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

Activity Report

1992/1993

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The division of Optimization and Systems Theory is part of the Department of Mathematics at the Royal Institute of Technology. This report summarizes the activities at this division during the academic year 1992/1993 (July 1992 – June 1993).

Optimization and Systems Theory is a discipline in Applied Mathematics primarily devoted to mathematical programming, optimal control theory, and systems theoretic aspects of control and signal processing. In addition, attention is also given to mathematical economics and more applied problems in operations research, systems engineering and control engineering.

Research performed at the division of Optimization and Systems Theory includes various topics in mathematical systems theory, with particular emphasis on stochastic systems, matrix Riccati equations, and robust and nonlinear control; dual optimization methods, with applications to crew and vehicle scheduling, large scale optimization and power planning; structural optimization; and nonlinear programming. The division also has an Optimization Laboratory devoted to collecting state-of-the-art optimization routines, making them available to research institutions and industry. For ease of reference, in this activity report research projects as well as publications are reported either under the heading of *Systems and Control* or under the heading of *Mathematical Programming.*

The division of Optimization and Systems Theory offers undergraduate courses in mathematical programming, mathematical systems theory, optimal control and calculus of variations, mathematical economics, as well as various topics in operations research and modeling. There is an active graduate program. During the academic year of 1992/93 three doctoral degrees in Optimization and Systems Theory were awarded. One person has been appointed to the position of Docent.

A regular *Optimization and Systems Theory Seminar* has been running weekly. In addition, more tutorial and informal seminars in mathematical programming and systems and control have been running.

For the third time, the *Gustafsson Postdoctoral Fellowship* has been awarded to a person to be stationed at the division of Optimization and Systems Theory.

Contents

1 Personnel

1.1 List of personnel

Professor (Professor)

Anders Lindquist, TeknD, docent

Docenter, högskolelektorer (Associate professors)

P. O. Lindberg, TeknD, docent
Krister Svanberg, TeknD, docent

Högskolelektor (Senior lecturer)

Tomas Björk, FD Director of undergraduate studies

Forskarassistent (Research associate)

Anders Forsgren, TeknD

Förste forskningsingenjörer (Researchers)

Xiaoming Hu, PhD
Anders Rantzer, TeknD (on leave from September 1992)

Postdoktorstipendiat (Postdoctoral fellow)

Alexandre Megretski, PhD (until September 1992)

Gästforskare (Guest researchers)

Claudio Baril, PhD (from June 1993)
Per-Olof Gutman, TeknD, docent

Intendent (Administrator)

Leena Druck

Doktorander (Graduate students)

Patrik Alfredsson, civing
Ove Bergkvist, civing
Ulf Brännlund, civing, MS (graduated (TeknD) April 1993)
Stefan Feltenmark, civing
Martin Hagström, civing
Jorge Mari, MS
Mattias Nordin, civing
Andreas Nöu, civing
Birgitta Olin, civing, TeknL (graduated (TeknD) June 1993)
Jan-Åke Sand, civing, TeknL
Omar Viera, civing
Yishao Zhou, MS (graduated (TeknD) January 1993)

1.2 Biographies

[0,l,[width=30mm]was born in Södertälje, Sweden, in 1967. He received a civilingenjör degree in Engineering Physics from KTH in 1991. His main research interests are systems engineering and systems efficiency, concentrated on spare parts optimization problems.,] **Patrik Alfredsson**

[0,l,[width=30mm]was born in Bahia Blanca, Argentina, on July 5, 1960. He received the Diploma in electrical engineering from the National University of the South, Bahia Blanca, Argentina. He received the M.Sc. and D.Sc. degrees from the Technion, Israel Institute of Technology, Haifa, Israel. His main research interests are robust control and nonlinear control theory, and their application to the design of feedback systems.,] **Claudio Baril**

[0,l,[width=30mm]was born in Stockholm, Sweden, in 1968. He received a civilingenjör degree in Engineering Physics from KTH in 1991. During the academic year 1992/1993 he was a doctorate student at the Division of Optimization and Systems Theory. Since July 1993 he is employed by Ericsson Radio Systems AB.,] **Ove Bergkvist**

Tomas Björk was born in Fagersta, Sweden, in 1947. He received 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 Senior 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.

[0,l,[width=30mm]was born in 1961. He received a civilingenjör degree in Aeronautical Engineering from KTH in 1986 and an MS degree in Engineering-Economic Systems from Stanford University in 1988 and his doctorate degree from KTH in 1993. His main research interests are nondifferentiable optimization and production planning problems.,] **Ulf Brännlund**

[0,l,[width=30mm]is the administrator at the Division of Optimization and Systems Theory since 1992.,] **Leena Druck**

[0,l,[width=30mm]was born in Boden in 1968. He received a civilingenjör degree in Engineering Physics from KTH in 1991. He is presently a PhD student at the Division of Optimization and Systems Theory. Main research interests are dual methods for large-scaled problems, particularly applied to short-term power production planning problems.,] **Stefan Feltenmark**

[0,l,[width=30mm]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. Since 1991, he is a research associate at the Division of Optimization and Systems Theory. His main research interest is nonlinear programming.,] **Anders Forsgren**

Per-Olof Gutman was born in Höganäs, Sweden on May 21, 1949. He received the Civ.-Ing. degree in engineering physics in 1973, the Ph.D. degree in automatic control, and the title of docent in automatic control in 1988, all from the Lund Institute of Technology, Lund, Sweden. As a Fulbright grant recipient, he received the M.S.E. degree in 1977 from the University of California, Los Angeles.

He taught mathematics in Tanzania 1973-1975. 1983-1984 he held a post-doctoral position with the Faculty of Electrical Engineering, Technion - Israel Institute of Technology, Haifa, Israel. 1984-1990 he was a scientist with the Control Systems Section, El-Op Electro-Optics Industries, Rehovot, Israel, where he designed high precision electro-optical and electro-mechanical control systems. Since 1990 he holds the position of Senior Lecturer with the Faculty of Agricultural Engineering, Technion, Haifa. He has spent several periods as a guest researcher at the Division of Optimization an Systems Theory, Royal Institute of Technology, Stockholm, Sweden.

His research interest include robust and adaptive control, control of non-linear systems, computer aided design and control of agricultural systems.

[0,l,[width=30mm]was born in Stockholm in 1963. He received a civilinjenjör degree in Aeronautical Science at KTH in 1988. His main research interest is nonlinear dynamics of filtering algorithms and stochastic realization theory and its applications.,] **Martin Hagström**

Xiaoming Hu was born in Chengdu, China, in 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, the analysis and design of nonlinear feedback systems and the applications of nonlinear dynamics in control and state estimation.

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.

Lindberg is on the editorial board of Computational Optimization and Applications.

Lindberg's 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 four for a Licentiate Degree. Furthermore he has guided well over 100 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 of Optimization and Systems Theory 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 (full) 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 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 Communicating Editor of the *Journal of Mathematical Systems, Estimation, and Control* (published by Birkhäuser Boston) and, until 1993, an Associate Editor of *Systems and Control Letters* (North-Holland). He also serves on the editorial boards of *Adaptive Control and Signal Processing* (John Wiley & Sons) and of the two book series *Systems and Control: Foundations and Applications* and *Progress in Systems and Control* (Birkhäuser Boston). Since 1983 he has been a member, and between 1985 and 1987 the chairman, of the steering committee for the biannual international symposia on the Mathematical Theory of Networks and Systems (MTNS).

Jorge Mari was born in 1966. He graduated as Electronics Engineer at the Engineering Faculty of Montevideo in 1992 and has also studied Mathematics at the Faculty of Sciences. He has been mathematics assistant professor from 1988 to 1992 and has also worked as project designer in power supply systems for ANTEL. He has been working since late 1992 in applied optimal control to fermentation processes. He is presently a PhD student at Optimization and Systems Theory, at KTH. His main interests include power electronics, electrical machines, computer controlled systems, optimization, dynamical systems and control theory.

Alexandre Megretski was born in Leningrad, USSR in 1963. He graduated from Leningrad University in 1985 and received a Ph.D. from there in 1988. Since then he is a research associate at the Laboratory of Theoretical Cybernetics, Leningrad (St. Petersburg) University. In 1990 he was awarded the Mittag-Leffler Institute Postdoctoral Fellowship, and in 1991 he was awarded a Göran Gustafsson Postdoctoral Fellowship to enable him to spend a year at the Division of Optimization and Systems Theory. Recently Alexandre Megretski became an Assistant Professor at the department of Electrical Engineering and Computer Engineering, Iowa State University, USA. His main research interests are robust control, Hankel operators, 2D optimal filtering, Riccati equations.

[0,l,[width=30mm]was born in Lund, Sweden, in 1967. He received a civilinjenjör degree in Engineering Physics from KTH in 1992. He is presently a PhD student at the Division of Optimization and Systems Theory. His main research interests are robust control and systems theory. At the moment he is studying the effect of backlash in control of electrical drives.,] **Mattias Nordin**

[0,l,[width=30mm]was born in Stockholm in 1967. He received a civilingenjör degree in Engineering Physics from KTH in 1991. He is presently a PhD student at the Division of Optimization and Systems Theory. His main research interests are dual methods in connection to Crew and Vehicle Scheduling.,] **Andreas Nöu**

[0,l,[width=30mm]was born in 1960 in Stockholm, Sweden. She received a civilingenjör degree in Engineering Physics from KTH in 1985, a TeknL degree in Optimization and Systems Theory from KTH in 1990 and a TeknD degree in Optimization and Systems Theory from KTH in 1993. Since July 1993, she is employed by Ericsson Telecom AB.,] **Birgitta Olin**

Anders Rantzer was born in 1963. He has a civ.ing. (MSc) degree (1987) in Engineering Physics, a Tekn.Lic. (1989) in Mathematics, both from Lund University and a PhD (1991) in Optimization and Systems Theory from KTH. He has spent the academic year 1992/93 as a postdoctoral fellow at Institute for Mathematics and its Applications (IMA), Univ. of Minnesota. His research is mainly devoted to analysis and synthesis of robust and adaptive control systems and to related problems in linear algebra and optimization theory.

