Activity Report

1989/1990

Division of Optimization and Systems Theory
Department of Mathematics
The Royal Institute of Technology
S–100 44 Stockholm, Sweden

Contents

1 Personnel

1.1 List of Personnel

Professor (Professor)

Anders Lindquist, TeknD, docent

Docent, högskolelektor (Associate professor)

P O Lindberg, TeknD, docent

Högskolelektorer (Lecturers)

Tomas Björk, FD
Krister Svanberg, TeknD

Adjungerad professor (Adjunct professor)

Chris Byrnes, PhD

Forskarassistent (Research associate)

Xiaoming Hu, PhD

Sekreterare (Secretary)

Elise Hanning

Doktorander (Graduate students)

Torgil Abrahamsson, civing
Erik Berglund, civing
Ulf Brännlund, civing, MS
Karin Falk-Skogh, civing (Employed by Ericsson July 1, 1990)
Anders Forsgren, civing, MS (Graduated June 8, 1990)
Martin Hagström, civing
Torbjörn Magnusson, civing
Birgitta Olin, civing
Anders Rantzer, civing, TeknL
Jan-Åke Sand, civing
Yishao Zhou, MS

Forskningsingenjör (Research engineer)

Omar Viera

1.2 Biographies

Torgil Abrahamsson was born in 1961 in Katarina, Stockholm. He received a civilingenjör degree in Engineering Physics at KTH in 1986. Since the summer of 1987 he is a PhD student at Optimization and Systems Theory at KTH. His main research interest is in traffic equilibria.

Erik Berglund was born in Stockholm in 1961. He received a civilingenjör degree in Engineering Physics at KTH in 1985. Since 1984 he has been with the National Defense Research Establishment (FOA) where he works in guidance and control of missiles and evaluation of weapon systems. He is also a part-time PhD student of Optimization and Systems Theory at KTH, his main intrests being in Systems and Control.

Tomas Björk was born in Fagersta, Sweden, in 1947. He recieved his B.A. from the University of Stockholm in 1971, and his PhD in Optimization and Systems Theory from the Royal Institute of Technology in 1981. Between 1971 and 1974 he worked as a Researcher at the National Defense Research Establishment (FOA). In 1981 he became a Research Associate and in 1987 a Lecturer of Optimization and Systems Theory at the Royal Institute of Technology. During the period 1987-1990 he has also given several courses in Mathematical Economics at the Stockholm School of Economics. His main research interests include martingale theory, nonlinear filtering and mathematical economics.

Ulf Brännlund was born in 1961. He received a civilingenjör degree in Aeronatical Engineering from KTH in 1986 and an MS degree in Engineering-Economic Systems from Stanford University in 1988. His main research interests are dual optimization methods and production planning problems.

Christopher I. Byrnes was born in New York, NY, on June 28, 1949. He received the B.S. degree from Manhattan College, Bronx, NY, in 1971 and the M.S. and Ph.D. degrees from the University of Massachusetts, Amherst, in 1973 and 1975, respectively.

He served as an Instructor in the Department of Mathematics at the University of Utah, Salt Lake City, from 1975 to 1978, when he was appointed Assistant Professor in the Department of Mathematics and in the Division of Applied Sciences at Harvard University, Cambridge, MA. From 1982 to 1985 he was Associate Professor of Applied Mathematics on the Gordon McKay Endowment at Harvard University. In 1984, he joined Arizona State University, Tempe, as a Research Professor of Engineering and Mathematics. He is currently Chairman and Professor in the Department of Systems Science and Mathematics at Washington University, St. Louis, MO, and Adjunct Professor of Mathematical System Theory at KTH. He has also held visiting positions at Bremen, Groningen, Harvard, IIASA, Kansas, KTH, Osaka, Paris-Dauphine, Rome-La Sapienza, Stanford and Tokyo. An editor of eleven research volumes and author of over 100 technical articles, his research interests include adaptive control, algebraic system theory, distributed parameter

systems, linear multivariate control, nonlinear control, and the applications of nonlinear dynamics in control and estimation.

Dr. Byrnes has served as an Associate Editor of four journals and is currently Editor of the two new book series, *Systems and Control: Foundations and Applications* and *Progress in Systems and Control* (Boston: Birkhäuser).

Karin Falk-Skogh was born in Stockholm, Sweden, in 1962. She received a civilingenjör degree in Aeronautical Engineering from KTH in 1987. Her main research interest is spare parts optimization.

Anders Forsgren was born in Danderyd, Sweden, in 1961. He received a civilingenjör degree in Engineering Physics from KTH in 1985, an MS degree in Operations Research from Stanford University in 1987 and a TeknD degree in Optimization and Systems Theory from KTH in 1990. His main research interest is nonlinear programming.

Martin Hagström was born in Stockholm in 1963. He received a civilinjenjör degree in Aeronautical Science at KTH in 1988. He is presently a PhD student at the department. His main research interest is nonlinear dynamics of filtering algorithms and stochastic realization theory and its applications.

Xiaoming Hu was born in Chengdu, China, on April 19, 1961. He received the B.S. degree from University of Science and Technology of China in 1983. He received the M.S. and Ph.D degrees from Arizona State University in 1986 and 1989 respectively. He served as a research assistant at the Institute of Automation, Academia Sinica, from 1983 to 1984. He was Gustafsson Postdoctoral Fellow at the Royal Institute of Technology, Stockholm, from 1989 to 1990. His main research interests are nonlinear control theory and the analysis and design of nonlinear feedback systems.

Per Olov Lindberg was born in Stockholm on February 20, 1942. He received a civilingenjörs examen in Engineering Physics at KTH in 1967 and a PhD in Optimization Theory at KTH in 1975.

He served as a Systems Analyst at Datema in 1967–68. From 1968 to 1974 he served as a Research Assistant at the Department of Mathematics at KTH, on Transportation Research Grants. From 1975 to 1979 he was Assistant Professor of Optimization and Systems Theory at KTH. From 1980 he has been Associate Professor at KTH. He also has served as Acting Professor on several instances, including the three year period Fall 1980–Spring 1983.

Lindberg was a board member of the Swedish OR Association 1974–1980. He has served on the board of the School of Computer Science at KTH and is presently serving at the boards of the Schools of Vehicle Engineering and Industrial Engineering.

