Self-Evaluation Applied Mathematics

2003-2008

University of Twente

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Applied Mathematics Department
University of Twente

ISBN: 978-90-365-2841-2

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June 2009

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Preface

This report contains the self-study for the research assessment of the Department of Applied Mathematics (AM) of the Faculty of Electrical Engineering, Mathematics and Computer Science (EEMCS) at the University of Twente (UT). The report provides the information for the Research Assessment Committee for Applied Mathematics, dealing with mathematical sciences at the three universities of technology in the Netherlands. It describes the state of affairs pertaining to the period 1 January 2003 to 31 December 2008.

The report consists of two parts: Part A describes the Department as a whole; Part B describes the research programmes of the Department of Applied Mathematics. A list of peer-reviewed publications in international journals, books and proceedings of international conferences concludes each section of Part B. The structure of all sections follows the Standard Evaluation Protocol 2003-2008 for Public Research Organisations, as agreed upon by the Dutch universities. To provide a link with the previous research assessment, covering the period 1996-2001, the publications of 2002 have also been added to this report.

Prof. A.J. Mouthaan,
Dean of the Faculty Electrical Engineering, Mathematics and Computer Science

Prof. J.J.W. van der Vegt,
Head of the Department of Applied Mathematics

Section A: Characterisation of the Institute (Faculty)

Full title

Department of Applied Mathematics
Faculty of Electrical Engineering, Mathematics and Computer Science
University of Twente

Date of establishment

1968 (since 2002 part of the Faculty of Electrical Engineering, Mathematics and Computer Science)

Affiliations

research schools and networks:

- Beta Research School for Operations Management and Logistics (chair Eindhoven University of Technology)
- DISC (Dutch Institute for Systems and Control) (chair Delft University of Technology)
- EIDMA (Euler Institute for Discrete Mathematics and its applications) (chair Eindhoven University of Technology)
- JMBC (J.M. Burgerscentrum Research School for Fluid Mechanics) (chair Delft University of Technology)
- LNMB (Dutch Network on the Mathematics of Operations Research) (chair University of Twente)
- MRI (Mathematical Research Institute) (chair Radboud University)

3TU.Federation:

- NIRICT (Netherlands Institute for Research in ICT)
- Multiscale Phenomena Centre of Excellence
- Intelligent Mechatronic Systems Centre of Excellence
- 3TU Applied Mathematics Institute (starting 2009)

Introduction

The Department of Applied Mathematics was established in 1968 as the Faculty of Applied Mathematics at the University of Twente. Since 2002 it has been a department in the Faculty of Electrical Engineering, Mathematics and Computer Science (EEMCS). The department is organised into chairs, each covering a distinguishing part of the broad field of applied mathematics. In addition to being involved in scientific research, the Applied Mathematics Chairs are also responsible for the curriculum of the BSc and MSc mathematics programmes (design and teaching) and service teaching in mathematics, which amounts to a substantial part of all teaching at the University of Twente.

This report presents a self-assessment of the research conducted in the Department of Applied Mathematics. This research finds a natural clustering in three research programmes, Applied Analysis and Computational Science, Stochastics and Operations Research, and Deterministic and Stochastic Systems Theory, which is reflected in the structure of this report.

In Twente the applied mathematics research programmes are carried out within the framework of multidisciplinary research institutes. The term 'institute'[1] here has a meaning that differs from the term used in the Standard Evaluation Protocol 2003-2008 for Public Research Organisations. A research institute in Twente is an institute at university level, comprising (parts of) research groups from different faculties.

The chairs in the Department of Applied Mathematics play an active role in the UT research institutes. Their research is part of the research programmes of the Centre for Telematics and Information Technology (CTIT), the Institute of Mechanics, Processes and Control Twente (IMPACT), the Institute for Biomedical Technology (BMTI) and the MESA+ Institute for Nanotechnology (MESA+).

1. Mission statement

The mission of the Department of Applied Mathematics is to perform high-level academic research and teaching in mathematics and its applications in a multidisciplinary context, motivated by questions of societal and technological relevance.

The research aims at contributing to multidisciplinary research through mathematical reasoning (abstraction, structuring and generalisation) and mathematical methods, either directly in joint research with non-mathematics colleagues, or indirectly by long-term fundamental mathematics research that is associated with the focus of the UT institutes. For this purpose the department pursues an active role in the multidisciplinary UT research institutes.

[1] 'Institute', referred to in the "Standard Evaluation Protocol 2003-2009 for Public Research Organisations", is the Department of Applied Mathematics of the Faculty of Electrical Engineering, Mathematics and Computer Science, University of Twente.

2. Leadership and management

Formal leadership and organisation

The faculties of the University of Twente are primarily responsible for teaching, whereas the institutes at the University are primarily responsible for research. Faculties are divided into departments, which are divided further into chairs. These chairs are also the smallest unit of organisation within the institutes. This creates a matrix structure, in which chairs are controlled both by the dean of a faculty and the director(s) of a research institute. Frequently, a chair participates in more than one UT research institute.

The Faculty of Electrical Engineering, Mathematics and Computer Science was established in the summer of 2002. Before 2002, the Department of Applied Mathematics was an independent faculty. The EEMCS Faculty is led by a dean, and the three departments each by a head of department. The dean and the heads of department for Electrical Engineering, Applied Mathematics and Computer Science form the Management Team of the faculty, assisted by the managing director and the financial controller. Table 1 provides an overview of the executive management of the EEMCS Faculty. The organization chart is given in Figure 1.

All staff are employed by the faculty. The chair holders are responsible for the research focus, quality of teaching, financial matters and management of human resources in their chair.

The formal responsibility to the Executive Board of the university for research activities carried out under the responsibility of the UT research institutes rests with the scientific directors. The directors receive an integral budget (to cover the salaries and infrastructure of the institute's organisation) from the university. Much of this budget is based on the research output and teaching effort by the chairs. Scientific directors are also allocated a strategic research incentive budget, which they use to initiate innovative research.

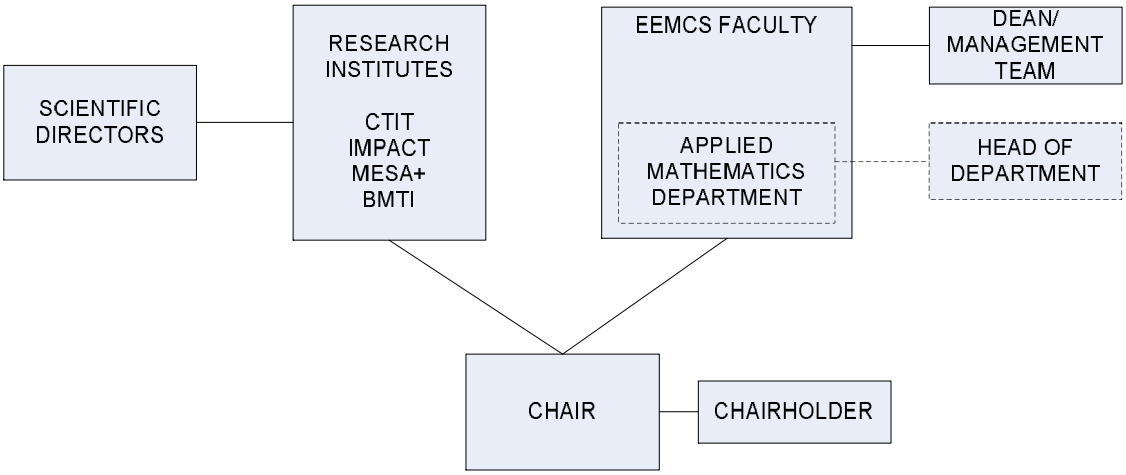

Figure 1. Organisation Chart

Table 2 gives an overview of the executive management of the research institutes relevant to the Department of Applied Mathematics. Table 3 shows the participating chairs and the management responsibilities.

Also indicated in Table 3 are the research programmes within the Department of Applied Mathematics and their participation in the UT research institutes.

Table 1. Overview of executive management of the EEMCS Faculty

Dean	Prof. A.J. Mouthaan
Head Department of Applied Mathematics	Prof. J.J.W. van der Vegt
Head Department of Electrical Engineering	Prof. J. van Amerongen
Head Department of Computer Science	Prof. R.J. Wieringa
Managing Director	H. van Egmond
Controller	M.W.M. Evers

Table 2. Overview of executive management of the research institutes relevant to the Department of Applied Mathematics

Centre for Telematics and Information Technology (CTIT)	Scientific director Prof. P.M.G. Apers
Institute of Mechanics, Processes and Control-Twente (IMPACT)	Scientific director Prof. J.A.M. Kuipers
MESA+ Institute for Nanotechnology (MESA+)	Scientific director Prof. D.H.A. Blank
Institute for Biomedical Technology (BMTI)	Scientific director Prof. C.A. van Blitterswijk

Table 3. Overview of Applied Mathematics Research Programmes, participating chairs and chair holders.

Research programmes and participating Chairs	**CTIT**	**IMPACT**	**MESA+**	**BMTI**
Applied Analysis and Computational Science				
1. Applied Analysis and Mathematical Physics (AAMP) Prof. E. van Groesen		x	X	x
2. Numerical Analysis and Computational Mechanics (NACM) Prof. J.J.W. van der Vegt		x		
Stochastics and Operations Research				
1. Stochastic Operations Research (SOR) Prof. R.J. Boucherie	x			
2. Discrete Mathematics and Mathematical Programming (DMMP) Prof. M.J. Uetz	x			x
3. Statistics and Probability (SP) Prof. W. Albers	x			
Deterministic and Stochastic Systems Theory				
1. Stochastic Systems and Signals (SST) Prof. A. Bagchi	x	x		
2. Mathematical Systems and Control Theory (MSCT) Prof. A.A. Stoorvogel	x	x		

Management

The Management Team (MT) of EEMCS meets once every two weeks. Once a month, the directors of education of all teaching programmes within EEMCS join the MT meeting. In the MT meetings all issues regarding personnel appointments, budgets, teaching programmes, investments and organisational topics are discussed. According to the Higher Education Act, the dean decides matters and is responsible for all formal decisions. The minutes of the MT meetings are available on Intranet to all staff.

Within the department a monthly meeting is organised, in which all chair holders, the dean, the director of education, the managing director and the head of department discuss current affairs affecting the department. The chair holders advise the Management Team of the faculty, when required. The dean also regularly consults the Faculty Council, consisting of staff and students, which formally approves and advises in relation to the decisions of the MT.

Twice a year, a general information meeting for all the staff of EEMCS is organised and once every quarter all chair holders and teaching directors within EEMCS meet over dinner to discuss more general topics that are important for the faculty.

Every year in spring, a meeting is organised between the Management Team of the faculty, each individual chair and the scientific director(s) of the research institute(s), in which the chair participates, to discuss and report on the situation of the chair with respect to teaching, research, personnel management and finances. A chair holder bears formal responsibilities in these areas, and in these meetings the chair holder is interviewed about that accountability. These meetings may lead to decisions regarding the activities of the chair.

The dean and the directors of the UT research institutes both have the right to propose new professorial positions to the Executive Board of the university. The faculty and the institute(s) are represented in all appointment committees of key research staff. The dean is represented on the management board of all relevant Institutes. This structure provides a framework in which the interests of individual chairs, the department and the university are covered, and balanced decisions can be made.

At the level of a chair, the chair holder is responsible for the teaching and research carried out in the chair. This is implemented in collaboration with the members of the chair. A chair holder reports on this research to the scientific director of the institute under which the specific programme resides. Institutes have internal and external advisory boards, where programme choices are discussed.

The chair holder conducts formal annual personnel assessments and job satisfaction meetings. Based on these assessments, bonuses can be proposed and staff development plans be initiated and monitored. Promotions of academic staff require a review based on the academic job ranking criteria. All financial aspects regarding personnel management rest with the dean. The final decision on promotions and appointments for positions at associate professor level and beyond is made by the Executive Board of the university.

The general management style is participatory; both within the chairs and at faculty level. Formal responsibilities are clearly defined to allow decisions to be made effectively and efficiently. The number of committees is kept to the legal minimum, and appointed managerial staff are considered responsible and accountable.

Quality control and processes of improvement and innovation

Quality control is based on the annual reporting of all scientific research activities in a QAR (quality assessment report). Statistics of publications, projects, PhD students and PostDocs and teaching effort are collected. The QAR provides the data for the self-evaluation, and results are discussed in the yearly meeting between the Management Team of EEMCS, directors of research institutes and the individual chairs. The QAR also provides data for the financial allocation, which is partly dependent on research output.

Half-way through the six-year reporting period, a midterm review was conducted by an external review committee. The midterm self-evaluation report followed the same protocol as that used for the current six-year self-evaluation. The midterm review provided an opportunity to discuss the effectiveness of measures that were taken after the previous six-year assessment and to adjust plans where necessary.

The prime source of innovation is the scientific curiosity of staff members in their research and collaboration with other scientists. This may result in new research directions and applications that strengthen the valorisation of the research output. All senior scientific staff (from assistant professor level and higher) are encouraged to submit research proposals for innovative research programmes and to apply for individual support from the National Research Council NWO. Key funding for our research programmes is obtained from research councils in the Netherlands and the EU and from industry.

New research initiatives in fields that involve more than one research group at the UT are stimulated particularly by the research institutes. The scientific directors are responsible for these programmes. A scientific director can, in consultation with the dean and the chair holders, provide a budget for new (temporary) appointments, investments, and/or existing staff members to engage in new activities.