[0,l,[width=30mm]was born in 1964 in Stockholm. He received the civilingenjör degree in Engineering Physics from KTH in 1988 and the TeknL degree in Optimization and Systems Theory from KTH in 1992. He is now a PhD student at the Division of Optimization and Systems Theory at KTH. His main research interest is in Stochastic Systems.,] **Jan-Åke Sand**

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. In 1993 he was appointed Docent. Between 1976 and 1985 he held a position as Research Associate with the Contract Research Group of Applied Mathematics at KTH, and since 1985 he is a Senior Lecturer of Optimization and Systems Theory. His main area of research is structural optimization, in which area he has kept scientific contacts with such industrial companies as SAAB and VOLVO.

[0,l,[width=30mm]was born in 1953 in Montevideo, Uruguay. He received his degree in Engineering Physics at KTH in 1992. His main research interest is nonlinear programming, in particular energy applications.,] **Omar Viera**

[0,l,[width=30mm]was born in Shanghai in 1959. She received BS and MS degrees in mathematics in 1982 and 1984 respectively. Both are from Fudan University, Shanghai. In 1993 she received a TeknD degree from KTH. From 1984 to 1987 she worked at the Department of Applied Mathematics of East China University of Chemical Technology, Shanghai. Her main research interests are the matrix Riccati equation, Kalman filtering, nonlinear dynamical systems and its applications in control and estimation and behavioral approach to systems theory.,] **Yishao Zhou**

1.3 Visiting and interacting scientists

- Professor Christopher I. Byrnes, Department of Systems Science and Mathematics, Washington University, St. Louis, Missouri, USA
- Dr. Anders E. Eriksson, Swedish Defense Research Establishment, Stockholm, Sweden
- Professor Philip E. Gill, Department of Mathematics, University of California at San Diego, La Jolla, California, USA
- Professor Donald W. Hearn, Department of Industrial and Systems Engineering, University of Florida, Gainesville, Florida, USA
- Dr. Björn Johansson, Department of Mathematical Statistics, University of Stockholm, Stockholm, Sweden
- Professor Krzystof C. Kiwiel, Systems Research Institute, Warsaw, Poland
- Professor Bernard C. Levy, Department of Electrical Engineering, University of California at Davis, California, USA
- Docent Lars-Göran Mattsson, Department of Regional Planning, KTH, Stockholm, Sweden
- Professor György Michaletzky, Department of Probability Theory and Statistics, Eötvös Lorand University, Budapest, Hungary
- Professor Walter Murray, Department of Operations Research, Stanford University, Stanford, California, USA
- Professor Giorgio Picci, Department of Electronics and Informatics, University of Padova, Padova, Italy
- Professor Alfredo Piria, Department of Mathematics, Facultad de Ingeneria, University Montevideo, Montevideo, Uruguay
- Dr. Ulf Ringertz, Deparment of Lightweight Structures, KTH, Stockholm, Sweden
- Professor Vladimir A. Yakubovich, Department of Mathematics, St. Petersburg University, St. Petersburg, Russia

2 Research

2.1 List of projects

2.1.1 List of projects in Systems and Control

- Acausal realization theory.
- Adaptive prediction and parameter identification.
- Estimation of lost state information in linear stochastic systems.
- Experimental optimization with biotechnical applications.
- Feedback stabilization and output regulation of nonlinear systems.
- Geometry of the discrete-time algebraic Riccati equation.
- Linear stochastic systems theory.
- On the nonlinear dynamics of Kalman filtering.
- Robust control of electrical drives.
- Stochastic realizations and geometric control theory – a synthesis.
- Stochastic realization theory and identification.
- The minimal rational covariance extension problem.

2.1.2 List of projects in Mathematical Programming

- Advanced optimization methods for crew and vehicle scheduling.
- Allocation of scarce track capacity.
- Dual methods for large scale optimization problems.
- Dual methods for short term power planning problems.
- Dual methods for the unit commitment problem.
- KTH Optimization Laboratory.
- Methods for structured dual problems.
- Optimal expansion strategies for transport networks.
- Optimal water flow through a hydro power station.
- 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.
- Structural optimization.

2.2 Description of projects

2.2.1 Description of projects in Systems and Control

Acausal realization theory

Researcher: Jan-Åke Sand (Anders Lindquist; advisor).

Stochastic models of random phenomena that are spatially distributed are useful in many areas of applications, such as image analysis and computer vision. We study stochastic processes defined on the two-dimensional integer lattice, and the problem of modeling such processes as outputs of Markov random fields. In particular, we analyze observability and minimality of such models, see e.g. [A22].

In cooperation with Bernard Levy at UC Davis we study a problem of optimal acausal interpolation and reconstruction of a stationary time series. The problem is believed to have great significance to the area of linear predictive data compression and transmission.

Adaptive prediction and parameter identification

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

The goal of this project is to build a theory of parameter identification for a fairly general class of semimartingales, but up to now we have confined ourselves to diffusions and point processes. We have studied the existence of unbiased parameter estimators (and their asymptotic properties), as well as the existence of asymptotically consistent parameter estimators. Based on earlier work on adaptive prediction [A1], we have shown that unbiased parameter estimation can be seen as a limiting case of adaptive prediction, a fact which leads to interesting connections between unbiased estimators and reverse martingales. We have also shown that the existence of an unbiased parameter estimate is equivalent to the existence of a solution to an inverse (ill posed) parabolic boundary value problem. The whole theory is based on so called prediction sufficient processes, and presently we are working on finite dimensional representations of asymptotically sufficient tail-σ-algebras.

Estimation of lost state information in linear stochastic systems

Researchers: Anders Lindquist, in cooperation with Gy. Michaletzky (Eötvös Lorand University, Budapest).

Sponsors: The Swedish Research Council for Engineering Sciences (TFR) and the Göran Gustafsson Foundation.

The geometric theory of stochastic realization described in the project *Linear stochastic systems* with its symmetry under reversal of time is a very natural tool for the analysis of noncausal estimation problems. A case in point is the smoothing problem, earlier studied by Badawi, Lindquist and Pavon, which is very naturally cast in this framework, and also the noncausal estimation problem used as mathematical devise by Lindquist and Picci.

Now, consider a linear stochastic system where both the state process and the output process is observed, but there is a "black out" of state information during a finite interval of time. The problem considered in [R4] is to reconstruct the lost state information from the remaining observations. This is precisely a problem of the type described above. It corresponds to the smoothing problem or the noncausal estimation problem with the important difference that the estimate becomes a linear combination of noninternal states rather than internal states. This gives a systems theoretical interpretation to *each* minimal stochastic realization akin to that of a minimum-phase solution in the classical theory. When the interval with the lost information grows, this pair of realizations converge to "the tightest internal bounds".

Experimental optimization with biotechnical applications

Researchers: P. O. Lindberg and Jorge Mari.

Sponsors: The Swedish National Board for Industrial and Technical Development (NUTEK) and Kabi-Pharmacia AB.

Industrial contacts: Kabi-Pharmacia AB.

This is a project which tries to apply modern mathematical tools to the understanding of some biotechnical processes. Specifically we have been working with the optimization of fermentation processes, with modeling assessment and computer simulations related to the problem. Modelling of these type of processes is difficult because of the underlying biological nature. Uncertain descriptions are common and complicate the subsequent control studies. We now mention some aspects that have been faced. First, models are usually nonlinear, hence, the nice linear-theoretic results are not of immediate application. Numerically, the differential equations handled turn out to be stiff. So after many trials and failures stiff integrators are currently being used. As a prerequisite scalings and transformations have proved to be fundamental in speeding up simulations and achieving accuracy. The nature of the optimal control problems posed is such that singular solutions are common. Thus, unless desingularizing techniques are applied, many theoretical conditions found in the literature for the search of solutions are not satisfied. To make matters worse, models deduced from flow-type reactors under steady state conditions are usually deficient when handling transients in fed-batch reactors. Specifically, we have faced discontinuous right hand sides. Despite these difficulties, we have achieved some interesting results by the application of Hilbert space conjugate gradient optimization algorithms. A natural extension is the application of Newton-type methods, but, the mentioned difficulties, don't allow for straightforward conversion. In particular we would have to solve a generalized type of time varying differential matrix Riccati equations, and here software becomes a major issue as well.

Feedback stabilization and output regulation of nonlinear systems

Researchers: Xiaoming Hu, in cooperation with C. I. Byrnes (Washington University, St. Louis).

Sponsor: The Swedish Research Council for Engineering Sciences (TFR).

The aim of this project is to solve the problems of feedback stabilization and output regulation for nonlinear control systems in any given compact region of initial data. During the period we have obtained some interesting results, see, for example, in [A3], [A9] and [A11]. These results can be summarized as follows. We have proposed some new control laws which solve the problems of output tracking and stabilization on compacta even for some globally nonminimum phase systems, by using both Liapunov approach and an invariant manifold approach. We have also studied the problem of stabilization of planar systems by analytic feedback control laws. This problem has been studied by many researchers. Solving this problem would help us significantly in understanding the problem of feedback stabilization for highly critical nonlinear control systems(where the center manifold approach will not work). Our work has extended the existing results. During the period we have also completed (at least for the time being) our research in exact tracking through singular points. By using mathematical tools such as convex analysis, viability theory, and semialgebraic sets, we have been able to give a fairly complete and satisfactory answer to a "rather difficult and potentially messy" problem. At the same time, we have generalized the zero dynamics algorithm to nonaffine nonlinear control systems.

