, the following shorter discussions would be included at the Chairman's discretion:

- review of conference on "Automated Control of Integrated Systems"
- topics for once-a-year seminars
- problems involving conflicts of multiple objectives
- text book on model formulation.

Non-Linear Large Scale Optimization

Professor Abadie presented a systematic review of non-linear programming with special emphasis on a generalized reduced gradient method. Mr. Breton presented the investment model used at EDF. It may be summarized as follows:

$$\min \sum_{t=0}^{T} [I^t (X^t)V^t + G^t(X^t,V^t) + D^t(X^t,V^t)]$$

subject to: $X^{t+1} = X^t + V^t$

$$a^t \leq V^t \leq b^t ,$$

where

I^t is the investment cost,

X^t is the site of the equipment,

V^t is a control variable,

G^t is the production cost, and

D^t is the shortage cost.

The difficulty of the resolution comes from the fact that D^t is an implicit function resulting from best management of existing investment.

Professor Beale presented his own experience in non-linear programming. A detailed report may be read in Appendix D. Special emphasis was put on Approximation Programming which was generalized and actually used in an application, though with mixed results.

A participant reported on the use of Approximation Programming on a large scale application at Union Carbide. However, he noted that this method was rejected for a different application after experimentation (D. Himmelblau "Applied Non linear Programming", 1971).

Professor Mitter made some remarks on optimal control problems. He mentioned problems of:

- how to discretize (careless discretization may lead to instabilities),
- reliability of data (state estimation and parameter identification), and
- devising control and information system at the same time in models with sub-models.

A speaker proposed the following model as a possible research topic--namely to find statistics of control processes based on the recurrence

$$X_{k+1} = A_k X_k + B_k Z_k + C_k U_k + W_k$$

$$Z_{k+1} = D_k X_k + \xi_{k+1}$$

$$\tilde{X}_{k+1} = E_k \tilde{X}_k + F_k Z_{k+1}$$

where Z are the observations and U are the controls. The stability characteristics of the solution to this system need to be studied when there is a lack of information about statistics of disturbances or changes of parameters. More should be known about the bad aspects of such problems.

He said that such a model was widely applicable to industry but it was presently impossible to decide which solution techniques were most favorable to any particular problem.

Another participant said that there was much computational experience in such problems but that such experience was not tabulated. He asked what IIASA might contribute to this problem. Professor Dantzig said he would try to find time later on the conference agenda to discuss this subject further.

Integer Programming (Prof. Geoffrion)

Professor A.M. Geoffrion made a presentation on the state of the art of linear integer programming. He pointed out that if this case could be solved satisfactorily, substantial progress could be made towards the solution of non-linear integer programming. He said there were four main areas to consider:

1) Modelling
2) Model Representation
3) Solution Techniques
4) Use of IP as a practical tool.

First, there is the interface between reality and mathematics. A research area would be to extend linear programming to accommodate nonlinearities (for example, economics of sale, yes/no choices, indivisibilities). Integer programming is important since it is a natural way to approach the operation and design of many systems. It also has importance in decision making with respect to project selection and portfolio handling.

Second, there is the interface between modelling and solution techniques, an important step often omitted in theory but essential in practical applications. For example, suppose that all assumptions have been made and it is now required to formulate the model in a manner which can be solved. There may be a variety of possible models with associated solution techniques. Which should be chosen? Professor Geoffrion stressed that it was not always the simplest (having finest constraints on variables for example) formulation that is the easiest to solve. He cited a paper by Dr. Wolfe which gave several different formulations of the Job Shop Scheduling problem that illustrated his point.

The third area could be divided into two subsections:

a) Algorithms--Traditional methods such as Branch and Bound, Cutting Planes, Group Theoretic

Procedures, Benders Decomposition and Probabilistic Techniques.

b) Software--Experimental codes such as MPL and SEXOP, Production Codes, UMPIRE, Ophile-Mixte. Commercial codes like that being developed by the National Bureau of Economic Research in the U.S.A. or experimental software available from Stanford's Systems Optimization Laboratory.

The fourth area, Integer Programming, is a tool to be used to solve problems. Validation is required to test data and the correctness of software. Probationary exercises are required to prove to management the efficiency of the tool by comparing its answers with other methods. Some topics for research are:

- More attention to Partial Optimization
- Variations (what if? changes)
- Sensitivity and Stability Analysis
- Tradeoff and Priority Analysis.

A questioner pointed out that it was not always necessary to use pure integer programming, that often with a little thought LP solutions could be adapted. He agreed that models should be oriented towards the solution techniques available. The Chairman asked for suggestions of what IIASA might do in this area. Someone commented that a study of the parameterization of coefficients would be useful. Professor Geoffrion then went on to describe his research ideas for the four sections above.

1. Aggregation is a worthwhile area for theoretical research, also the study of stability. A catalog of tricks is required with comparative effectiveness given. This could be developed by doing retrospective studies on past projects. A difficulty is that even the more successful projects are rarely well documented.

2. Again, experience is a major requirement. A study of how best to model a situation, for example, combinatorial problems are often easier to solve in a network formulation rather than by converting this to pure IP problems. Set Covering Problems, for instance, cannot be effectively solved with IP.

3. Test problems and parametric studies are needed. Some powerful new bounding techniques are now available (Lagrangian Dual Problems) and studies of how best to make

use of these are desirable. Over recent years there has been a proliferation of ways to generate cutting planes; a systematic evaluation of the relative worths could be undertaken. Sophisticated look-ahead rules for Branch and Bound could be studied to see how much they improve the efficiency. There is also the important need to provide a software clearinghouse facility.

4. Professor Geoffrion felt that a survey of present professional practice was most necessary to establish guidelines and to find out how important issues are handled in practice. Other projects at IIASA could provide spin off to inspire a particular research topic for the systems group. A simulation of coupling might be a good thing to try.

Professor Dantzig injected a cautionary word regarding over-emphasis and reliance on computer simulation to solve all problems. Simulation, he said, is a technique often used by managers because it is easy for them to understand. They use it as a substitute for good analytical research and optimization. Unfortunately at best simulation can yield expensive inconclusive results.

Professor Moiseev's Proposals:

Professor Moiseev described further his proposed areas of research at IIASA.

There are many basic models of problems of control of which the following is but one, a planning of a peoples economy.

$$\frac{dx(t+\tau)}{dt} = f(x,u,t,y)$$

x - state vector, describing the strength (e.g. production capacity, stockpiles) of a section of the economy.

u - control vector or investment policy. Includes planning for that sector.

τ - a delay time (possibly different for each sector and component)

$y(x)$ - boolean variables.

$$\left.\begin{array}{l} \emptyset_t(x,u) \geq 0 \\ x \geq 0,\ u \geq 0 \end{array}\right\}$$ is the feasible region of controls.

Many models belong to a family of this type. This problem can be described by some Turnpike Theory, and Dr. Takorav had some results for the case when f was linear. Numerical methods were used in the USSR to solve these problems. An example having 24 sectors and 20 time periods took 40 minutes of computer time.