3. Strategy and policy

3.a Strategy, policy and design and programme development in brief

Historical context

During the assessment period, the research strategy and policy of the Department of Applied Mathematics was strongly influenced by the decision of the University of Twente in 2002 to organise all research into multidisciplinary research institutes. Based on this decision, active participation of applied mathematics chairs in the programmes of UT research institutes was pursued. This has strengthened our multidisciplinary research and provided additional research funding.

The previous research assessment of the Department of Applied Mathematics covered the period 1996-2001. After this assessment the Fundamental Analysis chair was discontinued, since its research profile no longer fitted into the research activities at the University of Twente.

In 2007 a midterm review was conducted together with the Departments of Applied Mathematics at the universities of technology in Eindhoven and Delft. This review covered the period 2003-2005. An important consequence of this midterm review is the recent decision to establish the 3TU Applied Mathematics Institute (3TU-AMI). This institute will

combine all research and teaching in applied mathematics at the three technical universities in the Netherlands and will provide substantial funding for nine professorial positions.

The department is financially healthy and has achieved a significant increase in research volume and output since the previous research assessment. We have been able to attract young, talented staff and new professors for the chairs of Stochastic Operations Research, Mathematical Systems and Control Theory, and Discrete Mathematics and Mathematical Programming.

Strategy and Policy

The Department of Applied Mathematics pursues an active and high quality research programme in the fields of Applied Analysis and Computational Science, Stochastics and Operations Research, and Deterministic and Stochastic Systems Theory. This research receives international recognition and has close connections with important fields of application of technical and societal relevance. These objectives require excellent staff with a strong mathematical background, who are capable of developing close connections with different fields of application. This human capital is the basis for establishing a successful research programme and an inspiring working atmosphere.

The establishment of research institutes at the UT and the 3TU Federation with the universities of technology at Eindhoven and Delft have had a large influence on the research of the Department of Applied Mathematics. It provides focus and mass in selected key areas, and creates the opportunity for mathematicians to take part in decision processes concerning the research programmes within the institutes.

The UT research institutes offer good opportunities to participate in large research programmes, such as the BSIK and EU framework programmes. Applied mathematics chairs actively participate in these endeavours. The research institutes also have frequent discussions with funding agencies and large companies on their research agenda and strategy, benefiting our applied research.

Presently, the research in applied mathematics contributes to the UT research institutes Centre for Telematics and Information Technology (CTIT), the Institute of Mechanics, Processes and Control-Twente (IMPACT), the MESA+ Institute for Nanotechnology, and the Institute for Biomedical Technology (BMTI).

The activities of these research institutes can be summarised as follows:

1. The research of CTIT aims at the design and implementation of advanced telematics and information technology systems and their integration into user environments.
2. The research of IMPACT focuses on the mechanics of fluids and solids, process technology and control, with special emphasis on sustainable energy and smart devices and materials.
3. The MESA+ Institute conducts research in the fields of nanotechnology, microsystems, materials science and microelectronics. MESA+ operates the Clean Room and a Central Materials Analysis Laboratory.
4. BMTI conducts research to improve the quality of human life by restoring bodily functions impaired by disease, accident or age-related deterioration.

Each of these UT research institutes defined a number of strategic research orientations (SROs), which are headed by an SRO officer. From the Department of Applied Mathematics, Professor Boucherie heads the ‘Industrial Engineering & ICT’ SRO in CTIT

and Dr. Bokhove is responsible for the 'Fundamental Studies in Fluid and Solid Mechanics' programme within IMPACT.

The SRO officer is responsible for stimulating the research activities defined in an SRO programme and for initiating activities to obtain funding, by ensuring participation in large national and international research programmes. The institutes also provide the SRO with funds to stimulate new research activities, in particular those enforcing collaboration between different research groups. The SRO programmes are application oriented and strongly multidisciplinary.

The Applied Mathematics research is entirely embedded in the UT research institutes and plays an important role in various areas of research. The research in the Department of Applied Mathematics is application driven and naturally grouped into three focal programmes:

1. Applied Analysis and Computational Science (AACS);
2. Stochastics and Operations Research (STOR);
3. Deterministic and Stochastic Systems Theory (DSST).

These programmes have a close relationship to many research activities at the University of Twente. This ensures excellent embedding of applied mathematics research and also provides an interesting context for mathematical research and collaboration.

A detailed description of these programmes is given in Part B. Future plans are summarised in Section 3.b. An overview of the participation of the different chairs in these three programmes and their contribution to the UT research institutes is given in Table 3.

The Faculty pursues its long-term goals through its personnel policy. More details are given in Section 4.

3.b. Future Developments

The research in the Department of Applied Mathematics is strongly multidisciplinary and organised into the AACS, STOR and DSST programmes. The main activities for the coming years in the research programmes in the Department of Applied Mathematics can be summarised as follows:

1. Applied Analysis and Computational Science

The Applied Analysis and Computational Science programme aims at analysing, modelling and simulating complex problems from the natural, technical and life sciences, using advanced analytical and numerical techniques. This rests directly on a thorough understanding of the mathematical properties of the underlying models, which are generally described by (partial) differential equations. This research requires a strong interplay between modelling, analysis and computation.

Important areas of research are variational methods and dynamical systems theory, focusing on neuroscience and wave phenomena; high order solution-adaptive finite element methods, which are compatible by preserving important aspects of the mathematical structure of partial differential equations; development of fast solvers and large-scale computing; and genuine multi-scale techniques which couple micro and macrophenomena in fluid and solid mechanics, chemistry and the life sciences.

2. Stochastics and Operations Research

The Stochastics and Operations Research programme focuses on the mathematical approach to decision-making and quality control under complete or partial information. The emphasis is on the optimal design and operation of systems with scarce resources. Increasing task complexity in automated systems and the competition on economic markets will receive considerable attention. These activities require new models and algorithmic solution methods, examples being real-time (on-line) systems, decentralisation of complex systems, and fair work distribution or cost allocation.

Important research areas are algorithmic discrete optimisation, algorithmic game theory, dynamic programming, stochastic processes and mathematical statistics.

3. Deterministic and Stochastic Systems Theory

The Deterministic and Stochastic Systems Theory programme focuses on models to describe dynamical systems in interaction with their environment, both for technological and economic applications. Special attention is given to financial mathematics. Three aspects are crucial: model identification (often based on data obtained from measurements), filtering to extract information from measured data, and control problems where we influence the behaviour of the system to make it perform according to specifications.

Important areas of research are the analysis of the structure of observed signals to obtain information about the dynamics and current state of the process. The control of technological applications should allow for tighter specifications and more flexibility to switch between different modes of operation. This requires the analysis of hybrid and nonlinear models. For the financial markets the main focus is on obtaining realistic models for option pricing to avoid arbitrage. Filtering also plays a crucial role in obtaining the parameters of these models.

These three programmes share a number of areas of application. A good example is Health, important aspects of which are present in all three programmes, ranging from improved planning and patient data management, the design and operation of medical equipment to the understanding of fundamental processes in the human body and the treatment of disease.

A second example is Financial Mathematics, which necessitates the development of new tools in both stochastic systems theory and classical probability theory and statistics. Stochastic calculus is used most extensively for the modelling and reduction of risk in the financial trading of derivatives, while statistical techniques are typically used for the analysis of insurance and re-insurance contracts.

The department actively anticipates the retirement in the next few years of the professors of Stochastic Systems and Signals, Statistics and Probability, and Applied Analysis as well as two associate professors of Statistics and Probability. The faculty plans to hire new staff for all these key positions, to ensure that no gap will occur. As a first step, the process to hire a professor of Probability and Statistics was started.

3.c. Cooperation with the other universities of technology in the Netherlands

The research collaboration between the three universities of technology in the Netherlands (DUT, TUE and UT) in 3TU was formalised in 2007. All research is concentrated in the 3TU Institute for Science and Technology (IST). The policy of 3TU-IST is to ensure focus and mass in important areas of research, to reduce unnecessary overlap and to achieve and maintain scientific excellence in the selected focal areas. The 3TU collaboration includes consultation on establishing new professorial chairs and appointments.

The 3TU collaboration resulted in the formation of five centres of excellence: Dependable ICT Systems, Multiscale Phenomena, Sustainable Energy Technologies, Bio-Nano Applications, and Intelligent Mechatronic Systems, which have received in total €50 million funding for strengthening their research and establishing 27 new professorial positions. In 2007 Professor Stoorvogel was appointed as Professor of Mathematical Systems and Control Theory, funded for five years by the Intelligent Mechatronic Systems CoE.

The Mathematical Systems and Control Theory (MSCT) and Numerical Analysis and Computational Mechanics (NACM) chairs participate in the Intelligent Mechatronic Systems and Multiscale Phenomena CoEs, respectively. The other chairs in the department are members of the associated centres of competence (CoCs).

Collaboration with the 3TU partners is also strengthened by the exchange of professorial positions:

- Prof. B.J. Geurts (UT) is part-time Professor 'Anisotropic Turbulence' (0.2 fte) at Eindhoven University of Technology, Department of Applied Physics (2004-2011).
- Prof. H.J.H. Clercx (TUe) holds a part-time Professorship (0.2 fte) 'Mathematical Modelling of Geophysical Flows' at the UT (2005-2010).
- Prof. J. Molenaar (TUe, presently WUR) held a part-time Professorship 'Mathematical Modelling of Polymers' at the UT (1999-2005).

Within 3TU, collaboration includes educational programmes at various levels. For instance, joint master's programmes have been established (applied mathematics participates in the Systems & Control Master), joint classes in the MasterMath are provided and various PhD programmes are run by the research schools.

In March 2009 the three technical universities decided to establish the '3TU Applied Mathematics Institute' (3TU-AMI) as a new centre of excellence within the 3TU Institute for Science and Technology.

The 3TU Applied Mathematics Institute aims to coordinate and stimulate research and teaching in applied mathematics at the three universities of technology in the Netherlands. It will be represented by a director and supported by secretarial staff. An important task of this institute will be to increase the visibility of applied mathematics at 3TU, by organising joint conferences and workshops, inviting international visitors, exchange staff, and the responsibility for a 3TU-AMI website. The Institute will also organise advanced courses for PhD students.

The 3TU Applied Mathematics Institute will represent applied mathematics at 3TU in various organisations relevant to Mathematics in the Netherlands and maintain contact with industry and government.

An important task of the 3TU Applied Mathematics Institute will be the coordination of decisions on new professorial positions. The 3TU-AMI will provide substantial funding for a five-year period to establish three professorial positions at each of the three applied mathematics departments. This will allow a smooth transition when several key professorial positions become vacant due to retirement in the next few years.

3.d. Embedding within external (national and international) programmes

National collaborations are maintained with colleagues in the research schools and networks and the MasterMath programme. Chairs in the Department of Applied Mathematics actively participate in DISC, EIDMA, Beta, MRI, LNMB and JMBC, which have an important role in providing advanced courses to PhD students and in stimulating research collaboration between the participating chairs. In the MasterMath programme special courses are given for masters students in mathematics, which would otherwise not be feasible, due to the small number of students at individual universities. The Department of Applied Mathematics provides a substantial number of these courses.

The scientific staff are active both nationally and internationally in conferences and research collaborations, and provide members of editorial boards, as well as advisory and steering committees. These activities are described in Part B.

4. Researchers and other personnel

All staff are employed within the faculty and not in the research institutes. It is faculty policy that all permanent academic staff contribute to both teaching and research. This also applies to part-time professors, appointed to positions funded by outside sources. Full-time staff also contribute to management activities. PhD students and PostDocs spend most of their time on research; some time is dedicated to teaching. The chair holder determines, in consultation with staff members, the actual tasks of permanent academic staff members, facilitating some differentiation in profiles according to personal interests and capabilities.

Important components in human resource management are yearly meetings between a staff member and the chair holder. In these meetings an open discussion takes place on all factors influencing the performance and well-being of the staff member. Steps can be agreed on by both parties to enhance the collaboration and performance and to open new fields of interest whenever appropriate. The yearly meetings are prepared and documented at the UT using a web-based electronic system. A second type of meeting is an assessment of achieved results. These meetings are part of the steps required to promote a staff member to a higher rank or when serious performance problems occur. These assessment meetings are not held on a regular basis. The results of both types of meetings are archived in the personnel file.

Most senior staff members have recently attended the Academic Leadership programme facilitated by the university. New staff members lacking in teaching experience follow the DUIT programme to enhance their teaching skills.

New positions for a chair holder to an established chair are extensively advertised and also the network of senior staff members is used to identify candidates. The dean, the head of department, expert UT colleagues, and the scientific director(s) make a description of the field of activity of a new chair.

Part-time professors are appointed if there is a faculty/institutional interest in providing seniority for a specific sub-field for which collaboration with an external partner would be fruitful. These appointments are normally financed by third parties or through exchanges with other universities and made for a period of three years, extendable for another three years.

Personal professorial chairs are awarded to excellent senior permanent scientific staff in sub-fields of substantial width and size within a chair. Candidates must be outstanding in their field.

A tenure track programme has recently been initiated at the UT to attract promising young scientists at the assistant professor level. This programme offers promotion to the level of associate professor within five years if a number of quality criteria concerning research, teaching and acquisition of external funds are met. The faculty provides additional coaching and support to help meet these criteria. Candidates are reviewed on an annual basis. Both the university and the EEMCS Faculty have provided additional funding for a total of four positions within EEMCS dedicated to female staff in the tenure track programme.

Both the university and the EEMCS Faculty actively stimulate and support staff members who apply for the NWO 'Innovational Research Incentives' programme. This programme provides funding for both the researcher and temporary staff (PhD students and PostDocs) in their research projects.