Lindberg was visiting professor at Sloan School of Management, MIT, during the Spring Semester 1988. He has also been Visiting Scholar at Stanford University and University of Washington. He has recently been appointed Adjunct Professor at University of Florida.

Lindbergs research interests include most areas of Mathematical Programming and its applications, including Linear, Nonlinear, Dynamic and Integer Programming, Convexity and Duality, Inventory Control and Random Utility Models. He has guided six students to a PhD and and four for a Master's Degree. Furthermore he has guided well over 50 students for an Engineering Master's Thesis (examensarbete).

Anders Lindquist was born in Lund, Sweden, in 1942. He received the civiling., TeknL and TeknD degrees from the Royal Institute of Technology, Stockholm, Sweden, and in 1972 he was appointed a Docent there.

From 1972 to 1974 he held visiting positions at the University of Florida, Brown University, and State University of New York at Albany. In 1974 he became an Associate Professor, and in 1980 a Professor of Mathematics at the University of Kentucky, where he remained until 1983. He is presently a Professor at the Royal Institute of Technology, where in 1982 he was appointed to the Chair of Optimization and Systems Theory, and an Affiliate Professor at Washington University, St Louis. He has also held visiting positions at University of Padova, Italy, University of Arizona, USSR Academy of Sciences, Moscow, and East China Normal University, Shanghai. From 1975 to 1976 he was a SIAM Visiting Lecturer. He is the author of a many papers in the area of systems and control, especially stochastic control, filtering, stochastic systems theory, realization theory, and applications of nonlinear dynamics in estimation and control, and he is an editor of four research volumes. Since 1989 he is a Fellow of the IEEE (Institute of Electrical and Electronics Engineers).

Lindquist is a Regional Editor of the *Journal of Mathematical Systems, Estimation, and Control* and an Associate Editor of *Systems and Control Letters*. He also serves on the editorial boards of two book series, *Systems and Control: Foundations and Applications* and *Progress in Systems and Control*, published by Birkhäuser, Boston.

Birgitta Olin was born in 1960 in Stockholm, Sweden. She received a civilingenjör degree in Engineering Physics at KTH in 1985. At present, she is a PhD student at the Division of Optimization and Systems Theory at KTH.

Anders Rantzer was born in 1963. He has a civ.ing. (MSc) degree (1987) in Engineering Physics and a Tekn.Lic. (1989) in Mathematics, both from Lund University. At present, he is a PhD student at the Division of Optimization and Systems Theory at KTH. In 1990, he won the SIAM Student Paper Competition in Chicago. Main research interests are stabilization and robustness of linear control systems.

Jan-Åke Sand was born in 1964 in Stockholm. He received a civilingenjör degree in Engineering Physics at KTH in 1988 and is now a PhD student of Optimization and Systems Theory at KTH. His main research interest is in Stochastic Systems.

Krister Svanberg was born in Stockholm in 1950. He received his civilingenjör degree in Engineering Physics from KTH in 1975, and his TeknD degree in Optimization Theory from KTH in 1982. Between 1976 and 1985 he held a position as

Research Associate with the Contract Research Group of Applied Mathematics at the Royal Institute of Technology, and since 1985 he is a Lecturer of Optimization and Systems Theory. His main area of research is structural optimization, in which area he has kept continuous scientific contacts with such industrial companies as SAAB-SCANIA, VOLVO, and ALFA-LAVAL.

Omar Viera was born in 1953 in Montevideo, Uruguay. He will receive his degree in Engineering Physics at KTH in 1991. His main intrest is in nonlinear programming.

Yishao Zhou, Ph.D student at KTH, was born in Shanghai in 1959. She received BS and MS degrees in mathematics at Fudan University in 1982 and 1984 respectively. From 1984 to 1987 she worked at Department of Applied Mathematics of East China University of Chemical Technology. Her main research interests are the matrix Riccati equation, Kalman filtering, nonlinear dynamical systems and stochastic realization theory.

1.3 Visiting and interacting scientists

Dr. Anders E. Eriksson
Swedish Defense Research Establishment
Stockholm, Sweden

Professor Paul Fuhrmann
Department of Mathematics
Ben Gurion University of the Negev
Beer-Sheva, Israel

Professor Philip E. Gill
Department of Mathematics
University of California at San Diego
La Jolla, CA 92093, USA

Professor P. O. Gutman
Faculty of Agricultural Engineering
Technion
Haifa 32000, Israel

Professor Donald W. Hearn
Department of Industrial and Systems Engineering
University of Florida
Gainesville, FL 32611, USA

Professor Alberto Isidori
Department of Informatics and Systems Sciences
University of Rome
Rome, Italy

Dr. Björn Johansson
Department of Mathematical Statistics
University of Stockholm
Stockholm, Sweden

Professor Lars Lundqvist
Department of Regional Planning
KTH
Stockholm, Sweden

Dr. Lars-Göran Mattsson
Office of Regional Planning and Urban Transportation
Stockholm County Council
Stockholm, Sweden

Professor Walter Murray
Department of Operations Research
Stanford University
Stanford, CA 94305–4022, USA

Professor Giorgio Picci
Department of Electronics and Informatics
University of Padova
Padova, Italy

Professor Yu-Fan Zheng
Applied Math. Research Division
East China Normal University
Shanghai 200062, China

2 Research

2.1 List of projects

2.1.1 List of projects in Systems and Control

- Adaptive prediction and control.
- Control of spinning missiles.
- Feedback stabilization and output regulation of nonlinear systems.
- Nonlinear design problems in nonlinear control.
- On the nonlinear dynamics of Kalman filtering.
- Robustness of linear systems with uncertain parameters.
- Stochastic systems theory.
- Structured problems in systems theory.
- The minimal rational covariance extention problem.

2.1.2 List of projects in Mathematical Programming

- Dual methods for large scale optimization problems.
- Dual methods for the unit commitment problem.
- Higher order methods for structural optimization.
- Inventory control, in particular stochastic leadtimes and back-order-time shortage penalties.
- Optimal waterflow through a water power station.
- Optimization laboratory.
- Optimization of spare parts inventory systems.
- Random assignment problems.
- Random utility models.
- Second-derivative methods for nonlinear programming.
- Second-order decomposition methods for large-scale optimization problems, production planning problems in particular.
- Studies of the efficiency of the simplex method.
- Traffic equilibrium models and solution methods.