Geometry of the discrete-time algebraic Riccati equation

Researcher: Yishao Zhou (Anders Lindquist; advisor).

Sponsor: The Swedish Research Council for Engineering Sciences (TFR).

The matrix Riccati equation plays an important role in a wide variety of applications, e.g. the theory of stochastic processes, optimal control and filtering, network theory, digital control and H^{∞}-control. It is also of independent mathematical interest, because the Riccati equation arises when the power iterates are considered in the canonical charts of the Grassmann manifold. There is therefore a considerable amount of control theory literature devoted to the study of Riccati equations. The purpose of this project is to generalize some of the known results for the continuous-time algebraic Riccati equation to its discrete-time counterpart. The discrete-time Riccati equation appears in applications both through sampling of continuous-time models and in discrete implementations. A good knowledge of this equation is therefore important especially since it may, in some cases, exhibit a completely different dynamical behavior than its continuous-time counterpart. As many researchers have noticed, it is not at all trivial to carry over results for the continuous-time Riccati equation to the discrete-time setting, since many such results only exist in a weaker form in the discrete-time case. A clear understanding of the structure of the solution set of the discrete-time algebraic Riccati equation will be important in the study of the phase portrait of the corresponding Riccati difference equation and in developing numerical methods. In the single input or single output case, we are able to describe the structure of this solution set for an algebraic Riccati equation of more general form, both at a set-theoretic and a topological level. As in the (continuous-time) work by Lindquist and Picci, the geometry of the solution set is connected to the results on zeros of spectral factors, and, for example, the results on the "tightest local frame" can be generalized to the discrete-time case.

Linear stochastic systems theory

Researchers: Anders Lindquist, in cooperation with Giorgio Picci (University of Padova).

Sponsors: The Swedish Research Council for Engineering Sciences (TFR) and the Göran Gustafsson Foundation.

A comprehensive theory for state-space modelling of vector-valued (stationary and stationary-increment) stochastic processes has been developed within the framework of the geometric Hilbert space theory of Markovian splitting subspaces developed by Lindquist and Picci and others. It will be presented in detail in a forthcoming monograph, which is under preparation. This geometric theory should be regarded as a natural and logically consistent way of building up linear stochastic systems theory. Traditionally there has been little attention paid even to the most elementary structural concepts in linear stochastic systems, like, for example, minimality. This has led to derivations of filtering algorithms by formula manipulations without deeper understanding of why the estimates satisfy recursive equations and whether the algorithms obtained are of minimal complexity, etc. It is a fact that many structural properties important in dynamic estimation, such as, for example, the existence of recursive (i.e. differential-equation type) solutions, the minimality of filtering algorithms, and processing of specific observed signals, possibly with a noncausal information pattern, are best formulated and understood in a coordinate-free form, using the geometric language of Hilbert space theory. The use of coordinates may sometimes only obscure the basic issues.

On the nonlinear dynamics of Kalman filtering

Researchers: Anders Lindquist, Yishou Zhou and Martin Hagström, in cooperation with C. I. Byrnes (Washington University, St Louis).

Sponsors: The Swedish Research Council for Engineering Sciences (TFR) 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. Using a "fast filtering" algorithm, which incorporates the statistics of the observation process as initial conditions, (rather than coefficient parameters) for a dynamical system, these results are analyzed in terms of the phase portrait of a "universal" nonlinear dynamical system. This point of view has additional advantages as well, since it enables one to use the theory of dynamical systems to study the sensitivity of the Kalman filter to (small) changes in initial conditions; e.g. to change in the statistics of the underlying process. This is especially important since these statistics are often either approximated or estimated. This interesting dynamical behavior occurs already for one-dimensional filters, and we give a complete phase-portrait in this case. Most aspects of the general case is also studied in detail. See [A4], [A5] and a forthcoming licentiate thesis by Martin Hagström. Extensive simulations have been undertaken which show interesting dynamical behavior.

Robust control of electrical drives

Researchers: P. O. Gutman, Xiaoming Hu, Mattias Nordin and Anders Lindquist, in cooperation with C. G. Baril (Ph.D. 1993, Technion, Haifa), and Johann Galic (ABB Drives AB, Västerås).

Sponsors: The Swedish National Board for Industrial and Technical Development (NUTEK) and ABB Drives AB.

This project is a continuation of the project: Nonlinear control of uncertain systems with hard non-linearities. The current program has been running since January 1992, and has received continued funding until June 1996.

Electro-mechanical control systems in industry, such as motor drives or robots, can be modelled as uncertain linear dynamic systems, affected by nondifferentiable nonlinearities such as friction, backlash, limiters, etc. Current linear control design practice is unable to yield high precision for such systems without expensive high quality mechanical components. The aim of this project is to combine robust linear control with nonlinear control elements, implemented in a microprocessor, that alleviate the effects of the process nonlinearities. In particular will electrical drives with friction, back-lash and uncertain loads and disturbances be studied.

The following results have been obtained:

1. A robust linear controller has been designed using the H_∞ method for a simulation model of an electric drive with backlash, see **??** and [R6].
2. Extensive measurements have been performed on a 60 kW electrical drive system in the laboratory of ABB Drives AB, and frequency domain and time domain models are being developed. A robust controller based on the Horowitz method has been designed and will be laboratory tested.
3. A systematic design method for uncertain linear systems that include a class of uncertain hard nonlinearities has been developed. It is assumed that the nonlinearity can be described as an uncertain linear operator, and a bounded disturbance. Common friction and backlash models are included in this description. The method is based on the Horowitz robust design methodology, and the describing function method (or alternatively the circle criterion). The method is believed to be one of the first systematic, performance related design methods for this class of systems [A15].
4. A method to combine adaptive friction compensation with robust linear control for the servo case was developed. Only friction parameters are adapted in such a way as to minimize the mean square regulation error. The results are reported in C. Baril's Ph.D. thesis (Control of electromechanical systems affected by friction and other nondifferentiable nonlinearities, Technion, Haifa, Israel, May 1993), from which papers are under preparation.
5. A method to compensate for stick-slip motion due to static friction for the servo control of high precision electromechanical systems was developed in reported in Baril's Ph.D. thesis. The idea is to insert appropriate pulses to release the system from sticking in such a way that limit cycles are avoided.
6. A method to compute value sets for uncertain transfer functions in factored real form was developed [A8].
7. A method to estimate parameter intervals, on-line, for uncertain dynamical models using recursive least squares was presented [A7].

Stochastic realizations and geometric control theory – a synthesis

Researchers: Anders Lindquist and Jan-Åke Sand, in cooperation with Gy. Michaletzky (Eötvös Lorand University, Budapest) and G. Picci (University of Padova).

Sponsors: The Swedish Research Council for Engineering Sciences (TFR) and the Göran Gustafsson Foundation.

In this project we show that there is an important connection between the geometric theory of splitting subspaces and geometric control theory in the style of Wonham and Basile and Marro. We introduce the notion of *output-induced subspace* of a minimal Markovian splitting subspace, and show that it is the analogue of *supremal output nulling subspace* in geometric control theory. Then we show how the zero structure of the family of (not necessarily square) spectral factors relates to the family of minimal Markovian splitting subspaces in the sense that the relationship between the zeros of different spectral factors is reflected in the partial ordering of minimal splitting subspaces and the corresponding solutions of the algebraic Riccati inequality. In [A12] we considered the continuous-time systems with nonsingular noise. This is the simplest case in which the *supremal reachability space* becomes trivial under our correspondence. In general this is not the case, and consequently more structure is introduced, especially in the discrete-time case. This corresponds to singular control. Completing this work will clarify the systems-theoretical structure of the families of stochastic models and is certain to give important insight into certain questions of estimation and identification.

Finally, we generalize the well-known characterization of the the solutions of the algebraic Riccati equation in terms of Lagrangian subspaces invariant under the corresponding Hamiltonian to the larger solution set of the algebraic Riccati inequality.

Stochastic realization theory and identification

Researchers: Anders Lindquist, in cooperation with Giorgio Picci (University of Padova).

Sponsors: The Swedish Research Council for Engineering Sciences (TFR) and the Göran Gustafsson Foundation.

Recently there has been a renewed interest in identification algorithms based on a two steps procedure which in principle can be described as covariance estimation followed by stochastic realization. These algorithms are based on canonical correlation analysis and can naturally accomodate multivariate processes. They offer the major advantage of converting the nonlinear parameter estimation phase which is necessary in traditional ARMA-models identification into the solution of an algebraic Riccati equation, a much better understood problem for which efficient numerical solution techniques are available. On the other hand these methods introduce some very nontrivial mathematical problems related to positivity. In this project we analyze the above class of stochastic state-space identification methods in the light of recent results on stochastic systems theory. The statistical problem of stochastic model building from estimated covariances can be phrased entirely in the geometrical language of stochastic realization theory.

The idea is to do canonical correlation analysis and disregard modes corresponding to "small" canonical coefficients. This is called *balanced truncation*. A model reduction procedure based on these principles has been proposed by Desai and Pal but was never theoretically justified. We have shown, however, that this reduction procedure indeed produces a positive real and *balanced* reduced model structure [R5]. Notice that this is a nontrivial and surprising result since it really seems to be too much to hope for that the singular values of the truncated system are exactly equal to the r first singular values of the original system. A partial result was given by Harsharvardana, Jonckeere and Silverman in continuous time, but the discrete-time result is in several respects harder. These increased difficulties depend on the different behaviors of the spectral factors of the truncated approximate spectra in continuous and discrete time. While in continuous time the realizations of the "reduced" spectral factors are proper subsystems this is *not* the case in discrete time, contrary to early claims of Desai and Pal.