The University's policy is to organise support staff as much as possible at university level. This includes ICT (network, infrastructure and system management), Financial and Economic Affairs, and the Personnel Department. In order to ensure a short link to 'customers', part of the ICT staff is situated within the EEMCS buildings. Also, local administrative support, in particular regarding project administration and contracts, is available. A small personnel department handles many issues regarding the hiring of new staff, such as visa and working permits. Other personnel affairs are organised at university level.

The ratio of academic staff (including Postdocs and PhDs) to non-academic staff in the faculty (including Electrical Engineering and Computer Science) is 4 : 1 .(ac:non-ac). At university level this ratio is 2 : 1.

Table 4. Research staff employed by the Department of Applied Mathematics in the past six years. [Enumeration of Tables 10, 15 and 20 in Part B.; standardised.]

Research staff at institutional level (in full time equivalents)						
Name and present title	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Institutional level						
Tenured staff	12,42	12,24	11,94	11,17	10,80	11,10
Non-tenured staff	6,47	5,99	5,79	6,10	6,45	4,99
PhD students	29,78	33,47	33,39	30,13	20,03	18,51
Total staff	48,68	51,69	51,12	47,40	37,28	34,61

4.a PhD Programme and Policies

At the start of a four-year PhD project a clear research plan is available. Based on the background of the PhD student, an educational programme is set up, consisting of courses necessary for the PhD research. These courses are provided by the university, national research schools and through international programmes, and require a significant effort by the PhD candidate in his/her first year. PhD students are also offered general courses, such as professional effectiveness, technical writing and presenting, and career orientation. In addition, English and Dutch language courses are offered. Presently, about 50% of the PhD students originate from outside the Netherlands

All PhD students are supervised by a senior staff member and have regular meetings with their promoter and supervisor to discuss progress. At the end of the first year a formal evaluation takes place, in which the PhD student presents his/her research progress. At that time the plans for the coming years are also discussed and updated. If progress is satisfactory, the PhD project will be continued. In subsequent years progress is monitored in annual evaluations, during which adjustments to the research plan are also discussed.

PhD students present their research at international conferences, for which extensive travel funds are made available. They publish their research in peer-reviewed international journals. These publications provide the main body of their PhD theses.

Apart from the traditional PhD programme, a five-year combined MSc-PhD programme was started in 2008 for international students. The first year consists of the regular Applied Mathematics master's programme. The research that is performed for the final MSc project in the second year overlaps with the topic of the PhD research. If successful during this period, the student will continue with the PhD research, otherwise a master's degree will be obtained and the project discontinued.

Starting in 2009, the university will establish graduate schools in which both master's and PhD programmes will be combined. This will provide the opportunity to offer high-level specialised classes at graduate level and improve the visibility of the university to attract excellent national and international students.

Table 5 lists the names and projects of the PhD candidates participating in the research programmes of the institute. A distinction is made in the following categories:

- (**PhD**) Standard PhD candidate with employee status and conducting research, with primary aim/obligation to graduate.
- (**EPhD**) External PhD candidate without employee status, conducting research not under the authority of the institute, with primary aim to graduate.

Table 5. PhD Candidates and project overview

Name	Progr.	Project Name	Funding	PhD Type
Ambati, V.R.	AACS	Forecasting water waves and currents	UT	PhD
Baarsma, H.E.	STOR	Smart surroundings	BSIK	PhD
Ballast, A.	AACS	3D ship motions in 3D nonlinear waves	STW	PhD
Berg, J. van den	AACS	Offshore sand waves: process-oriented versus stochastic approach	STW	PhD
Bonsma, P.S.	STOR	Cuts in graphs	UT	PhD
Bos, F. van der	AACS	Advanced simulation techniques for vortex dominated flows	STW	PhD
Bouza Allende, G.	STOR	Mathematical programming with Equilibrium Constraints	Cuba/UT	(E)PhD
Brueggemann, T.	STOR	Local search with exponential neighbourhoods	NWO	PhD
Cadic, M.A.	DSST	Strongly robust adaptive control: the strong robustness approach.	EU-NCN	PhD
Cheung, S.K.	STOR	Beyond 3G: Building expertise yielding outperforming networks derived from 3G	Senter/Novem	PhD
Coenen, T.J.M.	STOR	PN@H: Quality of service for personal networks at home	Senter/Novem/IOP Gencom	PhD
Dieker, A.B.	STOR	EQUIP: Enabling quality of service in IP-based communication networks	NWO	PhD
Endrayanto, A.I.	STOR	Stochastic network analysis for the design of self optimising cellular mobile communications systems	STW	PhD
Foreest, N.D. van	STOR	Queues with congestion-dependent feedback	UT	PhD
Grigoras, D.R.	STOR	SST: Smart synthesis tools	Senter Novem	PhD
Hadianti, R.	STOR	Wiener-Hopf techniques for the analysis of the time-dependent behaviour of queues	UT	PhD
Harutyunyan, D.	AACS	Computational integrated optics for photonic structures	NWO	PhD
He, Y.	DSST	Real options in the energy markets	UT	PhD
Heideveld, S.A.	STOR	Game theory and supply chains	UT	PhD
Hiremath, K.R.	AACS	EU NAIS project	EU	PhD
Julius, A.A.	DSST	CASH: compositional analysis and specification of hybrid systems	NWO	PhD

Name	Progr.	Project Name	Funding	PhD Type
Kakumani, R.	DSST	AdHoc: Analysis and design of hybrid systems using optimal control	NWO	PhD
Karjanto, N.	AACS	Extreme waves	STW	PhD
Kholopova, M.	DSST	Estimating a two-factor model for the forward curve of electricity	UT	PhD
Klaij, C.M.	AACS	Advanced simulation techniques for vortex dominated flows	STW	PhD
Krystul, J.	DSST	HYBRIDGE. Distributed control and stochastic analysis of hybrid systems supporting safety critical real-time systems design	EU	PhD
Kuczaj, A.K.	AACS	Fractal forcing of anisotropic, inhomogeneous turbulence: flow-structures and heat transfer	FOM	PhD
Ligterink, dr. N.E.	DSST	PACDAS: port based approach complex distributed models	STW	PhD
Litjens, R.	STOR	Capacity allocation in Wireless Communication Networks	TNO	EphD
Lukocius, V.	STOR	Statistical analysis of dependence effects on insurance portfolios	STW	PhD
Maksimovic, M.	AACS	Nanoned: Optical switching by NEMS-modelling & simulation	STW	PhD
Margaretha, H.	AACS	Wave – current interaction	MARIN	PhD
Meent, R. van de	STOR	Monitoring the Internet	UT	PhD
Minina, V.	DSST	Optimization of event-based hedging strategies for derivatives	STW	PhD
Moelja, A.A.	DSST	Control of systems with delays	NWO	PhD
Mourik, S. van	DSST	Modelling and control of flows	STW	PhD
Netchaev, A.	AACS	Triangulation methods in surface construction	STW	PhD
Nicolau, J.B.	AACS	Computational integrated optics for photonic structures	NWO	PhD
Nieberg, T.	STOR	EYES: Energy-efficient sensor networks	EU	PhD
Nurdiati, S.N.	STOR	Control of control charts	STW	PhD

Name	Progr.	Project Name	Funding	PhD Type
Nurdin, H.I.	DSST	EOARD. Advanced robust STAP algorithms and fast performance evaluation techniques based on rare Event theory	EU	PhD
Pasumarthy, R.	DSST	GEOPLEX. Geometric network modelling and control of complex physical systems	EU	PhD
Pesch, L.	AACS	Two-phase flows with free surfaces	STW	PhD
Polner, M.A.	AACS	Numerical simulation of the dynamic behaviour of riser bundles and flexible hoses	MARIN	PhD
Salman, M.	STOR	Special topics in graph theory	ITB Indonesia/UT	(E)PhD
Sollie, W.E.H.	AACS	Space-time discontinuous Galerkin finite element methods for two-phase flows	UT	PhD
Sopaheluwakan, A.	AACS	EPAM	KNAW	PhD
Strubbe,S.N	DSST	HYBRIDGE. Distributed control and stochastic analysis of hybrid systems supporting safety critical real-time systems design	EU	PhD
Sudirham, J.J.	AACS	Analysis and control of transport phenomena in wet-chemical etching	STW	PhD
Sun, H.	STOR	Set game theory	China	EPhD
Suryanto, A.	AACS	Optics beyond SVEA	STW	PhD
Susanto, H.	AACS	EPAM	KNAW	PhD
Talasila, V.	DSST	A Hamiltonian approach to discrete mechanics: issues in geometry, modelling, simulation and control	UT	PhD
Tassi, P.	AACS	Discontinuous Galerkin method for shallow water equations forecasting river flows	EU	PhD
Tchesnokov, M.A.	AACS	Optics beyond SVEA	STW	PhD
Unteregge, M.	DSST	BOSS: Bounds on stable semigroups	NWO	PhD
Uranus, H.P.	AACS	Optics beyond SVEA	STW	PhD
Villegas, J.A.	DSST	ERACIS: Energy based representation, analysis and control of infinite-dimensional systems	NWO	PhD
Wang, F.	DSST	Volatility smile modelling for interest rate derivates	ABN-AMRO	PhD
Wang, X.	STOR	Exact algorithms	NWO	PhD

Name	Progr.	Project Name	Funding	PhD Type
Wang, L.	STOR	Integral trees and integral graphs	China	EPhD
Wibowo, A.	DSST	Continuous-time identification of exponential-affine term structure models	UT	PhD
Xu, G.	STOR	Matrix approach to cooperative game theory	China	EPhD
Zhao, H.	STOR	Chromaticity and adjoint polynomial of graphs	China	EPhD
Zilber, A.	DSST	Waardebepaling financiele derivaten	ABN-AMRO	PhD

Table 6. Success rates of PhD Graduates

Starting year	Enrollment (a+b+c+d+e+f)	Total number of PhD-Candidates	Graduated after 4 years (a)	Graduated after 5 years (b)	Graduated after 6 years (c)	Graduated after 7 years (d)	Not yet finished (e)	Discontinued (f)
2004	7	41	5 / 72%	1/ 14%	-	-	1 / 14%	-
2003	12	36	9 / 76%	1 / 8%	-	-	1 / 8%	1 / 8%
2002	11	27	7 / 64%	2 / 18%	-	-	1 / 9%	1 / 9%
2001	11	16	8 / 73%	2 / 18%	-	-	-	1 / 9%
2000	3	6	2 / 67%	-	-	-	-	1 / 33%
1999	4	4	-	1 / 25%	2 / 50%	1 / 25%	-	-
Total	46	-	29 / 63%	7 / 15%	2 / 4%	1 / 2%	3 / 7%	4 / 9%

Data in the grey-coloured cells are not representative because the information on PhD students who discontinued their study before 01.01.2004 is incomplete.

Table 7. Career destination of PhD graduates

Career Destination after end of contract (graduation or termination)	**Number**
Tenured academic staff in the Netherlands	1
Tenured academic staff abroad	10
Non-tenured academic staff in the Netherlands	4
Non-tenured academic staff abroad	22
Trade and Industry (including Technological Research Institutes)	23
Government	
Consultancy	
Miscellaneous (not looking for employment)	2
Continued PhD research after end of contract	3
Unemployed	

5. Resources, funding and facilities

The University policy is to make chairs accountable for their finances and to stimulate them to obtain external research funding. Establishing the research institutes supports this policy, as these institutes are better positioned to obtain research funds in larger research programmes, which is generally not possible for individual chairs.

In the financial system used during the reporting period most of the budget allocated to a chair is determined by the research and teaching output of that chair in the previous years. The main parameters are the number of successful PhD defences, the number of externally funded projects and the number of ECTS obtained by students with pass marks. Apart from this direct funding, a substantial amount of money is allocated to strategic programmes of the UT research institutes.

Additional funding for the Department of Applied Mathematics has been obtained from the 3TU Intelligent Mechatronic Systems Centre of Excellence, financing for five years the professorial position in Mathematical Systems and Control Theory.

Each year the chair holder is requested to make an integrated budget plan to be approved by the Management Team. A chair generally has financial reserves as a result of income generated and expenditure made in the past, which can be used for temporary staff and investments.

The UT financial system has been very successful in stimulating the acquisition of external research funds. The system was, however, primarily based on output financing, which is not always in line with the institutional research plans or with maintaining proper attention to long-term fundamental research. Starting in 2010, a significant part of the research funds will therefore be based on a five-year agreement between the research institute, faculty and the chair regarding their joint long-term research plans and the prospective number of externally funded projects. This new system should ensure a better balance between short-term and long-term objectives.

Following a reorganisation in 2006, the financial situation of the EEMCS Faculty is healthy, with a reserve currently of €34 million. About 65% of this reserve is directly allocated to the chairs within EEMCS.

The Department of Applied Mathematics has no separate lab facilities, and library services are organised at university level. Funding for personal computers is either obtained from research projects or from funding directly allocated to the chairs.

In Table 8 the annual funding is indicated. Direct funding is first budget tier (directly from the university). Research funds are accumulated second and third budget tiers (national research programmes and research contracts with third parties).

Table 8. Funding and expenditure at institutional level

Funding and expenditure at institutional level (in € K)						
1. Funding:	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Direct funding	5,765	6,029	6,713	6,603	6,510	7,376
Research funds	1,202	956	927	911	638	608
Contracts	821	779	665	646	839	586
Other						
2. Total	**7,789**	**7,764**	**8,305**	**8,160**	**7,986**	**8,570**
3. Expenditure:	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Personnel costs	4,662	5,134	5,313	5,256	4,772	5,729
Other costs	2,901	2,742	2,884	2,730	2,524	1,783
4. Total	**7,563**	**7,876**	**8,197**	**7,986**	**7,296**	**7,512**

6. Overview of the results

A full overview of scientific output is given in Table 9. Only reviewed publications in publicly accessible sources are shown.