Professor Moiseev then proposed two topics for his suggestion of once-a-year seminars.

The first was an intensive study of the Dantzig-Wolfe decomposition technique and some aggregation techniques. The second was still concerned with decomposition, for a special case of a central organization α having subsidiary organizations x, y, z.

$$\dot{X} = f(X,u,\xi)$$

where u is a control vector and $\xi \varepsilon \omega$ depends on certain parameters set by α.

We wish to let x, y, and z make their own decisions U_x, U_y, U_z respectively but to arrange it so that their decisions turn out to be optimal for the objective function f(x,y,z) of the control organization α.

Professor Raiffa mentioned that this last idea had been covered in a previous conference on Design and Management of Organizations. Indeed, Professor Miyasawa had already written IIASA's first technical publication on just this topic.

Professor Dantzig agreed that this was an important subject area and that the examples shown earlier by Jean Abadie were particular cases, so that some techniques for solution are available.

Professor Dantzig then spoke of some of his own work on a related model, namely, a linear control model with non-negativity constraints on the state vector.

$$\frac{dx}{dt} = Fx + Gu$$

$$Au = b$$

$$x, u \geq 0$$

with objective $\int c(t)u(t)dt$.

He has been studying detailed properties of the optimal solution. Much exists in the literature about <u>conditions</u>

for optimality, but these do not, in themselves, provide an algorithm for finding an optimal solution. His approach was to see if one can find an analog to the simplex method--namely, a dynamic simplex method making use of a dynamic basis. The idea of approximating the continuous model by a discrete time model and then using ordinary linear programming methods does not appear to be efficient because any change in the location of a break point in time requires at least one simplex iteration so that the finer the discrete time grid, the greater the number of iterations would be. Instead of discretizing time, a study of continuous methods of solution has just begun, and much research will be needed before very efficient solution techniques are developed. Another participant pointed out the difficulty that such problems often have singular solutions.

Decision Theory

Dr. Bossel then gave some thoughts on Decision Making in Optimization (see Appendix E). Briefly he pointed out that often at least 50% of inputs to an optimization problem are subjective but this fact is not often accounted for. This could be the reason that many decision makers ignore the results of their analysts. He gave three possible reasons for such an omission:

1. Things like societal laws are very subjective and impossible to quantify.
2. Dynamics are not included.
3. Decision processes are not understood so quantifiable objectives are optimized instead.

His general conclusions were that all the fuzzy areas of decision making should be subject to further study by IIASA.

Professor Raiffa reminded the participants that this conference represented only a small part of IIASA's activities and that most of Dr. Bossel's points had already been discussed in the other conferences; this conference was essentially methodological in nature. He asked the conference to spend some of the next day discussing a concrete agenda for 1974 which could take advantage of Professor Dantzig's presence at IIASA.

Professor Dantzig mentioned the possible role of IIASA in the development of Systems Optimization voiced concern about the cost that this would involve. Because of the lateness of the hour further discussion of this point was curtailed.

Professor Raiffa began the last day of the conference by welcoming the participants to the Historical Room of Schloss Laxenburg and inviting them to look around at lunch time.

Handbook of Systems Analysis

Professor Guardabassi spoke in favor of IIASA producing a handbook of systems analysis, for he felt that often two groups working the same area would be using different terminology to mean the same thing and in some cases even the reverse. A comprehensive presentation of the whole subject would be worthwhile both for specialists and for promoting interdisciplinary activities. With regard to studying case histories, he felt that the IIASA team could be motivated by other projects at the Institute, and these could provide the requisite case histories.

Professor Raiffa reminded the participants that IIASA was already committed to producing a handbook and had already appointed two co-editors for eighteen months starting in June 1974.

Energy Models at IIASA

Professor Manne then outlined the Energy Project at IIASA, saying that the project was oriented towards solving a problem rather than to using a particular discipline. He gave a list of ten different fields which interacted with the project. The question was, what could IIASA do best in this area and what should be left to others? In the short term there is need for a comparative survey of what is known. Although a large volume of work had been completed, few papers gave sufficient detail. There still remained a divorce between academics and decision makers.

He said that one topic to be researched was the interaction between time discounting and uncertainty. For a geologist, 100-150 years is the immediate future, but to an economist discounting at 10%, the next 15 years is three-quarters of the way to infinity.

In this field of energy, Professor Manne asked whether Mathematical Programming or Optimal Control would be the better tool. Dr. Avenhaus spoke on his part of the project which deals with safeguards for the control of nuclear materials and outlined the concept of accountability (See Appendix F). Aspects of game theory were included in the study of inventory checking, for a dishonest operator might try to divert material in an optimal manner to avoid detection.

In answer to a question, Professor Manne said that linear programming so far was the only technique used on his models, but he might well have used non-linear programming or optimal control. He urged that the methodologists should not work in isolation from other projects.

There was some question about the manner in which uncertainties could be incorporated into Control Theory.

Software for Large Scale Systems (Mr. Orchard-Hays)

Mr. William Orchard-Hays gave a presentation on the history of software. The study of software, he said, was not at all like a traditional discipline and newcomers were apt to try to start in the middle. He put the following historical synopsis on the blackboard:

1948-52	Prehistoric. Simplex Method.
1952-54	Work at Rand and USAF. Product form of Inverse. Organization of Simplex Routines.
1954-57	Development of Larger Programs. 101 rows→ 250 rows. Matrix Generator. Data Validation.
1957-59	Embryonic Systems. 500 rows. Report Generators.
1960-64	LP/90 became "big business." Beale's Standardized Decomposition.
1964-68	MPS 360, LP 600, OPTIMA, UMPIRE. Matrix Report Generators. Elaborate User Controls.
1968-71	Data Management. Generalized Upper Bounding.
1972-	Interactive Systems. Optimization Laboratories.

There were four aspects of software systems:

(1) Hierarchy of Routines

(2) Data Types. Access Methods

(3) User Controls

(4) Execution Controls.

Professor Raiffa asked what would be happening in the next six years. What were the potential uses? Mr. Orchard-Hayes said that Integer Programming and the improvement of inversion techniques were important. Cooperation was required for IP Decomposition. Interaction was needed between software/modellers/algorithms. Professor Manne recommended further study on report reproduction which he said was an often overlooked facility.

In order to give more time to suggestions for IIASA research the topic of Decomposition and Aggregation was omitted.

Cooperative Roles for IIASA with other Organizations

Professor Dantzig raised the possible role of IIASA as a clearinghouse where one could find out the work going on in different countries, and went on to say that Canada and Czechoslovakia representatives had already promised active support for IIASA and he asked if representatives from other countries would like to do the same.

A participant asked what the relations were between the program of research at IIASA and that of other organizations like WHO, UNESCO, IFORS, IFAC.