The minimal rational covariance extension problem

Researchers: Anders Lindquist, in cooperation with C. I. Byrnes (Washington University, St Louis).

Sponsors: The Swedish Research Council for Engineering Sciences (TFR) and the Göran Gustafsson Foundation.

The minimal rational covariance extension 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 topics we study parametrizations of this problem. In addition to studying the Kimura-Georgiou parametrization in terms the zeros of the corresponding modelling filter, we have developed an algebraic-Riccati-type matrix equation of nonstandard type, the positive semidefinite solutions of which parametrize the solution set of the rational covariance extension problem. So far no computational procedure is available for this nonstandard algebraic Riccati equation, and we are studying this question. Based on these results we have obtained important insights into the minimal partial stochastic realization problem. A clarification of these questions will provide us with a unification of methods of realization and identification of rational power spectra.

Recently, with the assistance of the group of V. A. Yakubovich in St. Petersburg (S. V. Gusev and A. S. Matveev), we have been able to prove an important conjecture by T. Georgiou, establishing a one-one correspondence between positive extensions and zero structures of modelling filters. This provides an important parametrization for the partial stochastic realization problem.

2.2.2 Description of projects in Mathematical Programming

Advanced optimization methods for crew and vehicle scheduling

Researchers: P. O. Lindberg and Andreas Nöu.

Sponsor: Swedish Tranport Research Board (TFB) and Nordic Graduate Education Academy (NorFA).

This project aims at using advanced dual methods on crew and vehicle scheduling problems.

Recently there has appeared optimizing methods for crew and vehicle scheduling problems. These methods solve time and capacity constrained path problems as subproblems and combine the subproblem solutions through Dantzig-Wolfe decomposition.

This framework fits very nicely into our metaproject on dual methods. We are looking at using more advanced dual methods in this framework. We also have some new ideas on how to solve the subproblems.

In June we organized a one day seminar in the area at KTH: “Modern Methods for Crew and Vehicle Scheduling: Models and Applications”. It attracted participants from industry and other universities. (See Section 8.2.)

We also have been inititators and coorganizers of an 8 day Nordic Reseacher Course on ”Time Constrained Routing and Scheduling”, that was held in Narvik, June 21-28, 1993. (See Section 8.3.)

We have applied to TFB for funding of a doctorate project in the area.

Allocation of scarce track capacity

Researchers: Ulf Brännlund, P. O. Lindberg and Andreas Nöu.

Sponsors: The Swedish Transport Research Board (TFB) and the Swedish National Rail Administration (Banverket).

Industrial contacts: The Swedish National Rail Administration.

This is a preliminary project concerning the optimal allocation of scarce track capacity between a number of different railway companies.

It is assumed that the companies can provide utility functions giving their monetary values of different time tables.

For the problem of allocating the capacity so that the total utility is maximized, we have set up an optimization model and devised an algorithm based on dual methods. The modelling has been done in close cooperation with Jan-Eric Nilsson at the Centre for Research in Transportation and Society at Borlänge. The resulting model is extremely large. A typical case with 25 trains, 17 stations and one-minute discretization gives on the order of 400 000 binary variables and constraints. Our method uses the structure of the model and does not have to treat these variables explicitly.

Preliminary computational testing shows that the method works and it gives close to optimal solutions within two hours in a rather slow computation environment (Matlab).

Dual methods for large scale optimization problems

Researchers: P. O. Lindberg, Ulf Brännlund, Stefan Feltenmark, Andreas Nöu, Birgitta Olin, in cooperation with Don Hearn (University of Florida) and Krzysztof Kiwiel (Polish Academy of Sciences).

Sponsors: The Swedish National Board for Industrial and Technical Development (NUTEK), Swedish Transport Research Board (TFB), Swedish Institute of Applied Mathematics (ITM), Swedish National Rail Administration (Banverket).

Industrial contacts: ABB Network Control AB, Krångede Power Pool, Swedish National Rail Administration (Banverket), Swedish State Power Board.

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

Central subprojects are the projects on short term power planning, structured duals and second order decomposition methods. 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 project on scarce track capacity also shares the same methodology. So does the project on crew and vehicle scheduling.

The random assignment project shares 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.

Finally, this meta project benefits strongly from the Optimization Laboratory.

Dual methods for short term power planning problems

Researchers: P. O. Lindberg, Stefan Feltenmark and Andreas Nöu.

Industrial contacts: ABB Network Control AB, Krångede Power Pool, Swedish State Power Board.

This is a project where we are applying for money.

The project concerns the computation of optimal short term plans for power generating systems, to cover demand at lowest costs given constraints on reserves.

In the Unit Commitment project we have already developed methods for the thermal part. Also the price determination methods from that project can be used to coordinate thermal and hydro generation.

We have done preliminary work at developing methods for the hydro part of the short term power planning problem. These have been reported in [P9] and [P13]. We are working at developing methods of different degrees of detail. From models with simple bilinear dependency of output on flows and water heights in the stations, to very complex models with detailed efficiency functions and commitments of the turbines in the stations.

Dual methods for the unit commitment problem

Researchers: P. O. Lindberg, Stefan Feltenmark and Andreas Nöu.

Sponsors: The Swedish National Board for Industrial and Technical Development (NUTEK), The Ernst Johnsson Foundation and the Swedish Institute for Applied Mathematics (ITM).

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).

In a previous licentiate thesis, Magnusson developed an efficient subgradient based code for the problem. This code has been streamlined and speeded up by Feltenmark and Nöu. During he year we have worked at several aspects of the problem:

- we have studied the static EDC problem, which is solved each time one constructs a primal feasible solution

- we have experimentally showed that there are few commitment plans optimal to the subproblems in the neighbourhood of the dual optimum.

- based on the previous observation, we have sketched an algorithm for the exact solution of the dual problem

- we have succesfully started using bundle methods for the dual problem

- we have initiated a student project in the school of computer science, where 10 students in an 8 weeek project developed a graphical interface to our code.

The project is under application to Elforsk together with the short term power planning project.

KTH Optimization Laboratory

Researchers: P. O. Lindberg, Patrik Alfredsson, Ulf Brännlund, Stefan Feltenmark, Anders Forsgren, Jorge Mari, Andreas Nöu, Birgitta Olin, Krister Svanberg.

Sponsors: The Swedish National Board for Industrial and Technical Development (NUTEK) and the Swedish Council for Planning and Coordination of Research (FRN).

Industrial contacts: ABB Network Control, Aeronautical Research Inst of Sweden, AlfGam Optimering AB, Avesta AB, Ericsson Telecom, Forest Operations Institute, Krångede Power Pool, Swedish Defense Material Administration (FMV), Swedish National Rail Administration (Banverket), Swedish State Power Board, Swedish Telecommunications Administration, Stockholm Transport (SL), Systecon AB.

This project aims at creating a productice research environment for development of optimization methods and at spreading modern optimization practice in Swedish industry. This is done by collecting state-of-the-art portable optimization routines as well as optimization problems and keeping them available in a network of work stations. This obviously will facilitate research, but through our projects and through making the routines available for testing, we also fulfill the other goal.

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)
NOA2	(Kiwiel, Polish Adademy of Sciences)
RSDNET, RSDTA	(Hearn, U Florida)
NAG	(NAG)
GAMS	(GAMS)
ELSUNC, ENLSIP	(Umeå University)

During the year we have continued working at collecting optimization routines and facilitating easy use of these routines. For several routines, we have written an interface to MATLAB, thereby making them easy to use. These interfaced routines have been used extensively, both in our own research and for educational purposes.

The lab has a SUN 670MP server with several work stations connected to it. During the year we have started upgrading our computer system, using funds supplied by FRN (Swedish Council for Planning and Coordination of Research).

Methods for structured dual problems

Researchers: P. O. Lindberg and Stefan Feltenmark, in cooperation with Alfredo Piria (University of Montevideo).

Sponsor: The Swedish National Board for Industrial and Technical Development (NUTEK).

Large decomposable problems often have a separable structure. The duals of such problems also have a separable structure. This can be utilized in developing solution techniques.

We have generalized the subgradient technique with Polyak steps to this setting. Then one updates the multipliers after each subproblem solution. Results have been reported in [P10] and [P13].

Optimal expansion strategies for transport networks

Researchers: P. O. Lindberg and Ulf Brännlund, in cooperation with Per Lindberg (Telia Research) and Anders Rudberg (Ericsson Telecom).

Sponsor: The Swedish National Board for Industrial and Technical Development (NUTEK).

Industrial contacts: Ericsson Telecom and Telia Research.

This project is concerned with optimal expansion strategies for transport networks in the face of large demand uncertainties. Typical networks could be telecom or electricity networks.

We aim to model the problem as a multistage stochastic programming problem. The underlying network structure implies that we could utilize the structure to devise efficient methods.

We have applied and received a preliminary grant for exploring the area under the "complex systems" program at NUTEK.

Optimal water flow through a hydro power station

Researchers: P. O. Lindberg and Omar Viera.

Sponsor: The Swedish National Board for Industrial and Technical Development (NUTEK).

Industrial contact: Swedish State Power Board.

This project addresses, and has developed methods for, the problem of finding the optimal water flow 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. In particular, we have for certain power stations established the existence of several local optima for most water flows, showing the inherent difficulties of the problem. Moreover, our method makes it possible to treat the combinatorial problem of choosing which turbines to run, without extra computations.

During the year we have started looking at discretization errors of the model.

Optimization of spare parts inventory systems

Researchers: P. O. Lindberg and Patrik Alfredsson.