Table 9. Overview of numbers of publications

		2002	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**Total**
1. Academic publications	a. PhD-theses	12	4	4	14	15	9	7	65
	b. in refereed journals	99	87	76	81	82	83	66	574
	c. international conference proceedings	66	57	80	64	55	28	45	395
	d. books	3	1				2		6
	e. book chapters	10	7	4	7	8	6	2	44
Total		190	156	164	166	160	128	120	1084
2. International patents			1						

7. Analysis, perspectives and expectations for the institute

A series of major decisions has been instrumental in the development of research in the Department of Applied Mathematics over the reporting period:

1. The University opted for the creation of a small number of key research institutes with strong incentives for research activities. The chairs in the Department of Applied Mathematics participate in four of the five UT research institutes, viz. CTIT, IMPACT, BMTI and MESA+.
2. The 3TU Federation was established in 2007. All the research of our department is part of the 3TU Institute of Science and Technology.
3. The merging of 3 faculties (Electrical Engineering, Applied Mathematics and Computer Science) in EEMCS and the participation in research institutes has intensified contacts and collaboration between research groups.

- *Strengths*
  - The research of the Department of Applied Mathematics plays a key role in the multidisciplinary programmes of the UT research institutes, illustrated, for example, by our intensive collaboration with a large number of chairs in other departments.
  - There is a significant second and third-tier research volume.
  - We have strong research ties with large technological research institutes, a variety of industries, banks and insurance companies, both nationally and abroad.
  - The appointment of three new professors well before the retirement of key professorial staff in our department.

- *Weaknesses*
  - The undergraduate influx is low, implying that we have to rely on talented students from elsewhere for our graduate programme.
  - Our presence in national mathematics organisations has been too limited.

- *Opportunities*
  - The new 3TU Applied Mathematics Institute will significantly strengthen the position and visibility of applied mathematics in the Netherlands.
  - Programme development within Institutes secures critical mass, embedding and greater possibilities for influencing national and international research agendas.
  - The participation of two chairs in the 3TU centres of excellence provides significant additional research funding.

- *Threats*
  - The need to acquire external research funding through projects with a high level of applicability might shift research too far towards short-term issues in lieu of more fundamental research.
  - The increased interest of students in multidisciplinary studies deflects talents from basic disciplines, such as applied mathematics.

- *Analysis*

  National and UT research policies have improved our research environment and provided new opportunities for interdisciplinary research. We will continue with our endeavours to strengthen our position and increase the student influx, stimulated by the planned new appointments of professors in our department and the opportunities provided by the 3TU Applied Mathematics Institute.

Section B: Documentation of the research programme

B1. Applied Analysis and Computational Science (AACS)

- **Sub-programmes:** three sub-programmes have been integrated into AACS

  - Applied Analysis
  - Numerical Analysis
  - Computational Science

- **Themes:** focal areas, defined across sub-programme boundaries are as follows;

  - Prof. J.J.W. (Jaap) van der Vegt holds the chair of 'Numerical Analysis and Computational Mechanics' (NACM), focusing on the analysis and development of finite element methods.
  - Prof. E. (Brenny) van Groesen holds the chair of 'Applied Analysis and Mathematical Physics' (AAMP), focusing on the mathematical physical analysis of nonlinear wave phenomena.
  - Prof. S.A. (Stephan) van Gils holds a professorship in 'Nonlinear Analysis', focusing on physical and bio-medical applications.
  - Prof. B.J. (Bernard) Geurts holds a professorship in 'Multiscale Modelling and Simulation', developing and analysing computational strategies for turbulent flow modulation and bio-medical applications.
  - Prof. H.J.H. (Herman) Clercx holds a part-time professorship (0.2 fte) in 'Mathematical Modelling of Geophysical Flows' (2005-2010), concentrating on turbulent Lagrangian dispersion and heat and mass transfer in rotating flows.
  - Prof. J. (Jaap) Molenaar held a part-time professorship (0.2 fte) in 'Mathematical Modelling of Polymers' (1999-2005), focusing on the analysis of non-Newtonian fluid mechanics.

- **NABS code:** N07

- **Chairmen during the review period:**

  - NACM: Prof. J.J.W. van der Vegt
  - AAMP: Prof. E. van Groesen
    (Starting 1.5.2009 Prof. S.A. van Gils)

- **Starting and/or ending date of (each sub-) programme:**

  - The part-time professorship in 'Mathematical Modelling of Polymers' held by Professor J. Molenaar ended in 2005 after a six-year period.
  - The part-time professorship in 'Mathematical Modelling of Geophysical Flows' has been held by Professor H.J.H. Clercx since 2005 and was extended for a second three-year period in 2007, running up to 2010.

- **Formal affiliations outside the department and other formal cooperations:**
  - Professor E. van Groesen has been scientific director of LabMath-Indonesia, Bandung Indonesia, since 1 January 2008.
  - Professor B.J. Geurts has been part-time Professor of 'Anisotropic Turbulence' at Eindhoven University of Technology, Department of Applied Physics (0.2 fte), since 2004.
  - Professor H.J.H. Clercx has been full Professor of 'Transport in Turbulent Flows' at Eindhoven University of Technology, Department of Applied Physics, since 2006.

1. Mission statement

The mission of the Applied Analysis and Computational Science (AACS) programme is the development of analytical and numerical methods that contribute to mathematics and its application in a multidisciplinary environment. We actively integrate the results of our work into computational (multiscale) strategies for the technical, natural and life sciences. This enables our research to play a central role in diverse research communities with which we collaborate. This strengthens our position in terms of high quality publications and international recognition and helps in providing a complete education to our students.

2. Leadership

Two chairmen are responsible for the integral management of the AACS programme, while all other staff members are involved in one or more specialised tasks, such as coordination of the educational programme and international collaboration. Staff meetings take place on a monthly basis. Staff colloquia are organised periodically, in which MSc and PhD students, research visitors and staff members present their work.

Personal development is stimulated generously, for example, through participation in courses that strengthen managerial skills, extended research visits to universities and institutions abroad, and participation in international conferences. A formal, annual appraisal is part of the faculty's HRM programme.

Grant applications for PhD projects generally involve the collaboration of several programme members. This improves the scope, impact and chances of success, while it also enhances communication in our team and increases innovation in our mathematical research. The formal responsibility for individual PhD projects resides with one member of staff, who is the daily supervisor.

All members of staff participate in a continuous process of systematic quality control, providing feedback on each other's performance in teaching, and in the guidance of BSc, MSc and PhD students. The progress of students is regularly discussed by the members of staff among themselves.

3. Strategy and policy

3.a. Design in brief

The distinctive aspect of research in the AACS programme is the thorough integration of mathematical modelling, applied analysis and numerical methods. The integration of these three areas of expertise is essential to achieving our role as a key partner in multidisciplinary research. This deliberate choice opens possibilities for high quality research, which would otherwise be closed if our focus were put exclusively on only one or two of these fields of study.

The research at AACS is strongly embedded in the IMPACT, MESA+ and BMTI research institutes of the UT. We actively participate in these institutes and contribute to their research organisation, for example, as coordinator of the 'Fluid and Solid Mechanics' strategic research orientation and as a member of the Management Team of IMPACT. In addition, an extensive network of collaborations exists nationally, in particular within 3TU, and internationally with numerous research groups from academia, research institutes and industry. This network provides excellent opportunities for multidisciplinary collaborations, in which applied mathematics is a binding element.

The integration of research into mathematical modelling, applied analysis and numerical methods provides an essential strengthening of AACS, as it improves collaborations both within the programme and with colleagues in UT research institutes. Examples include applied work on wave phenomena, on turbulence and aerodynamics, on optics, and on bio-medical applications. In multidisciplinary collaborations, our focus is on mathematical modelling and abstraction. A recurring theme in our work is the development of computational models that are consistent with the underlying physical principles and mathematical structures and properties. This opens up new capabilities for accurate predictions of systems of realistic complexity that are of relevance in a multitude of application areas. This general approach structures our long-term research in applied and numerical analysis.

Applied Analysis

Within our research programme the research in applied analysis concentrates on nonlinear and/or inhomogeneous partial differential equations, bifurcation & stability analysis, the development of rigorous small-scale turbulence models and the analysis of boundary conditions. The basic mathematical methods originate from dynamical system theory, variational methods and methods for free boundary problems.

Consistent mathematical models for multidisciplinary problems often have an underlying variational structure, which can be exploited. Important examples are the Euler and Maxwell equations. Consistency also guarantees that important symmetries are retained in simplified models, such as conservation of energy and circulation. Using advanced analytical methods we have looked for special solutions, their stability, degeneracy, etc. Various numerical techniques have been used for a further investigation, for instance, computer algebraic methods for bifurcation diagrams, and pseudo-spectral and mode-decomposition methods to obtain quantitative results for models of realistic complexity.

Numerical Analysis

The research on partial differential equations is combined with the development, analysis and application of finite element methods (FEM) suitable for problems in physics and engineering. Numerical schemes have been designed such that consistency with the underlying physical mechanisms and mathematical structure of the model is ensured as much as possible, also at the discrete level. An example is the imposition of Hamiltonian structure onto finite element models of wave phenomena.

Special attention is given to the development of solution adaptive discontinuous Galerkin methods. These techniques have been applied, for example, to fluid flow, including free surface problems as occur in water waves and at density fronts. The development of solution adaptive algorithms was accompanied by new implicit a posteriori error estimation techniques and efficient multigrid and pseudo-time integration methods. In addition, considerable attention has been given to translating algorithms to high-performance computing infrastructure.

Computational Science

Most of the problems under consideration contain a wide range of length and time-scales, which simultaneously govern the dynamics of these systems. This requires an intimate link between mathematical-physical modelling and large-scale computation. We work on the development of new modelling strategies that consistently represent the wide variety of physical, chemical and biological mechanisms at all scales.

One focal area of research is turbulence and its modulation due to the interaction of fluid-mechanical forces with competing dynamics arising, for example, from rotation, stratification, coupling to chemical processes, such as combustion, or physical processes, such as evaporation or buoyancy. A striking example is rotating Rayleigh-Benard convection, which represents fundamental processes in the Earth's atmosphere.

In most cases of interest it is not possible to compute in full detail all dynamically relevant scales – a coarsened description is pursued instead to capture the primary features. In particular, research has been conducted into Large-Eddy Simulation (LES) for turbulent flow. This work is aimed at a systematic framework for assessing, predicting and minimising simulation errors, thereby enhancing the reliability of large-scale computational models.

3.b. Programme development

The chairs within AACS will increasingly integrate their research, to allow for greater participation of mathematics chairs in university, national and international research efforts. Four main areas of concentration will be taken up in the coming years:

1. Computational bio-science: mathematical modelling is used to derive dynamic models that range from the level of a single cell to synaptic networks, connecting different parts of the brain or forming specialised tissues. Correspondingly, questions range from understanding the fundamental properties of cells and synapses to the role of the rhythms of the brain, to the long-term evolution of the mechanical health of arteries, of relevance to arteriosclerosis and the rupture of cerebral aneurysms. Nonlinearities are important as well as the many closed-loop systems that are involved.

2. Environmental safety: this focal area will benefit from developments in mathematical modelling, numerical representation, data assimilation and large-scale computation. Attention will be given to the generation of aerosols, the dispersion of pollutants in urban areas and transport in coastal areas. This will bring about new developments in solution adaptive numerical methods, multiscale modelling of complex, nonlinear phenomena and the formulation of effective boundary conditions.
3. Wave phenomena: considerable research will be dedicated to water waves and other wave phenomena, such as in optics. The focus in the research on water waves is on wave-vortex interaction by retaining the basic Hamiltonian description of the Euler equations, both in numerical discretisations and in various simpler models for uni-directional and multi-directional waves. Applications are the generation of extreme waves in model basins, coastal hydrodynamics and tsunami waves.
4. Compatible schemes: for many applications, higher order, accurate, physically and mathematically consistent numerical discretisations are crucial. New insights for compatible schemes will be sought by using the geometry of differential forms in finite element discretisations. Major challenges are the development and analysis of compatible schemes for solution adaptive algorithms and the efficient solution of the resulting (non)linear algebraic systems.

A binding element in many activities in the AACS programme is the development and analysis of genuine multiscale strategies, in which physical, chemical and biological processes at a wide range of length and timescales are consistently integrated, which is crucial for many applications.

The main mathematical challenges in multiscale problems that we will address are:

i.) inverse problems and parameter estimation to link models to real-world data,
ii.) reduction techniques to arrive at simpler problems suitable for analysis and numerical bifurcation theory,
iii.) coupling of models of different types across a physical interface, like the Navier Stokes equations coupled to lattice Boltzmann models.

4. Processes in research, internal and external collaboration

Work in the AACS programme is always a mixture of dedication to developing mathematical expertise per se and to developing close collaborations within multidisciplinary teams. Thus, research processes in AACS contain strong elements of teamwork, as well as individual research. The degree to which one or the other component prevails is strongly dependent on the preference of the particular member of staff. Research is supported primarily through funding from STW, NWO, FOM, EU and, to a lesser degree, by large technical research institutes in the Netherlands and national and international industries.

Communication within AACS is based on monthly meetings of the staff, and presentations during our joint colloquia, daily informal meetings, in addition to weekly meetings of dedicated working groups. The latter type of meeting is essential in transferring knowledge, controlling progress in specific projects and ensuring that work of high quality is developing. These aspects are externally assessed by frequent publications, exposing our work to peer reviewing.

In order to stimulate our research activities we pursue extensive collaboration with people from groups outside the AACS programme. Several members of our programme are also active in national and international organisations.