2.2 Description of projects

2.2.1 Description of projects in Systems and Control

Adaptive prediction and control

Researcher: Tomas Björk, in cooperation with Björn Johansson (University of Stockholm).

The goal of this project is to develop a systematic theory for prediction, filtering and control for stochastic processes where the probability law governing the process is not known. Using an extension of the classical theory of optimal parameter estimation we have been able to construct optimal unbiased predictors for some diffusion processes. The theory leads to inverse parabolic boundary value problems and is intimately connected to the theory of time reversal and reciprocal processes.

Control of spinning missiles

Researcher: Erik Berglund (Anders Lindquist; advisor).
Sponsor: National Defense Research Establishment (FOA).

The purpose of this project is to develop control laws suitable for spinning high velocity missiles. The problem of guidance and control of such missiles involves mainly the spin-induced coupling between motions in different directions and the short amount of time available for corrections. The method of approach is disturbance decoupling with control variable constraints.

Feedback stabilization and output regulation of nonlinear systems

Researchers: Xiaoming Hu and C. I. Byrnes, in cooperation with A. Isidori (University of Rome).
Sponsor: STU and STUF.

The feedback stabilization of nonlinear systems has occupied a central role in the nonlinear systems literature for at least three decades. As pointed out by a panel at an IEEE workshop in Santa Clara in 1987, it is "the most important unsolved problem" in nonlinear control. "Techniques must be developed for determining whether a nonlinear system can be stabilized within a given desired region of stability". Feedback stabilization is not only important in its own right, but also essential as a preliminary step in achieving additional control objectives such as asymptotic tracking, disturbance attenuation. We show that for minimum phase nonlinear control systems, a high gain output feedback control law can be used to stabilize the system in any given desired region. We also study the problem of global stabilization for a nonlinear system from the point view of *passivity* which is motivated by the dissipation of energy across resistors in an electrical circuit. Some preliminary results are obtained for the global stabilization of a system formed by cascading a minimum phase nonlinear system and a passive nonlinear system. Another important problem in control theory and engineering is that of controlling a plant in order to have its output tracking (or rejecting) reference (or disturbance) signals produced by some external generators. New methods have been proposed in which the results of output

regulation for linear systems are extended to the general case of nonlinear system in which the exosystem generates time-varying reference signals and/or disturbances.

Nonlinear design problems in nonlinear control

Researchers: P. O. Gutman, Xiaoming Hu, Yu-Fan Zheng.
Sponsor: STU.

One basic goal of this project is to bridge the gap between theory and engineering practice in nonlinear design. The purpose is to obtain effective engineering solutions of basic problems of industrial control with design examples taken from such areas as robotics and motor drives. The goal is to treat nonlinear control problems involving static nonlinearities of industrial importance and to make adaptive and nonlinear modifications and extensions of robust linear regulators. A new adaptive compensation technique which can be added to a conventional controller to diminish the Coulomb friction in motor drive systems is proposed. It uses an on-line optimum search algorithm which requires minimal computing effort. Another goal of this project is to develop effective procedures for disturbance decoupling with stability. Preliminary results are also obtained to extend the current results on disturbance decoupling with stability to also include the case in which a nonlinear system may have uncontrollable critical modes.

On the nonlinear dynamics of Kalman filtering

Researchers: C. I. Byrnes, Anders Lindquist, Yishou Zhou, Martin Hagström.
Sponsors: STU, FOA and the Göran Gustafsson Foundation.

In this project we study the dynamical behavior of the Kalman filter when the given parameters are allowed to vary in a way which does not necessarily correspond to an underlying stochastic system. This may correspond to situations in which the basic parameters are chosen incorrectly through estimates. We show that, as has been suggested by Kalman, the filter equations converge to a limit (corresponding to a steady-state filter) for a subset of the parameter space which is much larger than that corresponding to *bona fide* stochastic systems. More surprisingly, in the complement of this subset the filtering equations behave in both a regular and an unpredictable manner, representative of some of the basic aspects present in chaotic dynamics. This interesting dynamical behavior occurs already for one-dimensional filters, and we give a complete phase-portrait in this case. The general case is also studied in detail. Extensive simulations have been undertaken which show interesting dynamical behavior.

Robustness of linear systems with uncertain parameters

Researcher: Anders Rantzer (Anders Lindquist; advisor).

In the last decade the question of robustness of control systems have received a lot of interest. Two major paths have been followed. One is the H^∞ approach, which gives a nice mathematical theory, but does not take into account any prior knowledge of the structure of uncertainty. The other approach treats structured perturbations.

Since the appearance of Kharitonov's theorem, which gives a simple and powerful criterion for one special uncertainty structure and stability region, large efforts have been spent by the international scientific community to extend this result to more general situations, having resulted in several sessions at each major conference in control theory. Anders Rantzer has developed some very general criteria which cover most of the situations studied by others and many more. The biggest challenge is presently to treat general multi-linear parameter dependence, which is most common in applications. An important area is also the development of new robust control design methods, that take advantage of the new approach of analysis.

Stochastic systems theory

Researchers: Anders Lindquist, Giorgio Picci (University of Padova) and Jan-Åke Sand.
Sponsors: STU and the Göran Gustafsson Foundation.

A comprehensive theory for state-space modelling of vector-valued (stationary and stationary-increment) stochastic processes has been developed. This work is developed within the framework of the geometric Hilbert space theory of Markovian splitting subspaces developed by Lindquist and Picci. We introduce a partial ordering of stochastic realizations and a noncausal estimation problem. Within this framework we clarify the relations between the structure of minimal splitting subspaces, the local structure of the matrix Riccati inequality and the zero structure of (not necessarily square) spectral factors. As a result we obtain direct systems theoretical interpretations of all solutions of the algebraic Riccati equation, and it is shown that the structure of each facet of the convex polyhedral set $\mathcal{P}$ of all solutions of the algebraic Riccati inequality is completely determined by the common zeros of the corresponding minimal spectral factors. Preliminary steps have been undertaken to apply the above principles to the study of systems modeled by reciprocal processes.

Structured problems in systems theory

Researchers: Paul Fuhrmann (Ben Gurion University) and Anders Lindquist.
Sponsor: The Göran Gustafsson Foundation.