Sponsors: The Swedish National Board for Industrial and Technical Development (NUTEK) and the Swedish Defense Material Administration (FMV).

Industrial contact: Swedish Defense Material Administration.

This project entails a broad study of spare parts inventory systems. We are working with models for general multi-item, multi-echelon, multi-indenture systems for repairable spare parts. In particular we are studying optimization of spare parts inventories, location of repair facilities, and sensitivities of the optimal value with respect to inventory system parameters.

Presently we are extending the model to take parameter uncertainty into consideration when optimizing the inventory levels.

Random assignment problems

Researchers: P. O. Lindberg and Birgitta Olin.

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

During the year Olin defended her thesis [T2] and received a doctorate degree. The opponent was prof. Dimitri Bertsimas, Sloan School of Management, MIT.

Random utility models

Researchers: P. O. Lindberg, in cooperation with Anders E. Eriksson (Swedish Defense Research Establishment) and Lars-Göran Mattsson (KTH).

Industrial contact: Stockholm County Council.

This is a long running project aiming at developing the theoretical foundations of random-utility-models. During the year we have continued our work on the Robertsson-Strauss model.

Second-derivative methods for nonlinear programming

Researchers: Anders Forsgren, in cooperation with Philip E. Gill (UCSD), Walter Murray (Stanford University) and Ulf Ringertz (KTH).

The rapid development of computer hardware has made the use of optimization techniques viable for solving larger and larger problems. However, for solving large sparse problems efficiently, it is necessary to design algorithms that take advantage of matrix sparsity, when solving the systems of linear equations that arise.

The goal of this project is the development of computationally efficient methods for solving large sparse nonlinear optimization problems. We focus on methods that utilize second-derivatives, since we expect such methods to prove more robust and efficient than methods that only use first-derivative information.

Recent work include the development of modified Newton methods of the line-search type for linearly constrained optimization. The methods utilize both descent directions and directions of negative curvature. In particular, we have been focusing on suitable symmetric indefinite factorization methods for solving the systems of linear equations that arise, and an efficient way of combining the descent direction and the direction of negative curvature [A25].

In cooperation with Ulf Ringertz, a modified Newton method has been applied to an energy minimization problem within nonlinear finite-element analysis [A26]. An interesting feature of this subproject is that on one of the test problems, it was essential to use directions of negative curvature in order to identify a local minimizer. Without directions of negative curvature, a non-optimal saddle-point was found.

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

Researchers: Ulf Brännlund and P. O. Lindberg.

Sponsor: Swedish Research Council for Engineering Sciences (TFR).

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

The work in this project has been collected in thesis of Brännlund [T1].

The main focus has been on so called relaxation methods for general nonsmooth optimization. These methods typically assumes knowledge of the optimal value. (An example where this assumption is true is finding a feasible point to a set of inequalities.) We also use this name for methods, which use estimates of an unknown optimal value to find new iteration points.

In this project, some new interesting methods, for both the case with and without knowledge of the optimal value, have been suggested and shown to converge. These methods have also proved to give insight to other common methods in nonsmooth optimization, such as bundle methods and regular subgradient methods. The developed methods have been tested on duals of production planning problems.

The focus has now turned towards so called bundle methods. Although, the connection to relaxation methods is still strong. The project continues after Brännlund's dissertation under the name "Large Scale Decomposition and Nonsmooth Optimization".

Structural optimization

Researcher: Krister Svanberg.

Structural optimization deals with computer-aided optimal design of load-carrying structures. An illustrative example is the truss sizing problem (truss = *fackverk*), where the cross section areas of the different bars in a truss structure should be chosen such that the total weight is minimized subject to constraints on displacements and stresses under given load conditions.

The ultimate goal of this project is a reliable and fast method for solving structural optimization problems. To reach such a goal, one must first try to capture the special properties of structural optimization problems. Results in that direction are reported in [A27] and [R11].

3 Education

3.1 Undergraduate courses

FA190 Optimeringslära, allmän kurs för D och F, Optimization, General Course

T. Björk 3.5 p

FA191 Matematikens och datateknikens tillämpningar, Applications of Mathematics and Computer Science

K. Svanberg 3 p

FA192 Optimeringslära, allmän kurs för T, Optimization, General Course

K. Svanberg 4 p

FA195 Optimeringslära, grundkurs för M, Optimization

K. Svanberg 4 p

FA196 Matematisk programmering, Mathematical Programming

K. Svanberg 5 p

FA300 Systemteknik, Systems Engineering

P. O. Lindberg 7 p

FA302 Systemtekniska metoder, Methods of Systems Engineering

T. Björk 3.5 p

FA305 Produktions- och lagerstyrning, Production and Inventory Control

U. Brännlund 3 p

FA310 Matematisk systemteori, Mathematical System Theory

T. Björk 3.5 p

FA312 Optimal styrteori, Optimal Control Theory

T. Björk 3.5 p

FA315 Matematisk systemteori, fortsättningskurs, Advanced Course in Mathematical Systems Theory

A. Lindquist 4 p

FA320 Matematisk ekonomi, Mathematical Economics

T. Björk 3 p

FA325 Stokastisk kalkyl och kapitalmarknadsteori, Stochastic calculus and the theory of capital markets

T. Björk 4 p

3.2 Graduate courses

Course name	Instructor	Credit	Participants KTH	Participants industry
Introduction to Nonlinear Control Theory	X. Hu	5 p	5	-
Integer Programming	A. Forsgren	5 p	4	1
Network Flows	P. O. Lindberg	5 p	7	-

3.3 Doctoral theses

[T1] U. Brännlund, *On relaxation methods for nonsmooth convex optimization*, TRITA-MAT-1993-4, Division of Optimization and Systems Theory, Department of Mathematics, KTH, 1993. Advisor: P. O. Lindberg.

[T2] B. Olin, *Asymptotic properties of random assignment problems*, TRITA-MAT-1992-19, Division of Optimization and Systems Theory, Department of Mathematics, KTH, 1992. Advisor: P. O. Lindberg.

[T3] Y. Zhou, *On the dynamical behavior of the discrete-time matrix Riccati equation and related filtering algorithms*, TRITA-MAT-1992-39, Division of Optimization and Systems Theory, Department of Mathematics, KTH, 1992. Advisor: A. Lindquist.

3.4 Master theses (Examensarbeten)

[T4] Performance analysis of an intelligent network, *K. Svanberg*. Performed at Ericsson Telecom AB. Advisor: . (K. Örtendahl (F))

4 Publications

4.1 Published (and accepted) papers

4.1.1 Published (and accepted) papers in Systems and Control

[A1] T. Björk and B. Johansson, *Adaptive prediction and reverse martingales*, Stochastic Processes and their Applications 43(1992), 191-222.

[A2] T. Björk and B. Johansson, *On theorems of de Finetti type for continuous time stochastic processes*, To appear in Scandinavian Journal of Statistics.

[A3] C. I. Byrnes and X. Hu, *The zero dynamics algorithm for general nonlinear systems and its application in exact output tracking*, J. of Math. Systems, Estim., and Control, Vol. 3 (1993), 51-72.

[A4] C. I. Byrnes, A. Lindquist and Y. Zhou, *On the nonlinear dynamics of fast filtering algorithms*, SIAM J. Control and Optimization, to be published.

[A5] C. I. Byrnes, A. Lindquist and Y. Zhou, *On dynamical behavior of the Kalman filter*, Proc. of the 31st IEEE Conference on Decision and Control, Tucson, Arizona, December 1992, pp. 3678–3679.

[A6] P.-O. Gutman, P. O. Lindberg, I. Ioslovich, and I. Seginer, *A nonlinear optimal greenhouse control problem solved by linear programming*, Journal of Agricultural Engineering Research, 1993.

[A7] P.-O. Gutman, *On-line parameter interval estimation using recursive least squares*, Int. Journal on Adaptive Control and Signal Processing, 1993.

[A8] P.-O. Gutman, C. Baril, and L. Neumann, *An algorithm to compute value sets for uncertain transfer functions in factored real form*, To appear in IEEE Transactions on Automatic Control, June 1994.

[A9] X. Hu, *Some results in nonlinear output regulation and feedback stabilization*, to appear in Int. J. Control.

[A10] X. Hu, *Nonlinear feedback stabilization on compacta and invariant manifolds*, Proceedings of the 2nd European Control Conference, Groningen, the Netherlands, June, 1993, 53-57.

[A11] X. Hu, *Stabilization of planar nonlinear systems by polynomial feedback control*, To appear in Systems and Control Letters.

[A12] A. Lindquist, Gy. Michaletzky and G. Picci, *Zeros of spectral factors, the geometry of splitting subspaces, and the algebraic Riccati inequality*, SIAM J. Control and Optimization, to be published.

[A13] A. Lindquist, G. Michaletzky and G. Picci, *On the connections between splitting subspaces and geometric control theory*, Proceedings of the Second European Control Conference (1993), 1125-1131.

[A14] A. Megretski and A. Rantzer, *Robust control synthesis by convex optimization: Projective parametrization and duality*, Proceedings of IFAC Congress, Sydney, Australia, 1993.

[A15] S. Oldak, C. Baril, and P.-O. Gutman, *Quantitative design of a class of nonlinear systems with parameter uncertainty*, Int. Journal of Robust and Nonlinear Systems, 1993.

[A16] L. Qiu, B. Bernhardsson, A. Rantzer, E. J. Davison, P. M. Young and J. C. Doyle, *On the real structured stability radius*, Proceedings of IFAC Congress, Sydney, Australia, 1993.

[A17] A. Rantzer, *A weak Kharitonov theorem holds if and only if the stability region and its reciprocal are convex*, Int. Journal of Robust and Nonlinear Control 3(1993), 55-62.