5. Academic reputation

- O. Bokhove
  - Awarded KNAW research fellowship (2001-2006).
  - Visiting scientist in the Woods Hole Geophysical Fluid Dynamics Program, Woods Hole Oceanographic Institution, Woods Hole, U.S.A. (0.1fte/year; summers 2005, 2007, 2008).

- H.J.H. Clercx,
  - Awarded NWO VICI grant in the Innovational Research Incentives Programme of NWO (2003).
  - Full professor "Transport in Turbulent Flows" at Eindhoven University of Technology (since 2006).
  - Visiting Scientist at UCSB, Santa Barbara, USA (0.1 fte, 2004-2005).
  - Member of the Scientific Users Selection Panel (SUSP) for HPC-Europe2 (2008-2012).

- B.J. Geurts
  - Part-time Profesor of Anisotropic Turbulence at TUE, Department of Applied Physics (0.2 fte, since 2004).
  - Part-time Profesor of Large-Eddy Simulation at Queen Mary College, University of London (0.2 fte, 1999-2004).
  - Visiting Scientist at the Center for Nonlinear Studies, Los Alamos National Laboratory, USA (0.1 fte, 2003-2007).
  - Editor Journal of Applied Mathematics (since 2001).
  - Chair EU Project COST Action P20: LES-Advanced Industrial Design (since 2006).

- S.A. van Gils
  - Associate Editor of the SIAM Journal of Applied Dynamical Systems (2003-2007).

- E. van Groesen
  - Member of the International Advisory Board of the Centre of Nonlinear Studies (CENS), Tallinn University Estonia (till 2008).
  - Member of the Steering Committee SIAM Activity Group (SIAG) on Nonlinear Waves and Coherent Structures.
- C.C. Stolk
  - Awarded a VIDI grant in the Innovational Research Incentives Programme of NWO (2005).

- J.J.W. van der Vegt
  - Editor book series ‘Advances in Computational Fluid Dynamics’ (since 2008).
  - Associate Editor of the Journal of Scientific Computing (since 2009).
  - Member international reviewing committee INRIA programme ‘Computational Models and Simulation’ (2009).

6. External validation

6.a. Societal relevance

The scientific context of the AACS programme is characterised by attention to multidisciplinary research and applications. This stimulates close collaboration with researchers in many different disciplines, at universities, technological research institutes and industry. Correspondingly, an effective way to transfer knowledge to external partners is achieved, which is further stimulated by PhD and master's students working in various (research) companies after graduation.

Examples of a direct transfer of knowledge are the close collaboration with the Maritime Research Institute MARIN on the modelling of extreme waves and wave-current interaction in a model basin; the development and integration of new, discontinuous Galerkin finite element methods for compressible flows in the computer programmes of the Netherlands Aerospace Institute NLR; and the use of a simulator tool for 3D optical ring resonators by the company C2V.

We continue to expand these external contacts, since they provide challenging research questions, additional research funding and stimulate the transfer of knowledge to society.

New directions are in biomedical applications, seismic exploration, and are associated with many challenging topics in fluid mechanics, such as inkjet printing, complex multiphase flows and environmental problems.

6.b. Industrial contacts

- AKZO-Nobel (dispersed multiphase flows)
- Alkyon (water waves)
- Bubbling Minds (high-performance computing)
- C2V Concept to Volume (optics)
- Corus (dispersed multiphase flows)
- Deltares (coastal engineering)
- DSM (dispersed multiphase flows)
- Maritime Research Institute Netherlands (water waves)
- National Aerospace Laboratory NLR (aerodynamics)
- NUMECA (computational fluid dynamics)
- Philip Morris International (dispersed multiphase flows)
- PhoeniX (simulation methods for integrated optics)
- Shell Research (dispersed multiphase flows, seismic modelling)

7. Researchers and other personnel

Table 10. Researchers in the AACS programme

	Name	2003	2004	2005	2006	2007	2008
AACS							
Tenured staff							
professor (hgl)	Geurts, Prof. B.J.				0.23	0.40	0.40
	Gils, Prof. S.A. van		0.14	0.20	0.20	0.20	0.32
	Groesen, Prof. E. Van	0.32	0.40	0.40	0.40	0.40	0.40
	Vegt, Prof. J.J.W. van der	0.40	0.40	0.40	0.36	0.28	0.28
associate professor (uhd)	Damme, Dr. R.M.J. van	0.40	0.40	0.40	0.40	0.40	0.40
	Geurts, Prof. B.J.	0.40	0.40	0.40	0.17		
	Gils, Prof. S.A. van	0.40	0.06				
	Hammer, Dr. M.		0.10	0.40	0.38	0.17	0.17
assistant professor (ud)	Bochev, Dr. M.A.	0.40	0.40	0.40	0.40	0.40	0.40
	Bokhove, Dr. O.		0.50	0.60	0.40	0.40	0.40
	Hammer, Dr. M.	0.40	0.30				
	Lanser, Dr. D.	0.26					
	Meijer, Dr. H.G.E.					0.20	0.20
	Stolk, Dr. C.C.		0.15	0.40	0.40	0.40	0.25
Total tenured staff		**2.98**	**3.26**	**3.60**	**3.34**	**3.25**	**3.22**
Non-tenured staff							
professor (hgl)	Clercx, Prof. H.J.H.			0.11	0.11	0.11	0.11
	Molenaar, Prof. J.	0.11	0.11	0.11			
assistant professor (ud)	Bokhove, Dr. O.	0.75	0.12				
postdoctoral fellows	Ambati, Dr. V.R.					0.08	0.99
	Andonowati, Dr. A.			0.18	0,22	0.25	0.25
	Bell, Dr. A.	0.30	1.00	1.00	1.00	0.53	
	Iskandar, Dr. A.A.P.	0.83					

	Name	2003	2004	2005	2006	2007	2008
	Izsák, Dr. F.		0.29	0.50	0.50	0.50	0.28
	Sudirham, Dr. J.J.S.				1.00		
	Klaij, Dr.C.M.				0.42	0.33	
	Köster, Dr. D.T.P.					0.50	0.58
	Kuiken, Prof. H.K.	0.10	0.10	0.10			
	Sopaheluwakan, Dr. A.					0.29	0.21
	Stoffer, Dr. R.			0.20	0.39	0.19	
	Tomar, Dr. S.K.	0.50	0.40				
	Xu, Dr. Y.			0.42	1.00	0.58	
other junior staff (moz, twaio)	Bernsen, E.	0.04	0.52				
	Klopman, G.	0.26	0.34	0.34	0.34	0.11	
	Nining Sari Ningsih, N.S.N.			0.08			
	Pesch, Dr. L.					0.23	
	Stoffer, Dr. R.	0.40	0.42				
	Tassi, P.A.					0.10	
Total non-tenured staff		**3.29**	**3.30**	**3.04**	**4.98**	**3.80**	**2.42**
PhD Students							
junior staff (aio, oio, moz-p)	Ambati, V.R.	0.34	0.80	0.80	0.80	0.48	
	Berg, J. van den	0.60	0.80	0.80	0.80	0.20	
	Bos, F. van der	0.80	0.80	0.80	0.53		
	Deb, B. S.						0.13
	Ghazaryan, L.						0.20
	Harutyunyan, D.	0.80	0.80	0.80	0.64	0.03	
	Hiremath, K.R.	0.80	0.80	0.73			
	Ivanova, O.				0.80	0.80	0.80
	Sudirham, J.J.S.	0.80	0.80	0.80			
	Karjanto,N.	0.67	0.67	0.67	0.64		
	Klaij, C.M.	0.80	0.80	0.80	0.47		
	Kristina, W.						0.40
	Kuczaj, A.K.	0.80	0.80	0.80	0.80	0.39	
	Lakhturov, I.				0.27	0.80	0.80
	Lie She Liam, L.S.L.				0.27	0.80	0.80

	Name	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
	Lopez Penha, D. J.						0.54
	Lourens, M.A.J.						0.80
	Maksimovic, M.				0.80	0.80	0.46
	Margaretha, H.	0.48	0.30	0.39			
	Mikhal, I.						0.13
	Netchaev, A.	0.80	0.43				
	Nicolau, J.B.	0.80	0.80	0.80	0.44		
	Nurijanyan, S.						0.13
	Peeters, B.W.I.				0.18	0.80	0.80
	Pesch, L.	0.30	0.80	0.80	0.80	0.49	
	Polner, M.A.	0.80	0.80	0.59			
	Rhebergen, S.			0.20	0.80	0.80	0.80
	Root, T.J.P.M. op 't				0.51	0.80	0.80
	Sarmany, D.			0.27	0.80	0.80	0.80
	Sollie, W.E.H.	0.80	0.80	0.80	0.47		
	Sopaheluwakan, A.	0.07	0.80	0.80	0.80		
	Suryanto, A.	0.56					
	Susanto, H.	0.80	0.80	0.80	0.07		
	Tassi, P.A.	0.04	0.80	0.80	0.20		
	Tchesnokov, M.A.	0.80	0.80	0.66			
Total PhD Students		**12.66**	**14.20**	**13.91**	**11.89**	**7.99**	**8.39**
Total Research Staff AACS		**18.94**	**20.76**	**20.55**	**20.21**	**15.04**	**14.03**

8. Resources, funding and facilities

8.a. Laboratory infrastructure

Not applicable

8.b. FTE funding PhDs/postdocs

Table 11. Source of funding for PhD and Post Doctoral researchers in the AACS programme

Funding	2003	2004	2005	2006	2007	2008	Average
Direct funding	10%	25%	26%	37%	27%	20%	24%
Research funds	72%	60%	58%	54%	59%	41%	57%
Contracts	18%	15%	16%	9%	15%	39%	19%
Other	0%	0%	0%	0%	0%	0%	0%
Total	100%	100%	100%	100%	100%	100%	100%

8.c. List of external funds

Table 12. Overview of projects in the AACS programme

Name project	Start date	End date	Sponsor	Staff
Optics beyond SVEA	Sept 1999	Feb 2005	STW	1 PhD
Triangulation methods in surface construction	Sept 1999	Sept 2004	NWO	1 PhD 1 PD
Wave – current interaction	Sept 1999	Sept 2005	MARIN	1 PhD
EPAM coordinator	Jan 2000	Sept 2006	KNAW	--
Numerical simulation of the dynamic behaviour of riser bundles and flexible hoses	Jan 2000	Dec 2003	MARIN	1 PhD
Nonlinear parabolic and hyperbolic partial differential equations in the natural sciences (collaboration Netherlands-Hungary)	Jan 2001	Dec 2003	NWO	2 yr PhD
EPAM coastal engineering (collaboration with Indonesia)	Jul 2001	Sept 2006	KNAW	1 PhD
EPAM industrial mathematics (collaboration with Indonesia)	Jul 2001	Sept 2006	KNAW	2 PhD
KNAW Academie Onderzoeker (Bokhove)	Jul 2001	June 2006	KNAW	1 KNAW Researcher
Analysis and control of transport phenomena in wet-chemical	Sept 2001	Sept 2005	STW	1 PhD
EU NAIS project	Sept 2001	Nov 2006	European Commission	1 PhD 2 yr PD
Polymer extrusion	Sept 2001	Oct 2005	STW	1 PhD

Name project	**Start date**	**End date**	**Sponsor**	**Staff**
Finite element methods for the generation & evaluation of steep directional water waves	Oct 2001	Oct 2004	MARIN/ IMPACT	3 yr PD
Extreme waves	Dec 2001	Apr 2008	STW	2 PhD 2 yr PD
Fractal forcing of anisotropic, inhomogeneous turbulence: flow-structures and heat transfer	Jan 2002	Dec 2006	FOM	1 PhD
Advanced simulation techniques for vortex dominated flows	Apr 2002	June 2006	STW	2 PhD
Prediction of flow instabilities during polymer extrusion	Sept 2001	Oct 2005	STW	1 PhD
Computational integrated optics for photonic structures	Jul 2002	Jan 2007	NWO	2 PhD
Offshore sand waves: process-oriented versus stochastic approach	Apr 2003	Apr 2007	STW	1 PhD
Optical grating: visitor grant Iskandar	Jul 2003	Sept 2004	STW	1 yr PD
Two-phase flows with free surfaces	Aug 2003	Aug 2007	STW	1 PhD
Discontinuous Galerkin method for Shallow Water Equations forecasting river flows	Dec 2003	Mar 2006	European Commission	2.3 yr PhD
High-performance adaptive finite element solution of nonlinear multiscale Maxwell equations	Feb 2004	Feb 2007	NWO	0.5 yr PhD
Building math support for earth sciences	Mar 2005	Apr 2005	KNAW	--
Coastal impact of seismologically generated water waves	June 2005	Feb 2006	KNAW	--
Nanoned: Optical switching by NEMS-modelling & simulation	Jul 2005	Sept 2009	STW	2 PhD 0.8 yr PD
hp-Adaptive finite element methods for the Maxwell equations	Sept 2005	Sept 2009	BSIK/ BRICKS	1 PhD
Wave propagation and reflection seismology	Nov 2005	Oct 2010	NWO	1 PhD
Variational Boussinesq model for tsunami simulation (collaboration with Indonesia):	Dec 2005	Mar 2007	KNAW	--
Adaptive high-order variational methods for aerodynamic applications	Sept 2006	Sept 2009	European Commission	3 yr PD
Extreme surface waves, models, simulations and experiments	Sept 2006	Sept 2010	STW	2 PhD 2 yr PD
Hamiltonian-based numerical methods for forced dissipative climate prediction	Oct 2006	Oct 2010	NWO	1 PhD

Name project	Start date	End date	Sponsor	Staff
Study Group Mathematics and Industry SWI 2008	June 2007	Dec 2008	STW/NWO	--
Brain-computer and computer-brain interfaces	Sept 2007	Sept 2013	Senter Novem Smartmix	1 PhD
Simulation of heat and mass transport processes	Jan 2008	Jan 2012	Philip Morris	2 PhD
A numerical wave tank for complex wave and current interactions	Mar 2008	Dec 2012	STW	1 PhD 4 yr PD
Control of aerosol migration with temperature gradients	Mar 2008	Nov 2012	STW	1 PhD
Near shore tsunami modelling and simulation	Jul 2008	Jul 2012	NWO	1 PhD
Compatible mathematical models of coastal hydrodynamics	May 2009	May 2013	NWO	1 PhD

9. Overview of the results

9.a. Description of scientific results

The research in the AACS programme focuses on the integration of mathematical modelling, applied analysis and numerical methods. Areas of research which received significant attention during the reporting period are i.) the modelling, analysis and computation of wave phenomena, with particular attention to water waves, optical devices and Josephson junctions; ii.) the development, analysis and application of finite element methods, in particular discontinuous Galerkin discretisations and error analysis; iii.) the mathematically consistent modelling and simulation of complex multiscale problems, in particular turbulent (dispersed multiphase) flows. Also, new research activities were developed in the field of neuro-science.