The motivation for this project is that many complex systems are built up in a structured way, something that is not in general taken into account in current systems theory. The object is to use additional knowledge of structure in the analysis and synthesis of linear systems, particularly in partial realization, model reduction, feedback, and computational problems in stochastic realization. In treating these problems we exploit methodology from several areas of mathematics such as operator theory in general with specific stress on H^∞ theory centering around the lifting theorem and the AAK-theory of Hankel norm approximation, (Nevanlinna-Pick) interpolaton theory, and various factorization techniques such as Wiener-Hopf, inner-outer, spectral and coprime, all in the martrix case. On the algebraic side we lean heavily on the theory of polynomial models developed by P. Fuhrmann which incorporates some functional analytic ideas in the algebraic module theoretic setting.

The minimal rational covariance extention problem

Researchers: C. I. Byrnes and Anders Lindquist.
Sponsors: STU, FOA and the Göran Gustafsson Foundation.

The minimal rational covariance extention problem is a fundamental problem in systems theory, control theory, and signal processing, many aspects of which remain unsolved. As a step toward deeper understanding of these problems we have investigated the geometry (in the Kimura-Georgiou parametrization) of the set of all degree n positive real transfer functions with the first n coefficients in the Laurent expansion about infinity prescribed. One interesting question which has been raised is whether this set is star-shaped about the maximum entropy solution, i. e. the "all-pole solution". This, of course, would be implied by convexity and would imply that the solution set is diffeomorphic to Euclidean n-space. We show the last statement and present partial results on the other two. Based on these results we have obtained important insights into the minimal partial stochastic realization problem.

2.2.2 Description of projects in Mathematical Programming

Dual methods for large scale optimization problems

Researchers: P O Lindberg, Don Hearn, Ulf Brännlund, Torbjörn Magnusson, Torgil Abrahamsson, Birgitta Olin.
Sponsors: Swedish Board for Technical Development, ABB Network Control AB, Krångede Power Pool, Swedish State Power Board, Swedish Transport Research Board.
Industrial contacts: ABB Network Control AB, Krångede Power Pool, Swedish State Power Board.

This is a meta project aiming at obtaining efficient dual methods for large scale optimization problems.

Central subprojects are the unit commitment project and the production planning project. These projects share a common structure. Therefore it has been possible to exchange program modules between the projects (as planned). A similar project lead by Don Hearn in Florida is part of this program exchange.

The traffic equilibria project and the random assignment project share the ideas on a more methodological level, if not so far as to share codes. The common philosophy gives a strong backbone to our projects.

Dual methods for the unit commitment problem

Researchers: P O Lindberg and Torbjörn Magnusson.
Sponsors: Swedish Board for Technical Development, ABB Network Control AB, Krångede Power Pool, Swedish State Power Board.
Industrial contacts: ABB Network Control AB, Krångede Power Pool, Swedish State Power Board.

This project aims at developing efficient dual methods for large scale unit commitment problems (i.e. short term production planning for thermal power stations).

The dual methods consist of several modules:

- finding initial primal solutions
- determination of dual search directions
- determination of dual steplengths
- perturbation of relaxed primal solutions to get feasibility, consisting of
  - determining which unit should be on for each time slot
  - determining the production for each unit and time slot (the so called EDP problem).

A system containing these parts has been programmed and tested on several test cases. For some of the modules mentioned above, several methods have been tried. In particular several direction finding methods have been tried out. For the EDP problem, we have found a very efficient method.

Higher order methods for structural optimization

Researcher: Krister Svanberg.

Structural optimization is often defined as "Computer-aided optimal design of stressed systems". An example of a structural optimization problem is the "Truss sizing problem" in which the optimal cross section areas of the different elements (bars) in a truss structure should be calculated. With "optimal" is (in this case) meant that the structural weight is minimized subject to given constraints on structural stiffness and strength.

In this project, we develop and investigate different higher order optimization methods for the "Truss sizing problem", in particular methods based on second order derivatives of the constraint functions. We then try to generalize some promising approaches so that they can be applied also on more general problems, e.g. optimal shape design.

Inventory control, in particular stochastic leadtimes and back-order-time shortage penalties

Researcher: P O Lindberg.
Industrial contact: Systecon AB.

This is a project aiming at clarifying basic concepts and results of inventory theory. We have studied important aspects of inventory control that have not been treated sufficiently in the literature: stochastic leadtimes and shortage penalties on back-order-time. Results have been presented for the Poisson demand case.

Optimal waterflow through a water power station

Researchers: P O Lindberg and Omar Viera.
Sponsor: Swedish State Power Board.
Industrial contact: Swedish State Power Board.

This project aims at developing methods for finding the optimal waterflow through the turbines and tunnels of a water power station. The problem is difficult due to the inherent nonconvexities of the problem. The problem is attacked through a form of dynamic programming over the tunnel tree of the station. Preliminary results have been presented.

Optimization laboratory

Researchers: P O Lindberg, Ulf Brännlund, Anders Forsgren, Krister Svanberg, Torgil Abrahamsson.
Sponsors: Swedish Board for Technical Development.
Industrial contacts: ABB Network Control, Aeronautic Research Inst of Sweden, AlfGam Optimering AB, Krangede Power Pool, Swedish State Power Board, Swedish Telecommunications Administration, Systecon AB.

This project aims at collecting state of the art portable optimization routines as well as optimization problems. By making the routines and problems available to industry and government, we will enhance the spreading of optimization practice.

During the year we have mainly worked at collecting routines. A partial list of routines include:

MINOS, QPSOL, LSSOL, NPSOL	(Gill et al, Stanford)
MMA	(Svanberg, KTH)
GRG2	(Lasdon, U Texas)
RELAX	(Bertsekas, MIT)
NETFLO, NETSIDE	(Kennington, S Methodist U)
NLPQL	(Schittkowski, U Bayreuth)
RSDNET, RSDTA	(Hearn, U Florida)
NAG	(NAG)

Optimization of spare parts inventory systems

Researchers: P O Lindberg and Karin Falk-Skogh.
Sponsors: Swedish Board for Technical Development and Swedish Defense Material Administration.
Industrial contact: Swedish Defense Material Administration.

This project entails a broad study of spare parts inventory systems. During the year we have performed a litterature review, studied convexity properties of waiting time functions and solved the problem of simultaneous allocation of repair facilities and inventories. We also have made an in depth study of the prevailing spareparts optimization method in Sweden, OPUS.