[A18] A. Rantzer and A. Megretski, *A convex parameterization of robustly stabilizing controllers*, Accepted for publication in IEEE Transactions on Automatic Control.

[A19] A. Rantzer, *Linear matrix inequalities for rank one robust synthesis*, Accepted for Conference of Decision and Control, San Antonio, 1993.

[A20] A. Rantzer, *Uncertainties with bounded rates of variation*, Proceedings of American Control Conference, San Francisco, 1993.

[A21] J.-Å. Sand, *A geometric approach to the reciprocal realization problem*, Proc. of 31st CDC, Tucson, Arizona, December 1992, 3686-3689.

[A22] J.-Å. Sand, *Geometric concepts in acausal realization theory*, Proc. of MTNS-93 (to appear).

[A23] Y. Zheng and X. Hu, *Local disturbance decoupling with asymptotic stability for nonlinear systems*, To appear in J. of Control Theory and Application.

[A24] Y. Zhou, *On the discrete-time Riccati inequality: Existence of solutions*, Accepted by European Control Conference (1993), Groningen, The Netherlands.

4.1.2 Published (and accepted) papers in Mathematical Programming

[A25] A. Forsgren and W. Murray, *Newton methods for large-scale linear equality-constrained minimization*, SIAM Journal on Matrix Analysis and Applications 14(1993), 560-587.

[A26] A. Forsgren and U. Ringertz, *On the use of a modified Newton method for nonlinear finite element analysis*, To appear in Computer Methods in Applied Mechanics and Engineering.

[A27] K. Svanberg, *A new approximation of the constraints in truss sizing problems: an explicit second order approximation which is exact for statically determinate truss structures*, Structural Optimization 4(1992), 165-171.

[A28] K. Svanberg, *The method of moving asymptotes with some extensions*, Proceedings of the NATO/DFG ASI on Optimization of large structural systems, edited by G. I. N. Rozvany, Kluwer, 1993, 555-566.

[A29] K. Svanberg, *Some second order methods for structural optimization*, Proceedings of the NATO/DFG ASI on Optimization of large structural systems, edited by G. I. N. Rozvany, Kluwer, 1993, 567-578.

[A30] K. Svanberg, *Local and global optima*, Proceedings of the NATO/DFG ASI on Optimization of large structural systems, edited by G. I. N. Rozvany, Kluwer, 1993, 579-588.

4.2 Technical reports and preprints

4.2.1 Technical reports and preprints in Systems and Control

[R1] T. Björk, *Stokastisk kalkyl och kapitalmarknadsteori*, Lecture notes.

[R2] X. Hu, *Invariant manifolds on compacta for some singularly perturbed differential systems*, Preprint.

[R3] X. Hu, *Nonlinear control of servo systems affected by friction forces*, Preprint.

[R4] A. Lindquist and Gy. Michaletzky, *Estimation of lost state information in linear stochastic systems*, Preprint.

[R5] A. Lindquist and G. Picci, *Canonical correlation analysis, approximate covariance extension, and identification of stationary time series*, Preprint.

[R6] M. Nordin, *An H_∞ robust performance design method for numerator and denominator multiplicative uncertainty*, Preprint, Submitted for publication.

[R7] J.-Å. Sand, *A geometric approach to the reciprocal realization problem on the circle (revised August 1992)*, Report TRITA-MAT-1992-0028, Department of Mathematics, KTH, 1992.

4.2.2 Technical reports and preprints in Mathematical Programming

[R8] P. Alfredsson, *A note on robust optimization of spare parts inventory system*, Preprint.

[R9] U. Brännlund, *A descent method with relaxation type step*, Submitted for publication in IFIP Proceedings, Compiégne 1993.

[R10] A. Forsgren, P. E. Gill and W. Murray, *Computing modified Newton directions using a partial Cholesky factorization*, Report TRITA-MAT-1993-9, Department of Mathematics, Royal Institute of Technology, 1993. (Submitted for publication.).

[R11] K. Svanberg, *On the convexity and concavity of compliances*, Submitted for publication.

5 Seminars at the division

5.1 Formal seminars

- Docent Per-Olof Gutman, Technion—Israel Institute of Technology, Haifa, *Quantitative design of a class of nonlinear systems with parameter uncertainty*, Aug. 14, 1992.
- Mattias Nordin, Royal Institute of Technology, *Robust speed control of rolling mill with minimal impact drop*, Aug. 21, 1992.
- Professor Dimitris Bertsimas, Massachusetts Institute of Technology, *Average behavior of classical problems in combinatorial optimization and computational geometry*, Sep. 9, 1992.
- Professor Harold W. Kuhn, Princeton University, *The facets of traveling salesman polytopes*, Sep. 9, 1992.
- Professor Dimitris Bertsimas, Massachusetts Institute of Technology, *Dynamic vehicle routing problems*, Sep. 10, 1992.
- Professor Vladimir A. Yakubovich, St Petersburg University, *Some new optimization problems in control theory*, Sep. 18, 1992.
- Joachim Grenestedt, Royal Institute of Technology, *Layup optimization of composite material structures*, Sep. 25, 1992.
- Zhuangwei Liu, Linköping Institute of Technology, *A Lagrangean relaxation scheme for structured linear programs with applications*, Oct. 2, 1992.
- Professor Donald W. Hearn, University of Florida, Gainesville, *Network equilibrium models and methods*, Oct. 7, 1992.
- Professor Donald W. Hearn, University of Florida, Gainesville, *The traffic equilibrium model and basic algorithms*, Oct. 8, 1992.
- Professor Donald W. Hearn, University of Florida, Gainesville, *Asymmetric traffic equilibrium models and methods*, Oct. 9, 1992.
- Dr. Hoang Duong Tuan, National Center for Scientific Research, Hanoi, *On local controllability of hyperbolic inclusions*, Oct. 23, 1992.
- Dr. Alexander Barvinok, Royal Institute of Technology, *A new computational hierarchy for systems of polynomial equations*, Oct. 30, 1992.
- Docent John Wyller, Sivilingeniørutdanningen i Narvik, *Solitons: Theory and applications*, Nov. 13, 1992.
- Professor Karl Johan Åström, Lund Institute of Technology, *Relay oscillations*, Nov. 18, 1992.
- Professor Sjur Didrik Flåm, Bergen University, *Non-cooperative games; adaptive approximations to stochastic equilibrium*, Nov. 20, 1992.
- Professor Greg Ammar, Northern Illinois University, *Updating and downdating Szegö polynomials for discrete least squares approximation on the unit circle*, Dec. 4, 1992.
- Professor Sven Erlander, Linköping Institute of Technology, *Efficient population behavior and the simultaneous choices of origins, destinations and routes*, Dec. 11, 1992.

- Tekn.lic. Mårten Gulliksson, University of Umeå, *Modifying the QR decomposition to constrained and weighted linear least squares*, Dec. 18, 1992.
- Yishao Zhou, Royal Institute of Technology, *On the dynamical behavior of the discrete-time matrix Riccati equation and related filtering algorithms*, Jan. 15, 1993.
- Professor Clyde Martin, Texas Tech University, *The Riccati equation and exponential distributions*, Jan. 20, 1993.
- Professor Christopher I. Byrnes, Washington University, *Stability, observability and the converse theorems of Lyapunov for nonlinear systems*, Jan. 21, 1993.
- Professor Tryphon Georgiou, University of Minnesota, *Differential stability and robust control of nonlinear systems*, Jan. 22, 1993.
- Dr. Gus Gassmann, Norwegian Institute of Technology, *Some issues of model management in stochastic programming*, Feb. 11, 1993.
- Dr. Gus Gassmann, Norwegian Institute of Technology, *Multistage stochastic programming: models and algorithms*, Feb. 12, 1993.
- Dr. Vincent Blondel, Université Catholique de Louvain, Belgium, *When are linear systems simultaneously stabilizable?*, Febr. 19, 1993.
- Professor Sven-Åke Gustafsson, HSR, Norway, *On accurate rational approximation of power series*, Febr. 26, 1993.
- Dr. Martin Kulldorff, Uppsala University, *The mutual fund theorem in optimal portfolio theory*, Mar. 5, 1993.
- Professor Jürgen Ackermann, German Aerospace Research Establishment, *Robust decoupling and yaw stabilization for four-wheel steering cars*, Mar. 12, 1993.
- Professor Torkel Glad, Linköping Institute of Technology, *Dynamic systems described by characteristic sets*, Mar. 19, 1993.
- Professor Björn Wittenmark, Lund Institute of Technology, *Adaptive control of a stochastic nonlinear system: an example*, Mar. 26, 1993.
- Professor Vladimir A. Yakubovich, St Petersburg University, *Optimal damping of forced oscillations under unknown harmonic external disturbances*, Mar. 31, 1993.
- Ulf Brännlund, Royal Institute of Technology, *On relaxation methods for convex nonsmooth optimization*, Apr. 2, 1993.
- Professor Jean-Louis Goffin, McGill University, Montreal, Canada, *Interior point cutting plane methods*, Apr. 7, 1993.
- Professor Jørgen Tind, University of Aarhus, Denmark, *Price-directive decomposition in hierarchical systems with conflicting preferences*, Apr. 7, 1993.
- Senior lecturer Alexei Y. Mednikov, State Techn. University of St Petersburg, *Shape optimisation in applied problems of linear theory of elasticity*, Apr. 23, 1993.
- Dr. Angappa Gunasekaran, University of Vaasa, Finland, *Optimal investment and lot-sizing policies for improved productivity and quality*, Apr. 30, 1993.
- Dr. Vincent Blondel, Université Catholique de Louvain, Belgium, *Sequences of intersections of rational functions*, May 4, 1993.