Professor Raiffa said that many projects were often considered unsuitable for IIASA because some other agency on the surface appeared to be better suited. But this should not be taken as an indication of whether IIASA should do the work. He cited the director of WHO who asked him for assistance in areas of theoretical modelling. A group at MIT suggested cooperation in Artificial Intelligence and would invite IIASA members to work with them. The Institute for Control Services in Moscow had made a similar suggestion. Dr. Nomoto said Japan was interested in setting up a program in harmony with IIASA. Professor Raiffa warmly encouraged cooperation with other institutes, particularly those doing parallel research. He suggested a program of coordinated doctoral theses around the world.

Dr. Kirby from Canada suggested IIASA should take on a role of defining problems and studying interesting applied problems. He thought that with IIASA's backing, it would be easier to get grants in one's own country. He thought the coordinated doctoral theses idea should be extended to an exchange student program throughout the member nations. IIASA also could hold small conferences on narrow areas. He thought that people would be prepared to fund themselves to such meetings if the conferences were considered beneficial.

Professor Raiffa thought the idea of IIASA acting as an intermediary in providing a conference for two groups working on the same project but in different countries, was a good idea. IIASA could also have "satellite conferences" after large symposia.

On the subject of student exchange, Professor Raiffa said it was hoped to fund students to write their theses at IIASA. Professor Abadie emphasized the importance of having experienced software writers if a new code was to be implemented in a project.

A participant thought IIASA could play a vital role in reducing the amount of duplicated work being done in different countries by coordinating research.

One speaker favored the educational role that IIASA could play both with the handbook and by implementing Summer Schools.

Professor Moiseev spoke once again of the importance of regular intensive seminars.

Recommendations for Work at IIASA

The following issues were discussed:

1. Interdisciplinary Work. Professor Raiffa emphasized the difficulties of interdisciplinary work. The gap between disciplines is vast; it is just not enough to locate various types of research people close together. These people need special talent to interact fruitfully and, in general, must be strongly motivated by practical and important problems. It is hoped that IIASA can develop a matrix format with methodologists working on different applied projects. The selection of scholars will be partly based on interdisciplinary work.

2. Close Collaboration between IIASA and People in NMO's Interested in Applied Projects. IIASA would strongly encourage such collaboration, although it is impossible for scholars not physically present at IIASA to formulate the concrete details.

3. Handbook on the State of the Art in Systems Analysis. This handbook is directed towards the researchers as opposed to the managers. It should review questions of the type: who is doing what and where? It should also contain good expository papers on the state of the art as well as retrospective studies to point out the important issues for study. It is planned as a continuous task: the editing of a series of books with revisions, editing of journals, etc.

Several people commenting on the difficulties pointed out the need for a good committee to prevent uneven contributions, the need for the editors to spend an appreciable amount of their time at IIASA. It was also argued that high quality publications can only be produced with anonymous referees.

It was recommended that publications not be announced as IIASA's official position. Moreover, the editors will have to ensure a balance among contributions from the numerous scholars in the IIASA member countries.

It was also suggested that the writing of the handbook be combined with seminars on narrow subjects which would be defined by a committee. Thus the committee would decide the objectives of the articles.

4. System Optimization Laboratories. Professor Dantzig emphasized the importance of experimentation for making progress in large scale system optimization and the need for coordination in this domain. At the present time, laboratories are still in a developing stage, coordination by IIASA would be an excellent stimulation of this effort. IIASA could perform a clearinghouse function and develop standards for evaluation. It may also help in identifying good representative practical problems for experimentation.

It was suggested that IIASA should not develop its own laboratory so as to remain quite objective in its criticisms. It was also mentioned that we should keep in mind that a method is usually good for only a particular class of problems.

Professor Raiffa noticed that there seemed to be a good agreement for this project. With Professor Dantzig's presence at IIASA for the next six months, one could certainly start working on the idea. The project should be seen as experimentation of all numerical techniques for optimization of well-posed problems (and not as modelling of real world problems).

Professor Moiseev strongly supported the project with special emphasis on methods of decomposition. He would study the possibility for the Computing Center of the USSR to participate. It seemed to him that IIASA may want to have a conference occasionally to compare the results of experimentation.

Professor Raiffa expressed his full thanks to the participants of the conference for their time and interest in IIASA research activities. Special thanks were presented to Professor Dantzig for the organization of the conference. The Chairman then adjourned the meeting.

Appendix A

Agenda Items Prepared by Professor Dantzig

1. Most of the world problem areas that IIASA will be working on are interrelated. Should the general system group at IIASA encourage the formulation of complex interrelated models? If yes, would the results be worth the effort?

2. Should general systems research at IIASA be an independent research program or should it be directed only towards solving specific models as developed by other groups at IIASA?

3. What services should the systems group at IIASA offer other groups at IIASA?

4. What software research should be conducted at IIASA?

5. Should IIASA conduct an international survey of models of systems which have been successfully formulated and solved?

6. Should IIASA serve as a software clearinghouse for techniques for modelling and solving mathematical programming systems?

7. How should IIASA coordinate its activities with systems optimization laboratories in various countries?

8. Should IIASA try to set research priorities in universities and other research groups by developing a list of important unsolved system problems?

9. Should IIASA try to identify what are really good new ideas in system optimization and try to encourage their further development?

10. What kind of computer equipment should IIASA acquire or remotely use and what equipment and service software would be most suitable?

11. Who should IIASA hire permanently in the general system area? Who should be invited as visitors; should such individuals be restricted to nations supporting IIASA?

12. How does IIASA coordinate its activities so as to remain nonpolitical? How can it obtain good cooperation from groups throughout the world that have information and experience? What steps should it take to stimulate the use of models to solve important problems that face the world?

Appendix B

Work in Hungary in the Field of Operations Research and Applied Mathematics

I. Dancs

1. Decomposition Methods

In the mid-60s Tomas Liptak and Janos Kornai worked out a decomposition method based on game theory (Brown-Robinson method.) It turned out that it could not be applied in practice because of the slow convergence. We tried to use decomposition methods in the Hungarian Planning Office where the work was led by Istvan Dancs. A very large sectoral model with more than 3000 variables was built which included all the industrial branches of Hungary. We tried to use the Dantzig-Wolfe algorithm to solve the model but the convergence was very slow on the computers available in Hungary. Therefore, we tried to find an approximating solution solving many linear programming models separately for the industrial branches and then combining them into one general model. We worked out also a rough estimation of how far the solution is from the exact optimum.

Recently a similar model was implemented for intermediate-term planning but without use of the decomposition method. We use similar models for long-term planning--also without trying to decompose them. All these applications were in the field of economic planning. The next points will cover results in the field of theory.

2. Stochastic Programming

In the field of chance constraint programming we achieved several results. Much work has been done which reduces this problem to a quasi-concave programming problem. We also worked out a duality theorem in the case of special density function.

3. Special Problems in the Field of Mathematical Programming

There are some new results in the field of geometrical programming and its applications both in deterministic and in chance constraint versions.

4. <u>Control Theory</u>

   Differential games.

5. <u>Application of the ideas of mathematical programming in the classical branch of mathematics</u>, especially in approximation theory and in the theory of quasi-analytic functions.