Random assignment problems

Researchers: P. O. Lindberg and B. Olin.

This project aims at deriving better upper and lower bounds for the optimal value of random assignment problems.

For such problems, with cost coefficients uniformly distributed on the interval $[0, 1]$, simulation studies indicate that the average optimal cost is approximately 1.6 for large problems. Various researchers have derived upper and lower bounds on the expected cost of an optimal assignment as the problem size goes to infinity. We have derived improved lower bounds, on the order of 1.5 by considering suitable feasible solutions to the dual problem. The proofs rely on results concerning e.g. occupancy problems and negatively associated random variables.

Random utility models

Researchers: P O Lindberg, Anders E Eriksson, Lars-Göran Mattsson.
Industrial contact: Stockholm County Council.

This is a long running project aiming at developing the theoretical foundations of random-utility-models. During the year a paper has been written that lays the so called Robertsson-Straus model on a solid footing and connects it to generalized extreme value models. Several other ideas are in the pipeline.

Second-derivative methods for nonlinear programming

Researchers: P. O. Lindberg, Anders Forsgren, in cooperation with Philip E. Gill (UCSD), Walter Murray (Stanford University).
Sponsors: STU, STUF and the Göran Gustafsson Foundation.

The goal of this project is the development of computationally efficient second-derivative methods for solving nonlinear optimization problems.

Recent work include the development of a new modified Newton method for unconstrained minimization. Theoretical results have been established and the performance of the algorithm has been measured on a comprehensive set of test problems.

New modified Newton methods for linear equality-constrained minimization have been developed. These methods are suitable for solving sparse large-scale problems of this type. Theoretical results have been established.

Second-order decomposition methods for large-scale optimization problems, production planning problems in particular

Researchers: P. O. Lindberg, Ulf Brännlund, in cooperation with Donald W. Hearn (U. of Florida).
Sponsor: STU.
Industrial contact: IVF.

The goal of this project is the development of second order decomposition methods for large scale optimization problems, and production planning problems in particular

Recently an overview of lot-sizing problems and methods of solving such has been conducted. Studies of conjugate subgradients, least-squares approximation of the Hessian and exponential penalty methods for smoothing the dual objective function have been performed.

Studies of the efficiency of the simplex method

Researcher: P O Lindberg.

This is a long running project aiming at explaining the efficiency of the simplex method through experimental and theoretical investigations. During the year a theoretical model has been finalized and written up.

Traffic equilibrium models and solution methods

Researchers: P. O. Lindberg, Lars Lundqvist, Torgil Abrahamsson.
Sponsors: Swedish Transport Research Board (TFB).

The project falls in two parts. In the first, different models of the traffic equilibrium problem are developed and investigated. A first combined model containing trip distribution, modal split and traffic assignment with an application to the Stockholm region was presented at the RSA conference in Istanbul, 1990. The other part deals with solution techniques to the equivalent optimization formulation of the traffic equilibrium model. This problem is nonlinear and quite large, in terms of the number of variables. As a subproblem we have to solve a so called biproportional fit problem. For this we have improved the classical Cross-Fratar techniques. On the master problem a second order method is being developed and applied.

3 Education

3.1 Undergraduate courses

Number	Course name	Instructor	Credit
FA190	Optimization, General Course *(Optimeringslära, allmän kurs för D och F)*	P. O. Lindberg	3.5 p
FA191	Applications of Mathematics and Computer Science *(Matematikens och datateknikens tillämpningar)*	K. Svanberg	3 p
FA192	Optimization, General Course *(Optimeringslära, allmän kurs för T)*	T. Björk	4 p
FA195	Optimization *(Optimeringslära, grundkurs för M)*	K. Svanberg	4 p
FA196	Mathematical Programming *(Matematisk programmering)*	K. Svanberg	5 p
FA300	Systems Engineering *(Systemteknik)*	P. O. Lindberg	7 p
FA301	Systems Engineering *(Systemteknik, grundkurs)*	T. Björk	2 p
FA302	Methods of Systems Engineering *(Systemtekniska metoder)*	P. O. Lindberg	3.5 p
FA305	Production and Inventory Control *(Produktions- och lagerstyrning)*	P. O. Lindberg	3 p
FA310	Mathematical System Theory *(Matematisk systemteori)*	T. Björk	3.5 p
FA312	Calculus of Variations and Optimal Control *(Variationskalkyl och styrteori)*	T. Björk	3.5 p
FA320	Mathematical Economics *(Matematisk ekonomi)*	T. Björk	3 p

Normally the course FA314, Filtrering och stokastisk styrteori (Filtering and Stochastic Control), is taught each year, but during the academic year of 89/90 it was omitted because of being moved from the third to the fouth year of study.

3.2 Graduate courses

Course name	Instructor	Credit	Participants KTH	Participants industry
Convexity and optimization in linear spaces	T. Björk	5 p	10	2
Dual methods	P. O. Lindberg	2 p	8	-
Stochastic systems	A. Lindquist	10 p	8	-

3.3 Industrial courses

Course name	Instructor	Credit	Participants KTH	Participants industry
GAMS – Modelling course	P. O. Lindberg/ U. Brännlund	1 week	6	15

3.4 Doctoral thesis

A. Forsgren, *Newton methods for nonconvex optimization*, TRITA-MAT-1990-10, Division of Optimization and Systems Theory, Department of Mathematics, KTH, 1990. Advisor: P. O. Lindberg.

3.5 Master theses (Examensarbeten)

P. Bellman och J. Sjölund, *Studie av tidsåterrapporteringssystem för flygplansunderhåll*. Advisor: P. O. Lindberg. Performed at Linjeflyg.

P. Björkén, *Analys av lagerstyrning hos IBM i Järfälla*. Advisor: P. O. Lindberg. Performed at IBM, Järfälla.

C. Giordano, *Simulering av inverkan på trafikprogram av oplanerat tekniskt stillestånd*. Advisor: P. O. Lindberg. Performed at Linjeflyg.

C. Gyllencreutz and M. Jacobsson, *Dimensionering av underhållspersonal med hjälp av simulering*. Advisor: P. O. Lindberg. Performed at Televerket, Farsta.

J. Hedin, *Transportuppläggning: Optimering av lastbyten vid lastbilstransport*. Advisor: K. Svanberg. Performed at Transportforskningskommissionen.