- Dr. Krister Svanberg, Royal Institute of Technology, *Structural optimization - nature, methods and applications.* (Docent seminar), May 7, 1993.
- Professor Bernard C. Levy, University of California at Davis, *An extended probabilistic framework for recursive estimation with mixed information*, May 14, 1993.
- Professor Bernard C. Levy, University of California at Davis, *Reciprocal diffusions and stochastic mechanics*, May 17, 1993.
- TeknD Dag Wedelin, Chalmers University of Technology, *An algorithm for a class of 0-1 integer programming problems*, May 28, 1993.
- Professor Christodoulos A. Floudas, Princeton University, *Global optimization of non-linear problems: Theory, computations and applications*, Jun. 2, 1993.
- Professor Krzysztof C. Kiwiel, Systems Research Institute, Polish Academy of Sciences, *A Cholesky dual method for proximal piecewise linear programming*, Jun. 4, 1993.
- Professor Krzysztof C. Kiwiel, Systems Research Institute, Polish Academy of Sciences, *Proximal level bundle methods for convex nondifferentiable optimization, saddle-point problems and variational inequalities*, Jun. 9, 1993.

5.2 Informal seminars in Systems and Control

- Professor Vladimir A. Yakubovich, St. Petersburg, *Functional identification and its applications in adaptive control*, Sep. 14, 1992.
- Docent Per-Olof Gutman, Faculty of Agricultural Engineering, Technion, Haifa, Israel, *Self-oscillating adaptive design of systems with dry friction and significant parameter uncertainty*, Sep. 21, 1992.
- Janne Sand, Division of Optimization and Systems Theory, *Stochastic fields*, Oct. 5, 1992.
- Yishao Zhou, Division of Optimization and Systems Theory, *On non-convergence of the discrete-time matrix Riccati equation*, Oct. 12, 1992.
- Professor Greg Ammar, Northern Illinois University, *Toward a structure-preserving algorithm for solving control-theoretic algebraic Riccati equations*, Dec. 7, 1992.
- Professor Tryphon T. Georgiou, University of Minnesota, *Graphs, causality and stabilizability: linear, shift-invariant systems on* $L^2[0,\infty)$, Jan. 11, 1993.
- Mattias Nordin, Division of Optimization and Systems Theory, *An* H_∞ *method for assessing robust performance*, Feb. 15, 1993.
- Professor Jürgen Ackerman, German Aerospace Research Establishment, *On robust control*, Mar. 15, 1993.
- Professor Vladimir A. Yakubovich, St. Petersburg, *An abstract theory of optimal control*, Mar. 29, 1993.

5.3 Informal seminars in Mathematical Programming

- Dimitri Bertsimas, MIT, *Axiomatics for queues*, Sep. 8, 1992.
- Andreas Nöu and Stefan Feltenmark, Division of Optimization and Systems Theory, *Beam cutting optimization*, Sep. 22, 1992.
- P. O. Lindberg, Division of Optimization and Systems Theory, *Bilinear programming a la Konno and Kuno*, Sep. 22, 1992.
- P. O. Lindberg, Division of Optimization and Systems Theory, *Convex knapsack problems a la Bitran and Brucker with applications to economic dispath calculation*, Oct. 13, 1992.
- P. O. Lindberg, Division of Optimization and Systems Theory, *Unit commitment PFS and EDC*, Oct. 20, 1992.
- Ulf Brännlund, Division of Optimization and Systems Theory, *On subgradient optimization with constraints, simplex constraints in particular*, Nov. 10, 1992.
- Lars Svensson, Department of Mathematics, KTH, *Sturm sequences*, Nov. 24, 1992.
- Krister Svanberg, Division of Optimization and Systems Theory, *Structural optimization*, Dec. 3, 1992.
- P. O. Lindberg, Division of Optimization and Systems Theory, *Structured duals*, Dec. 12, 1992.
- Thomas Ericsson, CTH, *On PVM: "Parallell Virtual Machine"*, Dec. 17, 1992.
- P. O. Lindberg, Division of Optimization and Systems Theory, *Scarce track capacity, Banverket*, Mar. 23, 1993.
- Patrik Alfredsson, Division of Optimization and Systems Theory, *Opus solution more robust*, Apr. 1, 1993.
- P. O. Lindberg, Division of Optimization and Systems Theory, *Interior point methods*, Apr. 6, 1993.
- P. O. Lindberg, Division of Optimization and Systems Theory, *Exact solution of the UC dual*, Apr. 15, 1993.
- P. O. Lindberg, Division of Optimization and Systems Theory, *Crew scheduling problem at SL*, Apr. 29, 1993.
- Gert Svensson, PDC, KTH, *The Center for Parallel Computers*, May 6, 1993.
- Fredrik Davidsson, Transportforskningskomissionen, *Optimization of traffic signals*, May 13, 1993.
- J. Backlund, Dept for Material Casting, *Mimimization of an energy function*, May 27, 1993.
- Jorge Mari, Division of Optimization and Systems Theory, *Results on recombinant protein production*, June 3, 1993.

6 Awards and appointments

Vincent Blondel was awarded the *1992 Göran Gustafsson Postdoctoral Fellowship* to enable him to spend academic year 1993/94 at the Division of Optimization and Systems Theory.

Mattias Nordin received one of two Volvo Awards to the Volvo Royal Institute Technologist of the Year for his Master's thesis **??**.

Krister Svanberg was appointed Docent of Optimization and Systems Theory.

7 Presentations by staff

[P1] P. Alfredsson, *On spare parts optimization*, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA, December 2, 1992.

[P2] P. Alfredsson, *Parameter sensitivity in repairable item inventory systems*, Symposium on reliability and life-cycle cost, Royal Institute of Technology, March 18, 1993.

[P3] U. Brännlund, *Subgradient methods*, Nordic Network for Optimization, Linköping, August 1992.

[P4] A. Forsgren, *Newton methods for minimization*, Numerical Algorithms Group, Oxford, England, November 5, 1992.

[P5] A. Forsgren, *Newton methods for optimization*, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA, February 12, 1993.

[P6] A. Forsgren, *On the computation of search directions in modified Newton methods for optimization*, Conference on Large-Scale Optimization, Gainesville, Florida, February 15–17, 1993.

[P7] A. Forsgren, *Newton methods for optimization*, University of California at San Diego, La Jolla, California, USA, February 19, 1993.

[P8] X. Hu, *Nonlinear stabilization on compacta and invariant manifold*, the Second European Control Conference, Groningen, the Netherlands, June, 1993.

[P9] P. O. Lindberg, *The simple dynamic single station hydro power optimization problem*, Nordic MPS Meeting, Trondheim, August 14-16, 1993.

[P10] P. O. Lindberg, *Using primal structure in large scale dual problems*, Conference on Large Scale Optimization, Gainesville, Florida, February 15-17, 1993.

[P11] P. O. Lindberg, *A nonlinear greenhouse control problem solved by linear programming*, Dept of Industrial and Systems Engineering, University of Florida, Gainesville, February 19, 1993.

[P12] P. O. Lindberg, *How to model systems efficiency. Mathematical models and tools. (In Swedish)*, LCC-symposium, KTH, 18 mars, 1993.

[P13] P. O. Lindberg, *Optimization problems in the power industry*, University of Linz, Linz, Austria, March 30, 1993.

[P14] P. O. Lindberg, *A nonlinear greenhouse control problem solved by linear programming*, Denmark Technical University, Lyngby, May 17, 1993.

[P15] P. O. Lindberg, *Models as Decision Support*, Seminar on modern methods for crew and vehicle scheduling: Models and applications, KTH, June 19, 1993.

[P16] A. Lindquist, *Zeros of spectral factors and the geometry of slitting subspaces*, SIAM Conference on Control and its Appications, Minneapolis, Minnesota, September 17–19, 1992 (not able to attend; presented by Jan-Åke Sand).

[P17] A. Lindquist, *On the nonlinear dynamics of Kalman filtering*, SIAM Conference on Dynamical Systems, Salt Lake City, Utah, October 15–19, 1992 (invited minisymposium speaker).

[P18] A. Lindquist, *Systems and control theory: retrospect and prospect*, Workshop, Cortona, Italy, April 15–20, 1993.

[P19] A. Lindquist, *Estimation of lost state information in linear stochastic systems*, Institute for Mathematics and its Applications, University of Minnesota, June 4, 1993.

[P20] A. Lindquist, *On the connections between splitting subspaces and geometric control theory*, European Control Conference, Groningen, the Netherlands, June 29, 1993 (not able to attend; presented by Jan-Åke Sand).

[P21] M. Nordin, *Robust speed control of a rolling mill with minimal impact drop*, ABB Drives AB, Västerås, October 15, 1992.

[P22] M. Nordin, *Poster: Robust speed control of a rolling mill with minimal impact drop*, Reglermöte 92, Göteborg, November 4-5, 1992.

[P23] A. Nöu, *Applications of Lagrangian relaxation to short term power planning problems*, GÉRAD and École Polytechnique, Montreal, Canada, November 20-24, 1992.

[P24] A. Rantzer, *Robustness analysis in presence of uncertainties bounded by quadratic forms*, Univ. of Minnesota, Minneapolis, October 16, 1992.

[P25] A. Rantzer, *Real parametric uncertainty in linear systems*, Univ. of Minnesota, Minneapolis, October 28, 1992.

[P26] A. Rantzer, *Five seminars on robustness of linear control systems*, Caltech, Pasadena, California, January 6-13, 1993.

[P27] A. Rantzer, *Parametric uncertainty with bounded rate of variation*, UC Santa Barbara, California, January 15, 1993.