Appendix C

Report on the Italian Research Activity in the Field of Complex Systems

The Italian research activities in the field of applied systems analysis are basically supported by the National Research Council (CNR) through the Group of Researchers in Automatica and Systems Science (GRAS).

Within GRAS, subgroups have been constituted with the aim of coordinating the activity in the various areas.

The Large Scale Systems Subgroup consists of researchers from the following universities:

BOLOGNA

Topics

- Observability of discrete decentralized systems
- Identification of large linear systems
- Decomposition techniques and information structures in the numerical solution of complex models.

Contact Address

C. Bonivento
Istituto di Automatica
Facoltà di Ingegneria
Viale Risorgimento, 2
40136 Bologna

GENOVA

Topic

- Optimization of information structures in decentralized systems

Contact Address

R. Zoppoli
Istituto di Elettrotecnica
Facoltà di Ingegneria
Viale Cambiaso 6
16145 Genova

MILANO

Topics

- Periodic control of singularly perturbed systems
- Large scale techniques versus problem solving theory
- Decentralized operating systems
- Histogram of the acoustic nerve through the analysis of a large Markov chain
- A combinatorial approach to the stability analysis of a large network.

Contact Address

G. Guardabassi
Istituto di Elettrotecnica ed Elettronica
Politecnico di Milano
Piazza Leonardo da Vinci 32
20133 Milano

PADOVA

Topic

- Differential games

Contact Address

L. Mariani
Istituto di Elettronica ed Elettrotecnica
Università di Padova
Via Gradenigo 6/A
35100 Padova

PISA

Topic

- Coordinator design in a two-level linear control system

Contact Address

R. Montella
Istituto di Fisica Generale ed Applicata
Università di Pisa
Via Diotisalvi 2
56100 Pisa

ROMA

Topics

- Stability analysis of structurally perturbed systems
- Decomposition techniques in optimization problems

Contact Address

L. Grippo
Istituto di Automatica
Università di Roma
Via Eudossiana 18
00184 Roma

TRIESTE

Topics

- Game Theory
- Control strategies based on non-conventional information structures.

Contact Address

A. Marzollo
Istituto di Elettrotecnica ed Elettronica
Università di Trieste
Via A. Valerio 10
34127 Trieste

Research activities are also carried on at the National Board for Electrical Energy (ENEL) in the field of power systems.

Topics

- Stability of nonlinear systems
- Modelling and identification of networks including synchronous machines
- Optimal control of synchronous machines
- Safety limits tests by simulation
- Simplified models of complex nonlinear networks.

Contact Address

F. Saccomanno
Centro Ricerche di Automatica
ENEL
Via Valvassori Peroni 77
20133 Milano

Appendix D
Non Linear Programming

E.M.L. Beale

We have solved some non linear programming problems with about 1000 runs, a few hundred non linear variables and a larger number of non linear variables. I am not particularly proud of this, because we take about two hours on an 1108 computer to solve some of these problems and I think that our methods could be improved to reduce the time.

The applications have been essentially multi-time period models where the coefficients in one time period depend on actions in previous time periods. For example, in longer term studies of oilfield operations, the productivity of a well in a reservoir in Year 2 may depend on the amount of production from this reservoir in Year 1.

Our methods are based on the Method of Approximation Programming, published by Griffith and Stewart in Management Science in 1961. The strategy is to define some variables as non linear variables in such a way that the problem reduces to a linear programming problem when the non linear variables are given fixed values. Then one takes trial values for the non linear variables, and for the linear variables that have coefficients dependent on the non linear variables, and makes a local linearization of all the constraints and the objective function. We then solve the resulting linear programming problem, after adding upper and lower bounds on the non linear variables to prevent a solution out of the range of approximate validity of the linearized functions. The solution to the LP then suggests new trial values for all the variables.

The original implementation of this strategy by Griffith and Stewart appears now to be mathematically unsophisticated. But this approach is capable of producing a very sophisticated method. Let $\underline{x}$ denote the linear variables and $\underline{y}$ the non linear variables. Then we have to maximize some function $f(\underline{x},\underline{y})$ subject to constraints. But we can define the function $g(\underline{y}) = \max_{\underline{x}} f(\underline{x},\underline{y})$ subject to the same constraints. Then if we use very tight bounds on the non linear variables, each LP effectively evaluates g(y) for the chosen trial value of y. Furthermore, the reduced costs on the components of y are the derivatives of g(y). Actually the problem is a little more complicated than this, because g(y) is not necessarily differentiable, and it is best to think of it as a function of the nonbasic non linear variables only. Our solution strategy is described in detail in a forthcoming paper by E.M.L. Beale, "A Conjugate Gradient Method of Approximation Programming," in a book edited by R.W. Cottle and J. Kranup on "Large Scale Resource Allocation Problems" to be published by English Universities Press. In outline we give tight bounds to the nonbasic non linear variables and loose bounds to the other variables. The approach is then very similar in spirit to Jean Abadie's Generalized Reduced Gradient Method. But it does not seem to work as well as GRA.

I should be very pleased if IIASA had a project that involved studying methods of this type. Many non linear programming problems are likely to arise from other IIASA projects, and it would be convenient to have an efficient solution method that was based directly on a standard linear programming subroutine.

Appendix E

Some General Thoughts on Decision Making and Optimization and the Objectives of IIASA

Hartmut Bossel

The raison d'être of optimization is to bring science into decision making and to permit an optimal allocation of scarce resources. However, it is a practical fact that outside of areas such as production or transportation, decision makers do not seem to put too much trust in optimization and appear to prefer simulation or intuitive reasoning. Why is this so? In my opinion, optimization does not presently capture adequately the greater part of the important ingredients of decision making processes, especially in societal problems.

I suggest the following reasons why optimization as presently applied is often not adequate:

- Subjective information, such as preferences, values, intuitive assessments, are not adequately included.

- The dynamics of the decision situation and of likely future developments are not adequately represented in an optimization.

- Decision processes are not adequately understood at present; optimization of simply quantifiable objectives is evidently often not an adequate description.

There are three major components in a decision making system:

(1) a system requiring a control input;

(2) decision makers;

(3) a normative system to which the decision maker refers in making a decision, and from which he derives his operating goals. This system can be represented in a hierarchy which has basic values at the top (such as "survival"), derived values, objectives, general goals in the middle, and operating goals on the bottom. The

operating goals carry different weights, which again are derived from the normative structure. The operating goals constitute the inputs to the decision making process.

The stages of the decision process are roughly as follows:

(1) The system monitors certain variables which describe the system state in some aggregated fashion (the monitor variables may be biassed, delayed, or filtered).

(2) The system compares the monitor variables with its operating goals. If a discrepancy is detected which surpasses a certain tolerance, a decision has to be made.

(3) A trial policy choice is made.

(4) The policy choice is applied to a (mental) dynamic model and the results over a simulated time period are compared with the goals of the system.