S. Ho, *Studie av olika förbättringsförslag för materieltillförseln på SAAB-SCANIA:s schassiverkstad*. Advisor: K. Svanberg. Performed at SAAB-SCANIA, Södertälje.

J. Malmborg, *En matematisk modell för influenzaspridning i Sverige*. Advisor: T. Björk.

M. Malmström, *Optimeringsmodell för reservvägsallokering i DCC-nät*. Advisor: K. Svanberg. Performed at Ericsson Telecom.

A. Remmereit och H. Ring, *Dimensioneringsmodeller och nätstrukturer för SS7-nät*. Advisor: K. Svanberg. Performed at Ericsson Telecom.

4 Publications

4.1 Published (and accepted) papers

4.1.1 Published (and accepted) papers in Systems and Control

C. I. Byrnes and A. Lindquist, *On the geometry of the Kimura - Georgiou parameterization of modelling filters*, Intern. J. Control 50 (1989), 2301 - 2312.

C. I. Byrnes, A. Lindquist and T. McGregor, *Predictability and unpredictability in Kalman filtering*, IEEE Trans. Automatic Control (1990), to be published.

C. I. Byrnes, A. Lindquist and Y. Zhou, *Stable, unstable and center manifolds for fast filtering algorithms*, To be published in Birkhäuser's series Systems & Control.

X. Hu, *Asymptotic tracking with stability in the large for a planar nonlinear system*, To be published by Birkhäuser, Boston.

A. Isidori and C. I. Byrnes, *Output regulation of nonlinear systems*, IEEE Trans. Automatic Control AC-35 (1990), 131 - 140.

A. Lindquist, *Linear Stochastic Systems by P. Caines, John Wiley ,1988*, review article in SIAM Review 32(1990), 325 - 328.

A. Lindquist and G. Picci, *Stochastic realization and the local structure of the Riccati inequality*, in The Riccati Equation in Control, Systems, and Signals, S. Bittanti, ed. Pitagora Editrice Bolonga, 1989, 69-72.

A. Lindquist and G. Picci, *On noncausal estimation, stochastic realization and the Riccati inequality*, Proc. of 28 IEEE Conference on Decision and Control, Tampa, 1989.

A. Rantzer, *Equivalence between stability of partial realizations and feedback stabilization – Applications to reduced order stabilization*, Linear Algebra and its Applications 124 (1989), 641-653.

A. Rantzer, *Hurwitz testing sets for parallel polytopes of polynomials*, Systems & Control Letters 15 (1990), 99-104.

A. Rantzer, *A finite zero exclusion principle*, Proc. of the International Symposium MTNS-89, Birkhäuser, Boston, 1990.

4.1.2 Published (and accepted) papers in Mathematical Programming

A. Eriksson and P. O. Lindberg, *Stochastic equilibrium concepts in additive random utility models*, Papers of Regional Science Association 66(1989), 123-130.

A. Forsgren, P. E. Gill and W. Murray, *On the identification of local minimizers in inertia-controlling methods for quadratic programming*, Accepted for publication in SIAM Journal on Matrix Analysis and Applications.

P. O. Lindberg and P. Butovitsch, *Classification capability of the two-layer perceptron*, Proceedings of Int. Neural Network Conference, Paris, 1990.

P. O. Lindberg and T. Magnusson, *The unit commitment problem: a dual approach*, Proc. of 28 IEEE Conference on Decision and Control, Tampa, 1989.

K. Svanberg, *Optimal truss sizing based on explicit Taylor series expansions*, Accepted for publication in Structural Optimization.

4.2 Technical reports and preprints

4.2.1 Technical reports and preprints in Systems and Control

Cladio G. Baril and Per-Olof Gutman, *Performance related adaptive friction compensation for uncertain systems*, Submitted for publication.

C. I. Byrnes, A. Lindquist and Y. Zhou, *On the nonlinear dynamics of Kalman filtering*, Preprint.

C. I. Byrnes and X. Hu, *The zero dynamics approach for general nonlinear systems*, Preprint.

C. I. Byrnes, X. Hu and A. Isidori, *Output tracking with stability on compacta for nonlinear systems*, Preprint.

P. A. Fuhrmann, *A polynomial approach to Hankel norm and balanced realizations*, To be published in Linear Algebra and Applications.

X. Hu, *Output feedback stabilization of nonlinear systems in the large*, Submitted to SIAM Journal on Control and Optimization.

X. Hu and Y. F. Zheng, *Local disturbance decoupling problem with stability for nonlinear systems*, Preprint.

A. Lindquist and G. Picci, *A geometric approach to modeling and estimation of linear stochastic systems*, Preprint, 81 pages.

4.2.2 Technical reports and preprints in Mathematical Programming

A. Eriksson and P. O. Lindberg, *Equilibria in additive random utility models*, Submitted to Regional Science and Urban Economics, TRITA-MAT-1987-10.

A. Eriksson, P. O. Lindberg and L. G. Mattsson, *Generalized extreme value choice models and the invariance property*, Submitted to Environment and Planning.

A. L. Forsgren, P. E. Gill and W. Murray, *A modified Newton method for unconstrained minimization*, Report SOL 89-12, Department of Operations Research, Stanford University, 1989. Submitted to SIAM Journal on Scientific and Statistical Computing.

A. L. Forsgren and W. Murray, *Newton methods for large-scale linear equality-constrained minimization*, Report SOL 90-6, Department of Operations Research, Stanford University, 1990. Submitted to SIAM Journal on Matrix Analysis and Applications.

P. O. Lindberg, *A note on functional dependence*, Report TRITA-MAT-1990-16, Department of Mathematics, KTH, 1990.

P. O. Lindberg and T. Abrahamsson, *A note on network related optimization*, Report TRITA-MAT-1990-17, Department of Mathematics,KTH, 1990.

P. O. Lindberg and K. Falk-Skogh, *Repair facility location in a repairable item inventory system*, Report TRITA-MAT-1990-18, Department of Mathematics, KTH, 1990.

P. O. Lindberg and B. Olin, *Almost sure lower bounds in random assignment problems*, Report TRITA-MAT-1990-19, Department of Mathematics, KTH, 1990.

P. O. Lindberg and O. Viera, *Optimal water usage in a water power station*, Report TRITA-MAT-1990-20. Department of Mathematics, KTH, 1990.