[P28] A. Rantzer, *Parametric uncertainty with bounded rate of variation*, Univ. of Minnesota, Minneapolis, April 14, 1993.

[P29] A. Rantzer, *A convex parameterization of robustly stabilizing controllers*, Stanford University, California, June 1, 1993.

[P30] A. Rantzer, *Uncertainties with bounded rate of variation*, American Control Conference, San Francisco, June 2, 1993.

[P31] J.-Å. Sand, *Minimality and observability of reciprocal realizations on the circle*, University of California at Davis, September 14, 1992.

[P32] J.-Å. Sand, *Minimality and observability of reciprocal realizations on the circle*, SIAM Conf. on Control Theory and its Applications, Minneapolis, Minnesota, September 17-19, 1992.

[P33] J.-Å. Sand, *Minimality and observability of reciprocal realizations on the circle*, LIDS, MIT, Massachusetts, September 21, 1992.

[P34] J.-Å. Sand, *A Geometric approach to the reciprocal realization problem*, 31st CDC, Tucson, Arizona, December 16-18, 1992.

[P35] Y. Zhou, *On dynamical behavior of the Kalman filter*, The 31st IEEE Conference on Decision and Control, Tucson, Arizona, December 16–18, 1992.

[P36] Y. Zhou, *Some results on fast filtering algorithms for the Kalman filter*, Reglerteknik och Systemanalys, Uppsala University, November 25, 1992.

8 Conferences

8.1 Symposium on LCC

On March 18 1993, the division organized, together with the Systems Engineering students, a symposium at KTH on Availability and LCC. The symposium attracted around 30 participants from government and industry. The program was as follows. (All talks were in Swedish).

P. O. Lindberg, KTH. *How to model and optimize systems efficiency? Mathematical tools and models.*

Patrik Alfredsson, KTH. *How is the availability affected by parameter changes? Sensitivity analysis for spare parts inventory systems.*

Erik Söderman, ES-konsult. *How to improve availability in existing systems? Availability performance at "Soviet" and Swedish nuclear reactors.*

Sven Holmquist, Ovako Steel. *How to create an understanding for availability issues in the organization? Practical Availability. Methods that engage and save millions. Monotoring, analysis and feedback.*

Agne Hörberg, SJ and Bengt Burström, ABB Traction. *Are Availability and LCC analyses profitable? The case of the high-speed train X2000.*

8.2 Seminar on crew and vehicle scheduling

With support from TFB we organized a one day seminar entitled "Modern Methods for Crew and Vehicle Scheduling: Models and Applications." The seminar was held at KTH on June 18, 1993. Main speakers were Prof J. Desrosiers, HEC and GERAD, Montreal, Canada and Erik Andersson, Volvo Data AB. The seminar attracted people from among other places Banverket, SAS, SJ and SL and from other universities. The talks were as follows:

P. O. Lindberg, KTH. *Models as decision support.*

J. Desrosiers, HEC and GERAD. *A unified model for vehicle fleet planning and crew scheduling problems.*

E. Andersson, Volvo Data. *Making a planning system grow with the user.*

8.3 Nordic researcher course on time constrained routing and scheduling

Initiated by and with P O Lindberg as coorganizer, the nordic researcher course on "Time Constrained Routing and Scheduling" was held at Narvik, June 21-28, 1993. The teachers were:

- J. Desrosier, HEC and GERAD, Montreal, (main teacher)
- Oli Madsen, Technical University of Denmark, (routing)
- P. O. Lindberg, KTH, (networks, decomposition).

The course attracted more than 30 participants from Sweden, Norway and Denmark, out of which 4 came from our department. There were also participants from companies sush as SAS, SL and Volvo Data.

9 Other activities

Patrik Alfredsson

- Participated in EURO XII/TIMS XXXI Joint International Conference, Helsinki, Finland, June 29–July 1, 1992.
- Followed the Systems Engineering program at Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA, August 24– December 17, 1992.
- Participated in the Nordic research course on Time Constrained Routing and Scheduling, Narvik, Norway, June 21–28, 1993.
- Member of Board of the Swedish Operations Research Association.

Tomas Björk

- Director of Undergraduate Studies (studierektor) in Optimization and Systems Theory.
- Was a member of the evaluation committee for a Ph.D. thesis.
- Active as referee for Stochastic Processes and Systems and Control letters.
- Gave courses on stochastic calculus and arbitrage theory at Stockholm School of Economics, Stockholm University and Handelsbanken.

Ulf Brännlund

- Referee for Computational Optimization & Application and Naval Research Logistics.
- Gave with P. O. Lindberg a 1 day course in ”Modelling and Optimization” at Swedish Defense Research Establishment (FOA), April 27, 1992.

Stefan Feltenmark

- Participated in the 1992 IBM Europe Institute, Optimization Solutions, August 3–7, 1992.
- Participated in the conference “Large Scale Optimization”, February 1993, in Florida, U.S.A.
- Participated in a NorFA Research Course on “Time Constrained Routing and Scheduling” in Narvik, Norway, June 21-28, 1993.

Anders Forsgren

- Referee for SIAM Journal on Optimization.
- Visited the Numerical Libraries Division at the Numerical Algorithms Group Ltd., Oxford, England, November 2-6, 1992.
- Visited Sloan School of Management at the Massachusetts Institute of Technology, Cambridge, Massachusetts, USA, February 11-12, 1993.
- Visited the Department of Mathematics at the University of California at San Diego, La Jolla, California, USA, February 18-22, 1993.

Martin Hagström

- Participated in Regelermöte in Göteborg, November 3–4, 1992.

Xiaoming Hu

- Referee for IFAC Congress in Sydney, Australia, 1993.
- Referee for the Second European Control Conference in Groningen.
- Referee for the Int. J. of Adaptive Control and Signal Processing.

P. O. Lindberg

- Adjunct Professor in Industrial and Systems Engineering, University of Florida at Gainesville, USA.
- Head of organizing committee of the 4th Stockholm Optimization Days, Au-

gust 16-17, 1993.

- On editorial board of Computational Optimization and Applications.
- Inititator and administrator of student exchange program with dept of Industrial and Systems Engineering at U Florida, Gainesville, whereby this year 14 4th-year students were sent to Florida to complete a Master's thesis.
- Initiator, coorganizer and teacher for the Nordic researacher course "Time Constrained Routing and Scheduling" at Narvik, June 21-28 1993.
- Gave with U Brännlund a 1 day course in "Modelling and Optimization" at Swedish Defense Research Establishment (FOA), April 27, 1993.
- Visits to prof Müller at Technical University Wien, Prof Ruszczynski, IIASA, and Don Hearn, U Florida.
- Advisor of one ERASMUS student in the area of Systems Engineering: Vittorio Concetti, Pisa.

Anders Lindquist

- Communicating Editor, *Mathematical Systems, Estimation and Control*, journal published by Birkhäuser Boston.
- Associate Editor, *Systems and Control Letters*, journal published by North-Holland.
- Member Editorial Board, *Adaptive Control and Signal Processing*, journal published by John Wiley & Sons.
- 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.
- Referee for seven other journals.
- Referee for Airforce Office of Scientific Research, Washington D.C..
- Affiliate Professor, Washington University, St Louis, USA.
- Member of Swedish Committee for IIASA (International Instute for Applied System Analysis in Vienna, Austria).
- Vice Chairman of Board of Academic Appointments for the School of Engineering Physics (tjänsteförslagsnämnden för teknisk fysik).
- Expert Evaluation (Sakkunningutlåtande) for two academic positions.
- Steering Committee, International Symposium on the Mathematical Theory of Networks and Systems (MTNS).
- Member, International IFAC Committee for Mathematics in Control.
- Program Committee of MTNS-93, Regensburg, Germany, August 2- 6, 1993.
- Organizing Committee of the 24th ISCIE Symposium on Stochastic Systems Theory and its Applications, Kyoto, Japan, November 11–13, 1992.
- Organizing Committee of the Swedish-Italian Workshop on "New Perspectives in Modelling and Identification with Applications", Stockholm, September 2-3, 1993.
- Organizing Committee of the 25th ISCIE Symposium on Stochastic Systems Theory and its Applications, Osaka, Japan, November 10-12, 1993.

Mattias Nordin

- Visited The Institute for Mathematics and its Applications, University of Minnesota, November 9 - December 15, 1992
- Visited 31st IEEE CDC, Tucson, Arizona, December 16-18, 1992.

Andreas Nöu

- Participated in the 1992 IBM Europe Institute, Optimization Solutions, August 3–7, 1992.
- Participated in the 34th TIMS/ORSA Joint National Meeting, San Fransisco, California, USA, November 1–4, 1992.
- Visited GÉRAD and École Polytechnique, Montreal, Canada, November 20-24, 1992.
- Participated in a Conference on “Large Scale Optimization” at University of Florida, in Gainesville, Florida, USA, February 15-17, 1993.
- Participated in a NorFA Research Course on “Time Constrained Routing and Scheduling” in Narvik, Norway, June 21-28, 1993.

Jan-Åke Sand

- Refereed one paper for Mathematical Systems, Estimation, and Control.
- Participated in Reglermöte -92, Göteborg.

Krister Svanberg

- Opponent at a dissertation in Linköping.
- Member of the evaluation committee at a dissertation on KTH.
- Refereed four papers for Structural Optimization.
- Refereed one paper for Numerical Methods in Engineering.

Yishao Zhou

- Refereed 8 papers/times for “System & Control Letters”, “J. of Mathematical Systems, Estimation, and Control”, “Mathematics of Control, Signals and Systems” and ECC’93.
- Participated in Reglermöte in Göteborg November 3–4, 1992.
- Visiting researcher at the Department of Mathematics, University of Groningen, The Netherlands, April 20–30, 1993.