In all areas, research was conducted in close collaboration with partners from universities, research institutes and industry, who contributed significantly to the application of our applied mathematics research.

9.b. Key publications

Table 13. Key publications of the AACS programme

• N. V. Davydova, O. Diekmann, S.A. van Gils. (2003) Year class coexistence or competitive exclusion for strict biennials? *Journal of Mathematical Biology* 46(2), pp. 95-131.
• E. van Groesen & J. Molenaar. (2007) Continuum modeling in the Physical Sciences. *SIAM Mathematical Modeling and Computation* 13, 236 pages.
• R. Stoffer, K.R. Hiremath, M. Hammer, L. Prkna, J. Ctyroky. (2005) Cylindrical integrated optical microresonators: Modeling by 3-D vectorial coupled mode theory. *Optics Communications* 256(1-3), pp. 46-67.
• J.J.W. van der Vegt, F. Izsák and O. Bokhove. (2007) Error analysis of a continuous-discontinuous Galerkin finite element model for generalized 2D vorticity dynamics. *SIAM Journal on Numerical Analysis* 45(4), pp. 1349-1369.
• C.M. Klaij, J.J.W. van der Vegt, H. van der Ven. (2006) Space-time discontinuous Galerkin method for the compressible Navier-Stokes equations, *Journal of Computational Physics* 217(2), pp. 589-611.
• B.J. Geurts, D.D. Holm. (2003) Regularization modeling for large-eddy simulation. *Physics of Fluids* 15(1), pp. L13-L16.

9.c. Numerical overview of the results in a fixed format of categories

Table 14. Overview of the research output of the AACS programme

		2002	2003	2004	2005	2006	2007	2008	Total
1. Academic publications	a. PhD-theses	4	1	2	6	6	4	2	25
	b. in refereed journals	33	28	22	40	36	34	27	220
	c. international conference proceedings	16	13	25	11	17	12	17	111
	d. books	1					1		2
	e. book chapters	4			1	1	2		8
5. Total		58	42	49	58	60	53	46	366
2. International patents			1						1

9.d. Full outcome list

2002

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Cahyono, E., Analytical wave codes for predicting surface waves in a laboratory basin. (2002, June 13). 111 pp., Enschede PrintPartners, Thesis advisor(s): Prof. dr. ir. E. van Groesen, Dr. A. Andonowati. ISBN: 90-365-1763-x.

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10. SWOT analysis

- *Strengths*
- Excellent collaboration with scientists from other disciplines, providing a strong embedding of our research and underpinning its long-term mathematical development.
- Active participation in UT research institutes, where we play a key role in various research programmes.
- Ability to attract significant external funding both for fundamental and applied research from sources both within the Netherlands and in Europe.
- High international visibility of several members of staff.

- *Weaknesses*
- The underlying mathematical core of our work is not always visible to the mathematics community.

- *Opportunities*
- The 3TU Applied Mathematics Institute will enhance the visibility of our research, stimulate collaboration and provide funding for new professorial positions.
- Valorisation of our applied work, in combination with different industrial partners, is growing, thereby providing a separate gauging of the societal strengths of our programme.

- *Threats*
- The number of mathematics students interested in this area of research is not large enough to sustain an adequate influx of Dutch PhD students into graduate levels.

- *Analysis*
- The AACS programme is well positioned to conduct multidisciplinary research in applied analysis and scientific computing. We will actively pursue the new opportunities provided by the 3TU Applied Mathematics Institute and further extend our research collaborations to open new challenging research directions.

B2. Deterministic and Stochastic Systems Theory (DSST)

Sub-programmes:

- Control, Signals and Systems; Financial Mathematics.

NABS code: N07

Chairmen during the review period:

- MCST: Prof. A.J. van der Schaft (2003-2005), Dr. J.W. Polderman (2005-2007), Prof. A.A. Stoorvogel (2007-)
- SST: Prof. A. Bagchi

Starting and/or ending date of (each sub-)programme:

None

Formal affiliations outside the department and other formal cooperations:

- Dr. Vellekoop holds a position as Director of Research for TDTF, the Derivatives Technology Foundation, for 0.2 fte.
- DSST participates in the Dutch Institute on Systems and Control (DISC) research school

1. Mission statement

Research area

The research of the group is focused on systems and control. We obtain mathematical models, which are studied to obtain an insight into the properties of the system and its interactions with the environment. In particular, this insight yields controllers which provide prescribed closed-loop behaviour. Stochastic signals play a central role. An important area of application is mathematical finance.

Mission

The mission of the programme is to be a leader in the field of mathematical systems and control theory and in financial mathematics. The realisation of this mission is reflected in publications in international journals, participation in European networks, in the organisation of workshops, in PhD positions and in research grants from industry.

2. Leadership

Two full professors manage the group. Apart from the formal annual evaluation meetings with every individual staff member, there are many occasions during the year on which the staff meets. These include monthly group meetings and regular colloquia. At these colloquia, invited speakers present their work. The colloquia are also used to inform one another about the latest developments in the research themes. There is a steady flow of (foreign) guests, and participation in international conferences is strongly encouraged within the group. The programme leaders continually promote external contacts through national and international programmes and visits to other universities. The submission of research proposals is encouraged and the collaboration among group members to improve the quality of proposals is always stimulated. International publications are required for everybody and we stimulate publications in high quality journals.

The close cooperation of the Financial Mathematics researchers with the Financial Engineering group of the Finance and Accounting Department has led to the founding of the Financial Engineering Laboratory (FELab), which coordinates all teaching and research in this area at the university. It also organises a seminar series specially for PhD students of both departments, in order to stimulate the exchange of information on this topic.

3. Strategy and policy

3.a. Design in brief

There is a tremendous need for insight into systems that interact with their environment and the design of controllers for these systems. This need is only growing, since the industry requires more automation, higher accuracies and additional flexibility. An autopilot is no longer limited to maintaining the constant elevation and velocity of an

aircraft, but should also be able to handle involved manoeuvres such as take-off and landing. In nanotechnology, unprecedented accuracy has to be achieved in, for instance, positioning during chip manufacturing. In process technology, large investment in equipment requires multiple use and efficient switching between production stages. External inputs need to be chosen, based on measurements, to guarantee this smooth switching. For these kinds of tasks, it is no longer possible to decompose the system in simple sub-systems. The increased accuracy and flexibility also requires more complex models; traditional linear, finite-dimensional models will not suffice. Restricting attention to simple models was needed in the past, due to the bottleneck imposed by the computing power for embedded controllers. Due to major advances in computers, this is no longer the prime restriction.

In our group, we study classes of models which involve infinite-dimensional systems (described by PDEs instead of ODEs), nonlinear systems and hybrid models (combining discrete actions, such as switches with continuous actions, such as external forces). We also focus on signal analysis, which is becoming more and more crucial in the context of systems and control. After all, in sensors, exciting developments are taking place, where it has become possible to obtain a huge number of measurements through different types of sensor arrays, such as digital cameras and arrays to detect chemicals or electromagnetic waves. Finally, making effective use of the better (but more complex) models and the large number of measurements makes controller design much more difficult.

Applied mathematics research cannot be performed in isolation from meaningful applications. In that sense it is a great opportunity for us that the research activities at the University of Twente are grouped within research institutes. Our group participates in two institutes, CTIT (Centre of Telematics and Information Technology) and IMPACT (Institute for Mechanics, Processes and Control). This enables strong collaboration with researchers, both inside and outside the Faculty of EEMCS, who are directly involved in applications. Participation in the “High Tech Systems” Centre of Excellence within the 3TU collaboration provides extra financing as well as additional opportunities for collaboration.

In the period covered by this research evaluation, our group has been very active in the field of nonlinear systems. Within the recently developed framework of port-Hamiltonian systems it is possible to study interconnections of finite and infinite-dimensional physical subsystems (linear or nonlinear). This research is conducted in close collaboration with the chair of Control Engineering. In a European context the theory of port-Hamiltonian systems has been advanced and used in various domains of application within the recently ended EU-IST GeoPleX project. We have also extensively studied infinite dimensional systems theory for problems in which time and spatial behaviour are both important, as described by partial differential equations. Successful applications of this theory have been obtained in a research project funded by STW. Several very specific classes of infinite-dimensional systems have also been studied, such as models containing (communication) delays or sampled measurements (or inputs). Research in hybrid systems, in collaboration with the chair of Formal Methods and Tools and funded by NWO, looks at systems containing both continuous dynamics and discrete switches. Within the EU Hybridge project on aircraft collision avoidance in European airspace, stochastic hybrid models are studied and we have obtained methods for large-scale simulations that are used for aircraft collision avoidance.

Traditionally, systems and control is applied in process control, aerospace and mechatronics. An important new area of application is financial engineering, where our expertise in stochastic processes and stochastic systems and control in particular enables

us to obtain new results in option pricing. Through a very successful collaboration with the Financial Engineering group of the Finance and Accounting department, a new master's track on financial engineering has been set up and a successful research programme in this field has been initiated. Our research in the field, although highly mathematical, is always motivated by real problems facing the financial industry. We have developed, for example, methods to include dividends in the pricing of stock options. We are now able to obtain detailed weak convergence results which prove that our algorithms converge to the correct continuous-time limit. This has led to a new algorithm that is now used in the trading software for equity option market makers in Amsterdam. We have also developed models for the term structure of interest rates, which have been applied to study US treasury data. We have also estimated volatility in the popular Heston model of the evolution of stock prices and a comprehensive theory has been developed for American options. A field in financial mathematics that has received considerable attention is nonlinear filtering and estimation. This is associated with calibrating a class of financial models known as 'stochastic volatility models'. The development of practical algorithms to estimate the parameters in these nonlinear models necessitates the combination of techniques from (particle) filtering theory with nonlinear pricing methods for derivative financial products.

3.b. Programme development

There will be some change in focus in the group in the coming years. Partly, because of a recent change of staff and partly due to new challenges that have arisen because of technological advances, where additional computational power for embedded systems needs to be effectively used to achieve the accuracy and flexibility demanded by industry.

1. Control, systems and signals

The group is well positioned to address the many technological challenges that we will face in the coming years, on the basis of our background in infinite-dimensional systems, hybrid systems, nonlinear systems and signal processing. We will put more emphasis in the near future on controller design. In collaboration with our colleagues in (numerical) analysis of partial differential equations, we want to be able to test and design controllers using full-scale models, which have been efficiently implemented on a computer. It would be too much to expect a general methodology to design controllers for nonlinear plants. However, many systems which cannot be satisfactorily modelled linearly, can be modelled through models which are mostly linear but do contain specific nonlinear elements, such as a saturation, hysteresis or a switching element. Since this class of models can be used to derive accurate models for many applications, we want to study controller design for this class of models. Another goal for the coming period is to obtain a control design paradigm that explicitly takes into account the hybrid nature of switched systems. For many systems there are structural constraints for controller design, due to the decentralised nature of the system. Designing tools for controller design in the presence of these structural constraints will be of increasing importance in applications such as power systems or autonomous agents, and hence we intend to increase our research effort in this area. This decentralised structure is also important in our research with Thales, which will shift to distributed sensor placement for tracking with minimum energy. This research will be given a boost by the recent NWO support for a Casimir fellow. Also the presence of a part-time professor, A. Stein, with expertise in spatial and distributed structures in data acquisition, will be useful. In general, the developments in sensors require more emphasis on signal processing. Research in this area has been initiated in the last few years and will definitely be expanded. A large project on Monte Carlo-based

distributed sensor management has recently been approved by the EU with the University of Twente, Linköping University, the University of Lancaster along with Thales, SAAB and three other industrial partners taking part.

2. Financial Mathematics.

In mathematical finance the turmoils of the credit crunch have put the spotlight on modern risk management systems in financial engineering. Algorithms and models that were designed to minimise the risks in financial contracts continue to work well in almost all cases. But it has turned out that they did not work sufficiently well in a few critical cases, with serious consequences, and that, in fact, in some instances, such as risk-reducing hedging strategies, which our group is also working on, were not implemented at all by banks and insurance companies.

We believe that the coming years will see an increased, but somewhat different, activity in the applications of financial engineering. Prudent risk management for pension funds, insurance companies or market makers for all sorts of financial contracts will have to focus more on liquidity issues, counterparty risk, and long-term optimal planning. The correct formulation of the long-term stochastic control problem faced by an insurance company, the inclusion of discontinuous shocks to market prices in traders' market models, and the re-insurance risk of large claims are examples of the sort of issues that will receive more attention. Our proven expertise in jump diffusions and infinite-dimensional models will give us an excellent position when working on such problems.