P. O. Lindberg, *A theoretical model for the efficiency of the stochastic simplex method*, Report TRITA-MAT-1990-21, Department of Mathematics, KTH, 1990.

P. O. Lindberg, *Optimal (s,S)-policies for inventories with random lead times*, Report TRITA-MAT-1990-22, Department of Mathematics, KTH,1990.

5 Awards

Anders Lindquist was named Fellow of the IEEE (Institute of Electrical and Electronics Engineers). Diploma was awarded at the 28th IEEE Conference on Decision and Control, Tampa, Florida, USA, December 1989. Citation: *For contributions to filtering and estimation, stochastic control, and stochastic systems theory.*

Anders Rantzer was given "SIAM Best Student Paper Award" at the SIAM 1990 Annual Meeting, Chicago, USA.

6 Presentations by staff

T. Björk, *Adaptive prediction*, Linköpings Universitet, April 1990.

A. Eriksson, P. O. Lindberg and L. G. Mattsson, *Generalized extreme value choice models and the invariance property*, The 29th European Congress of the Regional Science Association, August 1989.

A. L. Forsgren, P. E. Gill and W. Murray, *A modified Newton method for unconstrained minimization*, The SIAM 1989 Annual Meeting, July 17-21 1989, San Diego, USA.

A. Forsgren, *Newton Methods for Nonconvex Optimization*, Linköpings Universitet, May 1990.

A. Forsgren, *Newton Methods for Nonconvex Optimization*, Umeå Universitet, May 1990.

A. L. Forsgren, P. E. Gill and W. Murray, *On the role of matrix inertia in second-derivative methods for numerical optimization*, The XI Householder Symposium, Tylösand, Sweden, June 18-22 1990.

P. O. Lindberg, *Översikt av optimering och optimeringslaboratorium*, ABB Network Control, October 1989.

P. O. Lindberg, *Network related optimization*, University of Florida, USA, December 1989.

P. O. Lindberg and T. Magnusson, *The unit commitment problem: a dual approach*, The 28 IEEE Conference on Decision and Control, Tampa, December 1989.

P. O. Lindberg, *Inventory control with stochastic lead times*, University of Florida, USA, December 1989.

P. O. Lindberg and P. Butovitsch, *Classification capability of the two-layer perceptron*, Int. Neural Network Conference, Paris, 1990.

P. O. Lindberg and T. Magnusson, *The unit commitment problem: A dual approach*, ECMI-90, Lahti, Finland, June 1990.

P. O. Lindberg, *Survey of current research in optimization at KTH*, The 1st Stockholm Optimization Day, KTH, June 7 1990.

A. Lindquist, , Workshop on Modelling and Inverse Problems of Control for Distributed Systems, Vienna, Austria, July 24 - 28, 1989. Invited speaker.

A. Lindquist and G. Picci, *On noncausal estimation, stochastic realization and the Riccati inequality*, The 28 IEEE Conference on Decision and Control, Tampa, December 1989.

A. Lindquist, *On the partial realization problem*, LADSEB-CNR, Padova, Italien, February 21 1990.

A. Lindquist, *En geometrisk teori för stokastisk realisation*, Teknikum, Uppsala, March 14 1990.

A. Lindquist, *On the nonlinear dynamics of Kalman filtering*, INRIA, Paris, June 19 1990.

A. Lindquist, *On the nonlinear dynamics of Kalman filtering*, The SIAM 1990 Annual Meeting, July 16-20 1990. Invited speaker.

A. Lindquist, *A review of fast algorithms for Kalman filtering*, Washington Univ. St Louis, July 19 1990.

A. Lindquist, *On the nonlinear dynamics of Kalman filtering*, Washington Univ. St Louis, July 20 1990.

A. Lindquist, *A geometric state space theory for modeling of stationary time series*, International Interdisciplinary Workshop on Modern Directions in Time Series Analysis (sponsored by the Institute of Mathematics and its Applications), University of Minnesota, July 1990. Invited Plenary Speaker.

A. Lindquist, *On the nonlinear dynamics of Kalman filtering*, Second Conference on Computation and Control, Bozeman, Montana, August 1 - 11, 1990. Invited plenary speaker.

A. Lindquist, *Geometric theory of linear stochastic systems*, The 11th World Congress of IFAC, Tallinn, Estonia, August 13 - 17, 1990. Invited speaker.

A. Rantzer, *Minimal testing sets: A generalization of Kharitonov's theorem, Maximizing the singular value over frequency*, New Trends in Systems Theory, Genua, Italy, July 9–11 1990.

A. Rantzer, *Zero locations of polytopes of polynomials*, The SIAM 1990 Annual Meeting, July 16-20 1990. Award presentation of paper awarded "SIAM Best Student Paper Award".

K. Svanberg, *MMA - A Mathematical Programming Method for Structural Optimization*, The 1st Stockholm Optimization Day, KTH, June 7 1990.

Y. Zhou, *Predictability and unpredictability in Kalman filtering*, LADSEB-CNR, Padova, Italy, July 1989.

7 Stockholm Optimization Day

The 1st Stockholm Optimization Day was held at KTH on June 7, 1990. It was a one-day conference where the following talks were given:

Robert Freund, Massachusetts Institute of Technology.
Newton's Method for Parametric Center Problems.

Don Hearn, University of Florida at Gainesville.
Generalized Linear Programming with Line Searches.

Per Olov Lindberg, The Royal Institute of Technology.
Survey of Current Research in Optimization at KTH.

Athanasios Migdalas, Linköping Institute of Technology.
Regularization of the Frank-Wolfe Method.

Walter Murray, Stanford University.
The Solution of Certain Linear Equations That Arise in Methods for Optimization.

Ulf Ringertz, The Aeronautical Research Institute of Sweden.
Optimal Design of Aircraft Structures.

Krister Svanberg, The Royal Institute of Technology.
MMA - A Mathematical Programming Method for Structural Optimization.

Philippe Toint, Facultés Universitaires ND de la Paix.
An introduction to the structure of large scale nonlinear optimization problems and the LANCELOT project.

The conference was organized by P. O. Lindberg and financially supported by the Swedish National Board for Technical Development (STU).