(5) This process is repeated a number of times until a policy mix has been found which minimizes in some fashion the expected dissatisfaction.

(6) The (heuristically found) "best" policy mix is applied to the system.

Several aspects of this process are worth noting:

- The process is not one of optimization, but one of "satisficing" (Simon).

- There is no search for a global optimum, but rather a "mixed scanning" search (Elzioni) for a "good" solution.

- The decision is made not solely on the basis of quantifiable objectives, but also with reference to very fuzzy subjective goals which may not evenly be explicitly stated.

- Neither the goals nor the environment of the system can be considered as static and constant; rather goals are changing dynamically with time and the decision maker refers to a dynamical subjective model.

As decision makers now often seem to prefer their fuzzy decision making process to optimization, we must conclude that we must consider and include in the optimization process more aspects than we do now. In order to provide better aids to the majority of real decision problems, I propose that IIASA devote some efforts to work in this area. I would like to suggest in particular the following research areas. Most of them have already been mentioned before in the course of this conference.

(1) Research on the decision processes in large-scale systems.

(2) Research on the role of qualitative, intuitive, and subjective information in decision making.

(3) Research on the normative systems underlying decision making, and their respective change processes.

(4) Research on ensuring completeness of objective functions and constraints for a given decision making process with particular attention to inclusion of all normative aspects.

(5) Research on fuzzy concepts and fuzzy systems theory (Zadeh) including modelling and simulation.

(6) Research on a theory of satisficing with particular attention to heuristic search processes.

(7) Research on the simulation of dynamic hierarchical systems on one hand and on the parallel optimization or satisficing of the systems operation on the other hand by different methods, and combination of the two approaches.

(8) Research on the interactive extraction by man-computer communication of the decision maker's intuitive models and his normative system.

(9) Research on some calculus to include intuitive, subjective, qualitative, and normative "fuzzy" quantities into a complete objective function, or on different methods to account for dissatisfaction from not reaching all qualitative and quantitative goals.

(10) Research on the inclusion of dynamic projective models (i.e. likely future results) into decision making processes and optimization.

My plan, then, is to go beyond the narrow confines of mathematical programming and strict optimization and to attempt to understand and improve the great majority of decision processes for which we can at present only supply very inadequate, if any, decision making aids.

Appendix F

Optimization of Material Accountability Systems

Rudolf Avenhaus

Introduction

In order to give an example for optimization problems which arise in the applied research and which could be of methodological interest I would like to report on some special material accountability problems. These considerations were made during the development of the IAEA safeguards system, and we are now intending in IIASA to extend the considerations and to apply the results obtained so far in the field of environmental pollution accountability.

The IAEA safeguards system has been developed in fulfillment of the Non-Proliferation treaty and is meant to detect early the diversion of a significant amount of nuclear material from the peaceful sector of the nuclear industry. The basic tool of this safeguards system is material accountability. This means that in a nuclear plant during a given period of time the book inventory (starting inventory plus input minus output) is established, and that at the end of this period of time the physical inventory is taken. If no material is missing both inventories should be the same; however, because of measurement errors in practice, they are not the same and a decision problem arises. The safeguards system is organized in such a way that the plant operators perform the measurements, generate the source data, and report these data to the safeguards authority. The safeguards authority verifies the reported data by means of independent measurements on a random sampling basis.

The Material Accountability Principle

The establishment of a material balance for the time interval (t_o, t_1) means the evaluation of the "Material Unaccounted For" (MUF) at the time t_1

$$\begin{aligned} MUF &= BI - PI_1 \\ &= PI_o + \Sigma R - \Sigma S - \Sigma D - PI_1 \quad , \qquad (1) \end{aligned}$$

where PI_o and PI_1 are the physical inventories at times t_o and t_1, and BI is the book inventory at time t_1 (starting physical inventory + sum of receipts - sum of shipments - sum of discards).

In case no material disappears (Null Hypothesis H_o), the expectation value of MUF is zero. In case the amount M disappears in (t_o, t_1) (Alternative Hypothesis H_1), the expectation value of MUF is M

$$E(MUF/H_o) = 0 \quad E(MUF/H_1) = M \quad . \tag{2}$$

Therefore, a significance test is made in order to check if H_o or H_1 is true. It is assumed that all measurements have normally distributed random errors. Then the probability of detection in case of disappearance of M is given by

$$1 - \beta = \text{prob}\ \{ MUF>x/H_1 \} = \phi(\frac{M}{\sigma} - U_{1-\alpha}) \quad , \tag{3}$$

where x is the significance threshold, σ^2 the variance of all measurement errors, α the false alarm probability and U the inverse function of the Gaussian function ϕ. The value of σ^2 is fixed by the measurement system. Thus $1 - \beta$ is determined once M and α are given. The question arises how these quantities shall be determined. To answer this let us go one step further.

Sequence of Inventory Periods

Let T be the reference time in consideration (e.g. one year) and let this reference time contain n inventory periods. Furthermore, let $M = \Sigma M_i$ be the total amount disappearing during the n inventory periods. Then the total probability of detection will be instead of (3)

$$1 - \beta = 1 - \text{prob}\ \{ MUF_1 \leq x_1 \wedge \ldots \wedge\ MUF_n \leq x_n/H_1\} \quad . \tag{4}$$

Because the starting inventory of the i-th inventory period has to be formed from the ending book and physical inventory of the i-1st inventory period, in general this expression cannot be written as a product of single inventory period probabilities. If one choses, however, the starting inventory as minimum variance estimate from the foregoing book and physical inventories, the different MUF random variables can be shown to be uncorrelated and furthermore, as they have been assumed to be normally distributed, independent. Therefore, one obtains from (4) corresponding to (3)

$$1 - \beta = \prod_i (\frac{M_i'}{\sigma_i} - U_{1-\alpha_i}) \ , \tag{5}$$

where M_i' is a linear combination of all M_j, $j = 1..i$

$$M_i' = a_{i-1} \cdot M_{i-1} + M_i$$

$$a_{i-1} = \frac{\text{var}\ I_{i-1}}{\text{var}\ B_{i-1} + \text{var}\ I_{i-1}}$$

$$M_1' = M_1 \tag{6}$$

The overall false alarm probability α is then given by

$$1 - \alpha = \prod_i (1 - \alpha_i) \quad , \tag{7}$$

where α_i, $i = 1..n$, is the single false alarm probability of the i-th inventory period.