We have already worked with the main Dutch investment banks on counterparty and credit risk modelling and with the market makers of SAEN options on the robustness of their trading models. Our recent membership of the Netspar research institute will provide opportunities to apply stochastic control theory to pension planning problems as well. Until recently we had been developing infinite-dimensional stochastic models for the term structure of interest rates. We are now concentrating on the perturbations of "exponential affine" models which naturally lead to genuine infinite-dimensional problems. In the coming period, we plan to extend this approach to modelling term structures for energy futures, and we intend to incorporate carbon emission in this model. Our ultimate purpose is to use this model to study tolling problems and swing options in the electricity market. Both of these will lead to new stochastic control problems. This research will be undertaken in close collaboration with the energy company Essent.

4. Processes in research, internal and external collaboration

Research is often strengthened by collaboration. Within the department a broad range of high-level mathematical expertise is available. The CTIT and IMPACT research institutes within the university bring together mathematical expertise and many different areas of application. Nationally, the 3TU "High-Tech Systems" Centre of Excellence and the DISC research school ensure close collaboration with our colleagues in systems and control. Internationally, we are involved with and are trying to expand European research projects funded by the EEC. In addition to the above formal structures, all staff members have close collaborations with individual researchers worldwide, as is obvious from joint publications and joint PhD projects.

5. Academic reputation

The academic reputation of our group is high. This follows from the fact that many members take part in editorial boards and international programme commissions or organise conferences. Many books written by staff members over the past 15 years have become standard works. Professor A.J. van der Schaft delivered an invited lecture at the International Congress of Mathematicians, Madrid, 22-30 August 2006, the most prestigious conference on mathematics. The paper, ``A Nonlinear Filtering Approach to Changepoint Detection Problems: Direct and Differential-Geometric Methods'', published by M. Vellekoop in 2003 (co-author: J.M.C. Clark Imperial College, London), was chosen as the 'SIGEST' paper for SIAM (Society of Industrial and Applied Mathematics) Review in 2006.

A.A. Stoorvogel
- Associate Editor at Large, IEEE Transactions on Automatic Control.
- Associate Editor MCSS.
- Associate Editor International Journal of Robust and Nonlinear Control.
- Member of Programme Committee for eight international conferences.
- Adjunct professor School of Electrical Engineering and Computer Science, Washington State University, Pullman, WA. (since 2008).

A.J. van der Schaft,
- Editor-at-Large for European Journal of Control.
- Associate Editor for Systems & Control Letters.
- Associate Editor for SIAM Journal on Control and Optimization.
- Member Editorial Board CWI Tracts.
- IEEE fellow.

H. Zwart,
- Associate Editor for SIAM Journal on Control and Optimization (2003-2007).
- Associate Editor for Journal of Mathematical Analysis and Applications (2008-).
- Chairman of the Steering Committee 'Workshops on Distributed Parameter Systems'.
- Chairman of the international programme Committee of 'Control of Distributed Parameter Systems', 23-27/7/2007.

J.W. Polderman,
- Associate Editor for Automatica (till 2003).
- Conference Editorial Board, IEEE Control Systems Society (since 2008).
- Associate Editor of the 2005 IEEE Conference on Decision and Control (CDC) combined with the ECC.

M. Vellekoop
- NWO Veni committee.
- Organiser yearly international scientific conference by The Derivatives Technology Foundation.

G. Meinsma
- Invited presentation at the "Dynamical Systems and Control" workshop (Haifa, 22-24 June 2004).
- Associate Editor of the 2005 IEEE Conference on Decision and Control (CDC) combined with the ECC 2005.

- Co-organiser in 2006 and main organiser in 2008 of the Benelux Meeting on Systems and Control.
- Invited presentation at the LAAS-CNRS (Toulouse, France, May 2006).
- Recipient of the Lady Davis Fellowship 2007.

A. Bagchi
- Member, programme committee, Conference on System Modeling and Optimization in 2003, 2005 and 2007.
- Member, programme committee, International Conference on Financial Engineering and Applications.
- Member, programme committee, Parallel and Distributed Computing in Finance.
- Recipient of Silver Core award, 2007, International Federation of Information Processing
- Sunahara Memorial Lecture, SSS'06 held in Suwa, Nagano, Japan.

6. External validation

6.a Societal relevance

The industry requires more automation, higher accuracies and additional flexibility. The field of Systems and Control plays a crucial role in obtaining these objectives. Our research is aimed at obtaining a powerful framework for modelling and control in a wide variety of applications. In our research we looked at, for instance, aircraft collision avoidance, temperature control of food storage and drinking water purification. To be even more specific, the storage of perishable foodstuff is most relevant to the agricultural industry. Each year approximately two billion kWh is used for ventilation. Hence a small improvement can result in huge savings. The part-time position of M. Vellekoop as director of research at the Derivatives Technology Foundation has contributed to the rapid dissemination of financial mathematics results to the financial industry in Amsterdam. Some numerical methods for pricing and risk management of equity options that have been developed in our group have now been implemented in derivative trading software used by market makers who trade on the Amsterdam options exchange. One volatility estimation method has led to a spin-off company run by one of our former PhD students.

6.b. Industrial contacts

- ING (volatility smile dynamics, asset management)
- ABN AMRO (counterparty risk, validation, foreign exchange)
- Saen Options (equity options and energy derivatives)
- Rabobank (credit/liquidity risk)
- AtomPro (option trading platforms)
- Essent (energy risk management)
- Thales Nederland (distributed sensor management)
- Philips CFT (channel estimation in multiplexing systems)
- Dutch Space (flexible structures)
- Océ (paper and printer scheduling)
- ATO B.V. (climate control in reefer containers)
- NLR (collision avoidance of aircraft)
- MARIN (system identification in ship manoeuvring)
- Strukton Systems (condition monitoring of trains and railroad crossings)
- Innovation Handling (spatial temperature measurements)
- Priva (purification of drinking water through UV disinfection)
- KIWA N.V. (water research)
- Witteveen + Bos (purification of drinking water through UV disinfection)
- Agrotechnology and Food Innovations BV (climate control for food storage)

7. Researchers and other personnel

Table 15. Researchers in the DSST programme

	Name	2003	2004	2005	2006	2007	2008
DSST							
Tenured staff							
professor (hgl)	Bagchi, Prof. A.	0.36	0.28	0.28	0.32	0.40	0.40
	Schaft, Prof. A.J. van der	0.40	0.40	0.28	0.05	0.03	
	Stoorvogel, Prof. A.A.					0.31	0.40
associate professor (uhd)	Polderman, Dr. J.W.	0.24	0.40	0.40	0.40	0.40	0.28
	Vellekoop, Dr. M.H.	0.14	0.40	0.40	0.40	0.40	0.40
	Zwart, Dr. H.J.	0.40	0.40	0.40	0.40	0.40	0.40
assistant professor (ud)	Broek, Dr. W.A. van den	0.40	0.40	0.40	0.40	0.06	
	Meinsma, Dr. G.	0.40	0.40	0.40	0.40	0.40	0.40
	Polderman, Dr. J.W.	0.16					
	Vellekoop, Dr. M.H.	0.26					
Total tenured staff		**2.76**	**2.68**	**2.56**	**2.37**	**2.41**	**2.28**
Non-tenured staff							
professor (hgl)	Jamshidian, Prof. F.		0.05	0.11	0.11	0.11	0.11
postdoctoral fellows	Boers, Dr. Y.						0.21
	Costa Castello, R.	0.33					
	Daws, C.F.				0.38	0.37	
	Golo, Dr. G.	0.46					
	Gomez Estern Aguilar, Dr. S.F.	0.25					
	Krystul, Dr. J.				0.13	1.00	0.83
	Neumann, Dr. C.D.D.	0.02					
	Piskarev, Dr. S.		0.20	0.05			
other junior staff (moz, twaio)	Alink, N.H.M.			0.17	0.17	0.17	0.07
	Diolaiti, N.	0.20					
	Ferkl, L.			0.80			
	Gentili, L.	0.20					

	Name	2003	2004	2005	2006	2007	2008
	Goswami, A.						0.14
	Jeltsema, D.			0.14			
	Kristalny, M.			0.40			
	Macchelli, A.	0.30					
	Morselli, R.		0.10				
	Witrant, E.J.C.	0.20					
Total non-tenured staff		1.96	0.36	1.67	0.79	1.65	1.36
PhD Students							
Junior staff (aio, oio, moz-p)	Besseling, N.C.					0.80	0.80
	Cadic, M.A.	0.63					
	Göttsche, O.E.					0.05	0.80
	Iftime, O.V.						
	Imreizeeq, E.S.N.	0.80	0.80	0.61			
	Julius, A.A.	0.80	0.80	0.13			
	Kakumani, R.	0.18	0.40	0.22			
	Kordy, P.T.			0.12	0.40	0.40	0.40
	Krystul, J.	0.80	0.80	0.80	0.59		
	Ligterink, N.E.	0.14	0.40				
	Minina, V.	0.25	0.80	0.80	0.80	0.80	
	Moelja, A.A.	0.80	0.80	0.69			
	Mourik, S. van		0.67	0.80	0.80	0.80	0.13
	Nurdin, H.I.	0.82	0.53				
	Ott, C.	0.22					
	Pasumarthy, R.	0.57	0.80	0.80	0.63		
	Pola, G.	0.20					
	Polenkova, S.V.						0.67
	Saha, S.			0.13	0.40	0.40	0.40
	Shekhawat, H.S.						0.07
	Strubbe, S.N.	0.80	0.80	0.80			
	Talasila, V.	0.80	0.80				
	Unteregge, M.			0.27	0.53		
	Villegas, J.A.	0.70	0.80	0.80	0.80	0.16	
	Wang, F.				0.04	0.80	0.53

	Name	2003	2004	2005	2006	2007	2008
	Wibowo, A.	0.80	0.80	0.80	0.80		
	Zilber, A.	0.40	0.80	0.80	0.80	0.12	
Total PhD Students		**9.71**	**10.80**	**8.57**	**6.59**	**4.33**	**3.80**
Total Research Staff DSST		**14.43**	**13.84**	**12.80**	**9.75**	**8.39**	**7.44**

8. Resources, funding and facilities

8.a. Laboratory infrastructure

Financial engineering laboratory

8.b. FTE funding PhDs/postdocs

Table 16. Source of funding for PhD and Post Doctoral researchers in the DSST programme

Funding	2003	2004	2005	2006	2007	2008	Average
Direct funding	28%	29%	32%	31%	16%	35%	28%
Research funds	26%	35%	36%	46%	50%	34%	38%
Contracts	47%	36%	33%	23%	35%	31%	34%
Other	0%	0%	0%	0%	0%	0%	0%
Total	100%	100%	100%	100%	100%	100%	100%

8.c. List of external funds

Table 17. Overview of projects in the DSST programme

Project	Start date	End date	Sponsor	Staff
Initial modelling “giraal” data services	Jan 1999	Dec 2005	Interpay Nederland B.V.	none
Strongly robust adaptive control: the strong robustness approach.	Oct 1999	Nov 2003	EU-NCN	1 PhD
NACO 2 Nonlinear and adaptive control -- theory and algorithms for the user.	Jan 2000	Dec 2004	European Commission	1.25yr PD 2yr PhD
CASH: compositional analysis and specification of hybrid systems	Dec 2000	Mar 2005	NWO	1 PhD
Control of systems with delays	Sept 2001	Nov 2005	NWO	1 PhD
TDF: Hedging interest rate derivatives	Sept 2001	Sept 2006	SFISS financial techno-logy B.V.	1 PhD
HYBRIDGE. Distributed control and stochastic analysis of hybrid systems supporting safety critical real-time systems design	Jan 2002	Jan 2006	European Commission	2 PhD
GEOPLEX. Geometric network modelling and control of complex physical systems.	Mar 2002	Mar 2006	European Commission	1 PhD
SICONOS. Modelling, simulation and control of nonsmooth dynamical systems	Sept 2002	Sept 2006	European Commission	none
PACDAS: port based approach complex distributed models	Oct 2002	Sept 2007	STW	1 PhD

Project	Start date	End date	Sponsor	Staff
EOARD. Advanced robust STAP algorithms and fast performance evaluation techniques based on rare Event theory	Dec 2002	Sept 2004	European office of aero-space	1 PhD
ERACIS: Energy based representation, analysis and control of infinite-dimensional systems	June 2003	June 2007	NWO	1 PhD
Waardebepaling financiele derivaten	Jul 2003	June 2007	ABN AMRO	1 PhD
AdHoc: Analysis and design of hybrid systems using optimal control	Jul 2003	Sept 2007	NWO	0.5 PhD 1.5 yr PD
Optimization of event-based hedging strategies for derivatives	Feb 2004	Jan 2008	STW	1 PhD
Modelling and control of flows	Mar 2004	Mar 2008	STW	1 PhD
Visitor grant L. Mirkin	Aug 2004	Aug 2005	NWO	1yr PD
Hybrid control: Taming heterogeneity and complexity of networked embedded system. (Hycon)	Sept 2004	Sept 2008	European Commission	none
Visitor grant S. Piskarev	Sept 2005	Feb 2006	NWO	0.5yr PD
BOSS: Bounds on stable semigroups	Sept 2005	Jan 2011	NWO	1 PhD
DARTS Design and Analysis of Robust Timed Systems	Sept 2005	Sept 2009	NWO	1 PhD
Particle filters and their application to target tracking	Oct 2005	Oct 2009	Thales Nederland B.V.	1 PhD
Volatility smile modelling for interest rate derivates	Dec 2006	Dec 2010	ABN AMRO	1 PhD
Scr based design and validation of highly automated ATM	Jan 2007	Jan 2010	National Aerospace Laboratory	3yr PD
Control and analysis for the stability of hybrid and embedded systems	Mar 2008	Mar 2012	NWO	1PhD
Marie Curie Control Training Site	Jan 2002	Jan 2007	European Commission	3.4yr PhD
Centre of Excellence “High Tech Systems”	Mar 2007	Mar 2011	Ministry for Education, Culture and Science	5yr full professo r
Visitor grant M. Kuijper	Aug 2005	Jan 2006	NWO	0.5yr PD
CASIMIR “Energy efficient tracking and detection in distributed systems”	Jan 2008	Jan 2012	NWO	0.6yr PD

9. Overview of the results

9.a. Description of scientific results

The recent projects that we consider to be the most exciting are those in which we show how new mathematical results in systems theory can lead to major contributions in other fields as well. Interdisciplinary research has always been important within our group. The range of applications now includes disciplines that were not even considered a decade ago. New results in decoding theory have been found that are based on the behavioural approach to systems theory. Similarly, recent developments in the classical theory for sampled systems turn out to provide a new and highly efficient language for problems in signal analysis, where intersample behaviour is important. Infinite-dimensional systems theory has been used to create more sophisticated models for the design of cooling units for agricultural products on the one hand, and the risk management of interest rate sensitivities on the other hand. Also, Monte Carlo techniques have been used for calculating the collision risks of aircraft. These examples emphasise how strong abstract mathematical results and models may be relevant to very different practical problems once such results have been translated into the appropriate domain of application. As such, they also serve as even further motivation to continue our theoretical research, but always with underlying practical problems providing the necessary stimulus.