8 Seminars at the division

Sept. 13, 1989 Sept. 15, 1989	Professor Paul Fuhrmann, Ben-Gurion University of the Negev, Ber-Sheva, Israel. *Hankel norms and balanced approximations.*
Sept. 27, 1989	Docent Per-Olof Gutman, Technion-Israel Institute of Technology, Haifa and Israel Electro-Optical Industry, Rehovot. *Control of uncertain systems with nondifferentiable nonlinearities - a survey.*
Oct. 13, 1989	Dr. Xiaoming Hu, Optimization and Systems Theory, KTH. *Nonlinear control theory and the zero dynamics approach.*
Oct. 18, 1989	Professor Masanao Aoki, University of California, Los Angeles. *Instrumental variable interpretations of stochastic realization of state space models.*
Nov. 3, 1989	Högskolelektor Lars Svensson, Matematiska Institutionen, KTH. *Gröbner bases and their use.*
Nov. 22, 1989	Professor Thomas L. Magnanti, Sloan School of Management and Operations Research Center, MIT. Currently Visiting CORE, Louvain-la-Neuve. *Recent advances in network design.*
Jan. 12, 1990	Professor Walter Murray, Stanford University. *Barrier methods for optimization.*
Jan. 19, 1990	Högskolelektor Peter Värbrand, Linköpings Tekniska Högskola. *Solving large scale generalized assignment problems - aggregation/disaggregation approach.*
Jan. 26, 1990	Tekn.lic. Anders Rantzer, Optimization and Systems Theory, KTH. *Stability and pole placement of uncertain systems.*
Feb. 2, 1990	Professor C.I. Byrnes, Washington University, St Louis, and Royal Institute of Technology. *Dissipative, positive real, and minimum phase nonlinear systems.*
Feb. 16, 1990	Professor Israel Gohberg, University of Tel Aviv and Free University, Amsterdam. *Interpolation problems for rational matrix functions.*
Feb. 23, 1990	Professor T. J. Tarn, Washington University, St Louis, U.S.A. *A canonical dynamic extension for noninteraction with stability for affine nonlinear systems.*

May 4, 1990	Professor Christopher I. Byrnes, Washington University, St. Louis, and Royal Institute of Technology, Stockholm. *Some partial differential equations arising in nonlinear feedback design.*
May 18, 1990	Anders Forsgren, Optimization and Systems Theory, KTH. *Newton methods for nonconvex optimization.*
May 23, 1990	Hoang Tuy, Institute of Mathematics, Hanoi. *Recent developments in global optimization.*
June 1, 1990 June 6, 1990	Professor Robert Freund, MIT, Cambridge, U.S.A. *Interior point algorithms.*
June 6, 1990	Professor Philippe Toint, Faculte Universitaire Notre Dame de la Paix, Namur, Belgium. *A proposal for a standard input format for nonlinear optimization problems.*

9 Economic support

Financial support to the division during the academic year 1989/1990. The numbers shown are given in thousands of SEK.

Finansering	Åtestår fr tid bå	Anslag 89/90	Användning Personal	Utrustn	Förbr mtrl	Övrigt
Grundutbildningsanslag	0	1310	1220	25	50	40
Fakultetsanslag	0	1400	1200	50	50	100
STU-projekt totalt	308	1392	976	0	72	178
FMV	0	140	0	0	0	0
FOA	0	60	60	0	0	0
Vattenfall	0	140	140	0	0	0
Göran Gustafssons Stiftelse	143	250	104	216	0	0

10 Other activities

Tomas Björk

- Director of Undergraduate Studies (studierektor) in Optimization and Systems Theory.
- Refereed one paper for Scandinavian Actuarial Journal.
- Refereed one paper for Manuscripta Geodaetica.

Ulf Brännlund

- Attended the IBM Europe Conference on Optimization, July 3–7 1989, Garmich Partenkirchen, Germany.

Anders Forsgren

- Refereed one paper for SIAM Journal on Scientific and Statistical Computing.

Xiaoming Hu

- Refereed one paper for IFAC conference in Tallinn.

Torbjörn Magnusson

- Member of cooperation group 'Power Systems Optimization', ECMI

P. O. Lindberg

- Nominated Adjunct Professor in Industrial and Systems Engineering, University of Florida at Gainesville, USA.
- Member of Board of Undergraduate Education in School of Applied Mechanics (linjenämnden T)
- Organizer of the 1st Stockholm Optimization Day, June 7 1990.
- Reviewer for appointment of associate professor at Naval Postgraduate School.
- Reviewer for appointment of position with tenure at MIT.
- Reviewer for appointment of högskolelektorat, LiTH.
- Refereed papers for European Journal of Operational Research.

Anders Lindquist

- Regional Editor, Mathematical Systems, Estimation and Control, journal published by Birkhäuser.
- Associate Editor, Systems and Control Letters, journal published by North-Holland.
- Associate Editor, Progress in Systems and Control Theory, book series published by Birkhäuser, Boston.
- Associate Editor, Systems and Control: Foundations and Applications, book series published by Birkhäuser, Boston.
- Affiliate Professor, Washington University, St Louis, USA.
- Vice Chairman of Board of Academic Appointments for the School of Engineering Physics (tjänsteförslagsnämnden för teknisk fysik).
- Member of Board of Research and Graduate Studies for the School of Engineering Physics (sektionsnämnden för teknisk fysik).
- International Board of Advisors, Second SIAM Conference on Linear Algebra in Signals, Systems and Control, San Francisco, November 1990.
- Steering Committee, International Symposium on the Mathematical Theory of Networks and Systems (MTNS).

- Member, International IFAC Committee for Mathematics in Control
- Organizing Committee, Pre-Conference to MTNS-91, Hangzhou, China, June 12–14 1991.
- Organizer of an Invited Minisymposium for the Second SIAM Conference on Linear Algebra in Signals, Systems and Control, San Francisco, November 5–7 1990.

Anders Rantzer

- Refereed three papers for Systems & Control Letters.
- Refereed three papers for IEEE Transactions of Automatic Control.
- Refereed one paper for Linear Algebra and its Applications.

Krister Svanberg

- Member of Board of Undergraduate Education for the School of Engineering Physics (linjenämnden fö teknisk fysik)
- Refereed two papers for Journal for Numerical Methods in Engineering.
- Refereed two papers for Structural Optimization.

Yishao Zhou

- Paper review for IFAC 11th World Congress, Tallinn '90.