Let us assume that the overall false alarm probability is given. Then the α_i should be chosen in such a way that the probability of detection $1 - \beta$ is maximized

$$\max_{\alpha_i} (1 - \beta) = \max_{\substack{\alpha_i: \\ \prod_i (1-\alpha_i) = 1-\alpha}} \prod_i \phi\left(\frac{M_i'}{\sigma_i} - U_{1-\alpha_i}\right) \quad . \tag{8}$$

This means that the single false alarm probabilities α_i are now determinants. If on the other hand a plant operator intends to divert the amount M during the reference time, one has to assume that he distributes the single diversions in such a way that the probability of detection is minimized. This means that the <u>guaranteed</u> probability of detection has to be determined in the form

$$\max_{\alpha_i} \min_{M_i} (1 - \beta) = \max_{\substack{\alpha_i: \\ \prod_i (1-\alpha_i) = 1-\alpha}} \min_{\substack{M_i: \\ \sum_i M_i = M}} \prod_i \phi\left(\frac{M_i}{\sigma_i} - U_{1-\alpha_i}\right) \quad . \tag{9}$$

The assumption that the operator and the inspection authority will consider the situation in similar ways leads to the problem of the determination of a saddle point, i.e. the determination of a set of α_i and M_i, $i = 1..n$, such that

$$\max_{\alpha_i} \min_{M_i} (1 - \beta) = \min_{M_i} \max_{\alpha_i} (1 - \beta) \quad . \tag{10}$$

Thus, the M_i also become determinants once M is determined. One could proceed further and determine by means of this optimization the values of M and α for the single plant after having fixed the corresponding values for a set of plants. However, it is clear that ultimately some values must be fixed in a more or less subjective way.

<u>Data Verification</u>

Once the material balance data are collected, the control authority has to verify these data with the help of independent measurements on a random sampling basis. This can be done, for example, by means of the so-called D-statistics: Let x_{ij} be the operator's reported data of the j-th batch of the i-th class ($j = 1...N_i$, $i = 1...R$) and let y_{ij} be the corresponding measurements of the control authority ($j = 1..n_i$, $i = 1...R$). Then the difference

$$D = \sum_i \frac{N_i}{n_i} \sum_j (y_{ij} - x_{ij}) \qquad (11)$$

is formed, and a significance test is performed where the Null Hypothesis H_o and the Alternative Hypothesis H_1 are given by

$$E (D / H_o) = 0 \qquad E (D / H_1) = \Sigma_i \mu_i r_i \quad . \qquad (12)$$

Here, r_i is the number of the falsified batches in the i-th class and μ_i is the amount falsified per batch in the i-th class.

If one assumes that G is the total verification effort available and ε_i the effort for the verification of the data of one batch in the i-th class, then the problem arises to distribute the effort available in such a way that the probability of detection

$$\text{prob} \{ D > x / H_1\} \qquad (13)$$

(where x is the significance threshold) is maximized with respect to the n_i under the constraint $\Sigma\varepsilon_i n_i = G$. On the other hand, the operator who wants to divert the amount M by means of data falsification, will distribute this falsification so that the probability of detection is minimized with respect to the r_i under the constraint $M = \Sigma_i \mu_i r_i$. Thus, similar to the prior case, a game theoretical treatment is necessary.

<u>Global Optimization</u>

In the final evaluation of the whole system, all "strategies" of both the operator and the control authority must be taken into account. This means that the global probability of detection for the reference time (which may include n inventory periods and n D-statistics to be performed)

$$1 - \beta = 1 - \text{prob}\{MUF_1 \leq x_1 \wedge ... \wedge MUF_n \leq x_n \wedge D_1 \leq x_{n+1} \wedge ... \wedge D_n \leq x_{2n} / H_1\} \qquad (14)$$

must be minimized with respect to the M_i, $i = 1..2n$ and maximized with respect to the x_i, and where the constraints

$$\sum_{i=1}^{2n} M_i = M \qquad (15)$$

$$1 - \alpha = 1 - \text{prob}\{MUF_1 \leq x_1 \wedge .. \wedge D_n \leq x_{2n} / H_o\} \qquad (16)$$

are given. As the MUF_i, i = 1..n, and the D_i, i = 1..n, are dependent -- the original data are used for both the material balance establishment and the date verification -- the expression (14) cannot be factorized.

Concluding Remarks

Up to now saddle points have been determined for a sequence of two inventory periods, and for D-statistics for R classes under special assumptions. In the case of n inventory periods it seems also possible to determine solutions under special assumptions.

A completely different situation arises if one assumes that at the beginning of a reference time the operator does not have the intention to divert the amount M of material, but rather decides from inventory period to inventory period whether or not he will divert something. Problems of this nature have already been treated by Dresher, et.al. and they have also already begun to be treated in the safeguards case. However, the related optimization problems in the sense sketched above have not yet been tackled.

Appendix G

On the Need for System Optimization Laboratories

G. Dantzig

Need

From its very inception, it was envisioned that techniques like linear programming would be applied to very large, detailed models of economic and logistical systems. Kantorovich's 1939 proposals, which were before the advent of the electronic computer, mentioned such possibilities. In the intervening 25 or so years, electronic computers have become increasingly more powerful, permitting general techniques for solving linear programs to be applied to larger and larger practical problems. Additional steps are now necessary if there is to be significant progress in solving certain pressing problems that face the world today.

Society could benefit greatly if certain total systems can be modelled and successfully solved. For example, crude economic planning models of many developing countries indicate a potential growth rate of GNP of 10% to 15% per year. To implement such a growth (aside from political difficulties) requires a carefully worked out detailed model and the availability of computer programs that can solve the resulting large-scale systems. The world is currently faced with difficult problems related to population growth, availability of natural resources, ecological evaluation and control, urban redesign, design of large scale engineering systems (e.g. atomic energy, and recycling systems), and the modelling of man's physiological system for the purpose of diagnosis and treatment. These problems are complex, are urgent and can only be solved if viewed as total systems. If not, then only patchwork, piecemeal solutions will be developed (as it has been in the past) and the world will continue to be plagued by one crisis after another caused by poor planning techniques. For solutions, these problems require total system planning, modelling, and optimization.

It is recommended that several system optimization laboratories be established where enough critical mass would exist in each that representative large scale models (of the type referred to above) could be practically modelled and numerically solved. Solving large scale systems cannot be approached piecemeal or by publishing few theoretical papers. It is a complex art requiring the development of a whole arsenal of special tools.

Background

The optimization of large scale systems is technically an extremely difficult subject. Historically, starting with U.S. Air Force problems in 1947, linear programs were formulated to solve just such systems. These problems involved systems of interlocking relations involving many planning periods, functional units, types of personnel, and supply. It led to thousands of equations in many thousands of unknowns. This was beyond computational capabilities. It was necessary to severely restrict the class of practical problems to be solved. Starting around 1954 a series of purely theoretical papers began to appear on how to efficiently solve large systems and by 1970 they numbered about 200. There was little in the way of implementation. Exceptions were the out-of-kilter algorithms for network flow problems proposed by Ford and Fulkerson (1958) and the "decomposition principle" of Philip Wolfe and myself which had been tried but with variable results (1960). On the other hand a more modest proposal of Richard Van Slyke and myself (generalized-upper bounds) has been very successful (1967). Apparently a great deal in the way of empirical testing of ideas is necessary and this has not been easy to do because the test models have to be complex to be pertinent and cost a great deal of money to program and solve. Therefore progress has been slow up to the time of the Elsinore meeting.

Since its origins in the development of transport allocation methods in the early 1940's, and especially since the introduction of the Simplex Method of linear programming in 1947, the power of the methods of mathematical programming, and the range of effectiveness of its applications, have grown enormously. In the intervening decades the methodology has been extended to include non linear and integer programming, dynamic programming and optimal control, and a host of other types of optimization problems. The range of applications has been extended from simple allocation problems to an enormous variety of problems in intertemporal allocation and investment planning, engineering design and optimization, and scientific studies of physical, biological, and ecological systems. There is, in fact, no end foreseeable to the applications of mathematical programming to a number of important (and crucial) optimization problems.

Examples of Important Applications

A) Investment Planning (Intertemporal Allocation)

Problems of aggregate economic planning for a (developing) country, present an exploitable special structure that has been studies intensively and has great potential. Related structures occur in problems of dynamic programming and optimal control. Related but more complicated structures arise, for example, in problems of plant location and time-phasing, and in investment planning in general in the firm.

B) Decentralized Allocation

The origin of the modern methods of decomposition, and still one of the major areas of application, is the class of decentralized allocation problems, in which scarce resources are to be allocated among several otherwise independent enterprises or "divisions." Closely related is the class of problems of two-stage allocation under uncertainty, for which in the linear case it is known that the dual problem is one of decentralized allocation. It is of particular importance to realize that the "divisional subproblems" may themselves be of a special structure (e.g. a transportation problem) which can be exploited.

C) Engineering Design and Optimization

A variety of engineering design and process optimization problems present specially structured mathematical programs for which the structural features are highly dependent on the process being studied. Probelms of this type illustrate the need for a flexible and comprehensive software package from which components can be drawn to build up models of very complex systems.

D) Physical, Biological, and Ecological Systems

A number of problems in the physical sciences (e.g. X-ray crystallography) and biological sciences (e.g. models of body processes) present specially structured mathematical programming problems. An extreme example are models of ecological systems in which the many and varied relationships among the components again require a flexible and comprehensive software package.

E) Urban Planning

Coordinated planning of the many component subsystems (e.g. transport, recreation, education, etc.) of an urban environment presents a complex systems optimization problem for which ordinarily the most powerful and flexible methods are required.

F) Logistics

Coordinated logistical support for any large industrial (e.g. warehousing and transport) or government (military) activity normally presents a system optimization problem of considerable size and complexity, but with exploitable structural features.

G) Transportation Systems

Various problems concerning the design of transportation systems can be formulated as network optimization models of a combinatorial nature. These models typically have very special mathematical programming structures for which highly efficient algorithms can be devised.

The Functions of a Systems Optimization Laboratory

The purpose of such a laboratory would be to support the development of computational methods and associated computer routines for numerical analysis and optimization of large scale systems. The ultimate objective of the development effort would be to provide an integrated set of computer routines for systems optimization. It is the nature of human activity, and in large part of the physical world as well, that large and complicated endeavours are organized as systems of interrelated parts, and indeed, as systematic hierarchies of interrelated sub-systems. Such systems typically exhibit special mathematical structures. These special structures permit numerical analysis and optimization via methods that exploit the special structure, whereas general structure methods would be infeasible if the problem is of the size normally encountered in practice. The extension of the range of applications of mathematical programming is, therefore, most promising for pressing world probelms involving total system optimization discussed earlier since they exhibit special structures.

Research Projects of a Systems Optimization Laboratory

A. Software Packages

A major activity of System Optimization Laboratory would be the development of software packages for systems optimization. This development effort could proceed on two different levels. First, a major activity would be the completion of a macro language for organizing and calling routines in the software package. Mainly this could be an extension of the macro language Mathematical Programming Language (MPL) under development. The second major activity could be the programming, testing, and documentation of algorithms for decomposition and special structures, including experimentation with alternative algorithms, and testing of algorithms on practical problems. Computer routines would be thoroughly documented, tested on standard problems, and written in a format compatible with and callable by the macro language.

B. Decomposition Methods

The chief requirement in the construction of numerical methods for optimizing large systems is that the algorithm exploit the special structure of the system. The body of theory and techniques which addresses this requirement are generally called decomposition methods. The range of decomposition methods is quite diverse, however, since of necessity a particular algorithm must reflect the special structure of the class of problems to which it is applicable.

One preliminary task in the development of decomposition methods would be the construction of an efficient taxonomy for system structures. This task is only partially complete. The major taxonomic features that are well understood can be described briefly as follows. First, there is a large and important class of problems whose special structure permits the design of an efficient algorithm based directly on this structure. Usually, duality and compact representation schemes play a key role in the design of the network problems, problems with upper and lower bound constraints, and a number of nonlinear problems (geometric programming, fractional programming, variable factor programming, etc.). Often problems with these special structures occur as subproblems in larger systems and it is therefore important to have available efficient, tested, and documented routines for these problems which are easily callable.

Surveys of the major decomposition methods are given by Geoffrion (1970) and Lasdon (1971).

Recommendations

To model and to solve a host of pressing world problems in the areas of population, food, energy, water, ecology, urban development, it is recommended that several System Optimization Laboratories be established. Large scale system optimization requires laboratories where a large number of test models, computer programs, and special software tools are assembled in a systematic way. It is further recommended that software developed 1) be thoroughly tested on representative large-scale systems optimization problems arising in practice, and 2) be made freely and publicly available to users of government, science, and industry.

Appendix H

IIASA Conference on Optimization of Large Scale Systems

M. Sakarovitch

This note is intended to present a short summary of the research activities on optimization and control of complex dynamic systems currently pursued in the O.R. Group of the Institute for Advanced Mathematical Research at Grenoble (IMAG).

These research activities, done in collaboration with the Agence d'Urbanisme de la Ville de Grenoble (City Planning Office) are concerned with urban transportation. The dynamic feature is not an intrinsic part of the model but rather comes from the use of a specific solution technique. The problems under study (design of a one-way street system, design of a network for Public Transportation) are complex not only because of their combinatorial structure but also because they are very difficult to model with precision since the relevant parameters are not easily identifiable and even less easily quantifiable. However, the local specialists in charge of the traffic or transportation do have a good synthetic view of the problem. Their choices will take into account--sometimes in an unconscious manner--many more or less diffuse constraints. On the other hand, the mathematical model allows for a rigorous analytic approach which should not be neglected.

The idea which is the basis of our research is to combine these different but complementary viewpoints so as to find a solution which, however non-optimal (indeed the optimality of a solution in this context is an ill-defined concept), is "good." The procedure to obtain such a solution is a man-model dialogue through the use of a cathodic console which visualizes the results at each step, the role of the model being of pertaining some suboptimization as well as of guiding the specialist who is tentatively looking for the solution.

1. One-way Street System

Two methods were explored.

a) Using the origin-destination matrix of the travel demand

A map of the city is shown on the console. The traffic engineer proposes a one-way street schema; the model computes the value of the objective function (total time spent in the system) for this schema, and gives an evaluation of the solution. The overloaded streets are displayed and the engineer can modify the schema.

b) Without using the origin-destination matrix

It appeared that a "good" schema should be relatively independent of the O.D. matrix and that the knowledge of the engineer about the main traffic flows should be largely sufficient. Usually a traffic engineer would first look for a solution at the most difficult street intersections and then would solve the overall problem by an approximation following these lines of reasoning: "given that this street is one way north/south, this next street should be one way south/north," or more generally, "...it would be better that this next street be south/north, but if it is not, then this third one absolutely must be south/north." The method consists of entering--automatically or by programs--some of these "fuzzy" implications and then developing (using a S.E.P. procedure) all the consequences of some initial choices. The final result may appear quite inacceptable to the engineer. In this case a new constraint ruling out this configuration is entered and so on to the appearance of a good solution. This approach allows for much flexibility.

2. Design of a Network for Public Transportation

Essentially the same approach as the one described in §1-a is used. For a given design the model optimally assigns buses to different routes (for some criterion: social welfare of the citizen), then evaluates other criteria (e.g. number of users, loss for the transportation company). The man proposes a different design for one or several routes, and the dialogue goes on until a satisfactory solution has be found.

Appendix I

Opinions on the Questions Raised in Appendix A

W. Orchard-Hays

1. The general system group at IIASA should utilize difficult models to develop methodology, algorithms, and software. It should also encourage other groups to use its expertise in determining the scope and practicability of complex interrelated models. It should not seek to encourage grandiose models for their own sake.

2. General systems research should carry on its own independent research but should seek to help in the formulation and solution of problems from other groups. The latter is, indeed, the best way to instigate the former. A fruitful synergism is essential to progress. We already have too many ivory tower methods and models.

3. It would be presumptuous for me to define precisely what services the system group should offer other groups. However, such a definition--clear cut, understood, and enforced--is essential. When the system group lacks certain expertise, everyone's interests will be better served if the appropriate group loans the necessary expert to the system group, and vice versa. Competition in approaches can be very valuable but it should not become competition in empire building.

4. It does not seem to me that IIASA is the proper place for software research, per se. However, evaluation of software and suggestions for new capabilities are not only appropriate but a part of IIASA's function as I see it. Building software is essentially an engineering activity but it needs guidance for its efforts. I might also point out that the problem of approved publications would arise to at least the second power with approved software with IIASA's stamp on it.

5. Yes, IIASA should conduct an international survey of successful system models (formulation and solution), within reasonable limits (wide application, innovative methodology, verifiable results).

6. I think it would be a mistake for IIASA to attempt to become a clearing house for software, except in the sense

of 4. The workload would be enormous and the necessary facilities very expensive. IIASA should use software which works, at least as claimed. If capabilities are lacking, then IIASA should specify what it needs. If no assistance is forthcoming, IIASA should bring pressure to bear through other channels.

7. The question of coordinating activities with system optimization laboratories in various countries is premature. A great many practical arrangements--hardware, software, communications, personnel time--must be made before detailed administrative rules can be set forth. IIASA will probably have to start with specific arrangements with two or three groups and feel its way. It must protect its flexibility and options without undue hesitancy.

8. Yes, IIASA should develop a list of important unsolved system problems and try to set research priorities in universities and elsewhere. However, the list should not be too long or too difficult. The main goal should be to provide leadership in the field with the aim of promoting practical use of existing and state-of-the-art technology. The universities cannot be controlled anyway and will think up enough esoteric problems. The substantial resources of research departments in large industrial firms should not be overlooked.

9. IIASA should certainly try to identify really good new ideas in system optimization and encourage their further development. The difficulties are that not many such ideas germinate and, when they do, are often hard to discern. Some sort of periodic review committee, plus general familiarity with work in the field, is about all the effort that appears warranted. If IIASA can avoid being blinded by its own vested interests, that will be a significant accomplishment.

10. The questions of what computer equipment and software would be most suitable for IIASA and whether it should be acquired or remotely used, are very complicated. I expressed strong opinions at the Conference against IIASA having its own large computer. However, Professor Raiffa's recital of the practical difficulties in communications were a powerful antidote. Ideally, I still believe IIASA should not tie itself to one computer but should have very adequate, even elaborate, facilities for remote access to any of several computing centers. This is technically feasible and even common in the U.S. but the financial, political, and even technical problems may be overwhelming in Laxenburg. I hope not. If IIASA must select one large computer, I strongly recommend an IBM 360/67 or a 370 with virtual memory. Such

a selection does not please me but the overwhelming ubiquity of IBM software and hardware plus the absolute criticality of interactive systems of great power and capacity, forces the decision. Unfortunately, such a local facility would almost completely isolate IIASA from continuing effort with other groups, except for the use of the mail, telephone calls and the necessarily limited visits. IIASA should be able to

(a) Communicate on-line via typed messages,

(b) Log in to various systems and access various software packages,

(c) Manipulate data remotely and even transmit it (both ways) in reasonable volume,

(d) Assemble/compile and install new routines remotely.

This should be possible to IBM, CDC, Univac, and perhaps other U.S. makes, and, to the extent permissible, USSR and other Eastern European computers. I believe this is the kind of flexible capability IIASA should have. In addition to terminals, you need at least one each remote line printer, card reader and tape drive (probably two or more tapes to accomodate non-US makes). A sizeable array of equipment is required to drive all this, without a big computer. But perhaps this is all gratuitous since a detailed study is required. However, I cannot overemphasize the fact the IIASA is already late if significant work is to be done in 1974.

11. I would be presumptuous in suggesting all the permanent IIASA staff in the general system area or whether they should be restricted to nations supporting IIASA. However, one class of personnel will be essential and their selection difficult. There is no good name but the general category is "application analysts, programmers, and aides" in a software sense. It is such people who really make the use of computers practical and their value is highly dependent on their continuing familiarity with how things work in a particular environment. It is important not to create a "Systems Programming Department" as such (the greatest empire builders extant) but equally important not to have hacks or trainees. Whether or not such people can be attracted to IIASA is hard to say but the more difficult problem will be identifying them, particularly an international crew. In the U.S., they tend to be quite well paid but with little academic or professional standing.

12. This question had three parts and I will not attempt

to answer the last two except to say that IIASA must quickly develop a profile of responsible leadership. As to the first part--remaining non-political--I hope this will not be overdone. Obviously, any issues which are currently sensitive or aggravating must be shied away from. But the important issues to which systems technology needs application are inevitably politico-economic. It seems to me that IIASA must encourage those with opposing viewpoints to cooperate with an open mind on projects deemed important by their opponents. Neither East nor West, nor any similar dichotomy has a corner on dogmatism and suspicion. For example, an honest study of a planned economy by capitalistic-minded analysts might provide them with new insights and methodology. Yet, there seems to be a universal tendency to dismiss such a suggestion out-of-hand. But if we are to turn to, say, global ecological problems, how can a project be fully fruitful without mutual understanding--whether sympathetic or not--of the viewpoints and motivations of the nations involved. But perhaps I am becoming presumptuous in spite of myself.