During the period under review, projects in new areas of application led to new developments in mathematical system theory, along with their implementations. The other exciting development is the research performed in Financial Mathematics. Various fundamental mathematical issues arising from financial markets have been studied. They include the pricing of derivatives on assets with discontinuities due to discrete dividends, an infinite dimensional model for the forward rate of interest and an iterative scheme for American options using Doob's decomposition theorem for supermartingales.

9.b. Key publications

Table 18. Key publications of the DSST programme

• Le Gorrec, Y. and Zwart, H.J. and Maschke, B.M.J. (2005) Dirac structures and boundary control systems associated with skew-symmetric differential operators. SIAM Journal on Control and Optimization, 44 (5). pp. 1864-1892.
• Kuijper, M. and Polderman, J.W. (2004) Reed-Solomon list decoding from a system theoretic perspective. IEEE Transactions on Information Theory, Vol. 50, 259-271.
• Vellekoop, M.H. and Nieuwenhuis, J.W. (2006) Efficient Pricing of Derivatives on Assets with Discrete Dividends, Applied Mathematical Finance 13(3), pp. 265-284.
• Aihara, S.I. and Bagchi, A. (2005) Stochastic hyperbolic dynamics for infinite-dimensional forward rates and option pricing. Mathematical Finance 15 (1). pp. 27-47.
• Meinsma G. and Mirkin L. (2005) H-infinity control of systems with multiple I/O delays via decomposition to adobe problems. IEEE Transactions on Automatic Control, 50(2), pp. 199-211.
• Saberi, A., Stoorvogel, A.A., Sannuti, P. (2007) Filtering Theory - With Applications to Fault Detection, Isolation, and Estimation. 723 pp. Boston Birkhauser ISBN: 978-0-8176-4301-0.

9.c. Numerical overview of the results in a fixed format of categories

Table 19. Overview of the research output of the DSST programme

		2002	2003	2004	2005	2006	2007	2008	Total
1. Academic publications	a. PhD-theses	3	1	1	4	4	3	2	18
	b. in refereed journals	110	10	14	13	11	14	6	79
	c. international conference proceedings	27	18	26	32	25	5	9	142
	d. books						1		1
	e. book chapters	1	3	2	2	5	3	1	17
6. Total		42	32	43	51	45	26	18	257
2. International patents									

9.d. Full outcome list

2002

PhD theses

Golo, G., Interconnection structures in port-based modelling: tools for analysis and simulation. (2002, October 11). 229 pp., Enschede Universiteit Twente, Thesis advisor(s): Prof. dr. A.J. van der Schaft, Prof. dr. ir. J. van Amerongen. ISBN: 9036518113.

Iftime, O.V., A J-spectral factorization approach to H-inf control problems. (2002, June 28). 147 pp. Enschede Universiteit Twente, Thesis advisor(s): Prof. dr. A. Bagchi, Dr. H.J. Zwart. ISBN: 903651746.

Schrijver, E., Improved robot tracking control for laser welding. Disturbance estimation and compensation. (2002, April 5). 161 pp., Enschede Print Partners Ipskamp, Thesis advisor(s): Prof. dr. ir. J.B. Jonker, Prof. dr. A.J. van der Schaft, Dr. ir. J. van Dijk. ISBN: 90-365-1730-3.

Journal articles

Blankenstein, G. , Ortega, R., Schaft, A.J. van der, The matching conditions of controlled Lagrangians and interconnection assignment passivity based control. International journal of robust and nonlinear control 75, (2002), pp. 645-665, ISSN: 1049-8923.

Cantrijn, F., Cortes monforte, J., Cosymplectic reduction of constrained systems with symmetry. Reports on mathematical physics 49, (2002), pp. 167-182, ISSN: 0034-4877.

Cortes monforte, J., Martinez, S., Skinner-Rusk approach to time-dependent mechanics. Physics letters. Section A (2-3), 300, (2002), pp. 250-258, ISSN: 0375-9601.

Iftime, O.V., Zwart, H.J., Nehari problems and equalizing vectors for infinite-dimensional systems. Systems and control letters 45(3), (2002), pp. 217-225, ISSN: 0167-6911.

Jacob, B., Zwart, H.J., Properties of the realization of inner functions. Mathematics of control, signals and systems 15, (2002), pp. 356-379, ISSN: 0932-4194.

Meinsma, G., Mirkin, L., Zhong, Q.C., Control of systems with I/O delay via reduction to a one-block problem. IEEE transactions on automatic control 47(11), (2002), pp. 1890-1895, ISSN: 0018-9286.

Ortega, R., Schaft, A.J. van der, Maschke, B.M., Escobar, G., Interconnection and damping assignment passivity-based control of port-controlled Hamiltonian systems. Automatica 38, (2002), pp. 585-596, ISSN: 0005-1098.

Polderman, J.W., Daams, J., Almost optimal adaptive LQ control: SISO case. Mathematics of control, signals and systems 15, (2002), pp. 71-100, ISSN: 0932-4194.

Prajna, S, Schaft, A.J. van der, Meinsma, G., An LMI approach to stabilization of linear port-controlled Hamiltonian systems. Systems and control letters 45, (2002), pp. 371-385, ISSN: 0167-6911.

Schaft, A.J. van der, Maschke, B.M., Hamiltonian formulation of distributed-parameter systems with boundary energy flow. Journal of geometry and physics 42, (2002), pp. 166-194, ISSN: 0393-0440.

Stramigioli, S., Schaft, A.J. van der, Mashke, B., Melchiorri, C., Geometric scattering in robotic telemanipulation. IEEE transactions on robotics and automation 18(4), (2002), ISSN: 1042-296X.

Conference proceedings

Aihara, S.I., Bagchi, A., Stochastic parabolic model for infinite-dimensional forward rate and mean-variance optimal control. Proceedings of the 15th World Congress of the International Federation of Automatic Control (2002, July 21-26). (6 p.) Barcelona ISBN: 008 044184.

Blankenstein, G., Ortega, R., Schaft, A.J. van der, Matching of Euler-Lagrange and Hamiltonian systems. 15th Triennial World Congress of the International Federation of Automatic Control (2002, July 21-26). (6 p.) Barcelona ISBN: 008 044184 X.

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10. SWOT analysis

- *Strengths*
- The group is well positioned within the successful DISC research school and has a central role in the 3TU Centre of Excellence on High-Tech Systems.
- Participation in Netspar and the existence of FELab, which coordinates all financial engineering activities within the UT.
- Strong research connections in collaboration with several financial institutions.

- *Weaknesses*
- Low numbers of mathematics students, difficulty finding qualified PhD students.
- Visibility of systems and control in industrial applications.

- *Opportunities*
- The extra funding for the MSCT chair through the 3TU Centre of Excellence on High-Tech Systems and extra funding for a new chair in Stochastic Control from the 3TU-AMI will enable us to expand and strengthen our activities.
- The 3TU Master on Systems and Control has recently been accredited and gives new possibilities to attract PhD students and will raise our visibility.
- In the wake of the credit crisis, we expect there to be increased interest in prudent risk measurement and management based on advanced mathematical models.
- Possibilities to expand our research in the area of health care, which is a focal point of the university and for which we are well positioned.

- *Threats*
- Current banking crisis may reduce financial support from banks for financial engineering research/
- For funding from industry, we need to compete with control engineering groups, which are perceived to be better prepared to obtain quick solutions to systems and control problems in industry/

- *Analysis*
- In the review period, financial engineering as an area of research at the UT has matured and the credit crisis provides many fascinating opportunities for the coming years.
- Research in Systems and Control is doing well, but could use a more clearly defined focus to become a stronger partner for industry.

B3. Stochastics and Operations Research (STOR)

- **Sub-programmes or themes:**
  - Discrete Mathematics & Mathematical Programming (DMMP)
  - Statistics & Probability (SP)
  - Stochastic Operations Research (SOR)

- **NABS code:** N07

- **Chairmen during the review period:**

  - DMMP: Prof. G.J. Woeginger (2003 – 03/2004), Prof. H.J. Broersma (04/2004 - 08/2004), Dr. J.L. Hurink (09/2004 – 10/2007), Prof. M. Uetz (from 11/2007)
  - SP: Prof. W. Albers
  - SOR: Prof. W.H.M. Zijm (2003 – 05/2005), Prof. R.J. Boucherie (from 05/2005)

- **Starting and/or ending date of (each sub-) programme:**

  N.A.

- ***Formal affiliations outside the department and other formal co-operations:***

  - Prof. J.L. van den Berg is senior researcher at TNO ICT, Delft (0.6 fte)
  - Prof. R.J. Boucherie is scientific advisor Eurandom (0.05 fte)
  - Prof. H.J. Broersma is full professor at Durham University (0.95 fte)
  - Prof. L.C.M. Kallenberg is director of the LNMB (0.4 fte) and affiliated with UL (0.6fte)
  - Prof. M.R.H. Mandjes is senior researcher at CWI, Amsterdam (0.6 fte)
  - Dr. G. Post is senior consultant at ORTEC (0.5 fte)
  - Dr. W.R.W. Scheinhardt is senior researcher at CWI (0.2 fte)
  - Prof. M. Uetz is researcher at Universiteit Maastricht (0.1 fte)

1. Mission statement

Area of Research
The “Stochastics and Operations Research” research programme covers stochastics and mathematics for operations research, with a clear focus on mathematical methods in the multidisciplinary setting of mathematics and its engineering environment. The aim is the development of mathematical models and methods for the design, control and optimisation of complex systems. Research topics are inspired by societally relevant areas of application, such as communications, production & logistics, health care and risk.

Mission
The mission of the STOR programme is to achieve mathematical education and research of internationally high standards in the areas of stochastics and mathematics for operations research, to contribute to the development of mathematics in a multidisciplinary engineering environment, and thereby contribute to a better understanding and functioning of our increasingly complex society.

2. Leadership

STOR is the joint research programme of the three chairs of Discrete Mathematics & Mathematical Programming, Statistics & Probability, and Stochastic Operations Research. The three full professors are responsible for the management of the chairs. The scientific interaction within the programme is stimulated through a weekly seminar, at which staff members, students and guests present their ongoing research. Individual informal research contacts within the programme are frequent.

The programme leaders strongly encourage, stimulate and guide
- external contacts through participation in research institutes (e.g. CWI, Eurandom), visits to other universities and research institutes, invitation of guest researchers,
- active participation in national and international conferences by staff members and PhD students,
- submission of research proposals,
- personal development, including participation in courses that strengthen management, teaching and research skills
- an active and lively research community, which has been established by, for example, interaction between PhD and MSc students through joint research and project meetings, and collaboration in the research projects of researchers from different disciplines within the STOR programme, for example, the health care project and the ad hoc networks project.

Each chair holds a monthly formal senior staff meeting. A formal review meeting between the chair holders and staff members about performance and work context takes place annually and is reported to the faculty. Each PhD student has a primary (daily) supervisor, and a secondary advisor, who shares the supervision.

3. Strategy and policy

3.a. Design in brief

The mission of the "Stochastics and Operations Research" (STOR) research programme has a clear focus on mathematical methods in the multidisciplinary setting of mathematics and its engineering environment, inspired by relevant societal areas of application.

The engineering environment is supported by the strategic research orientations (SROs) of the University of Twente, in which the STOR programme is embedded. The "Industrial Engineering & ICT" SRO enables and funds multidisciplinary research initiatives amongst groups from Mathematics, Computer Science, Civil Engineering, Mechanical Engineering, Management, and Accounting. The STOR programme plays a central role in this SRO and provides its chair. The engineering environment is further supported by other SROs of the CTIT, in which communication systems are studied in cooperation with groups from Computer Science and Electrical Engineering. These SROs are Wise (Wireless and Sensor Systems), DSN (Dependable Systems and Networks), and ASSIST (Applied Science of Services for Information Society Technologies). Funding of a limited number of PhD students from first-tier funds is facilitated by these SROs.

The area of application Health Care is embedded in the UT centre CHOIR (Centre for Health Care Operations Improvement and Research www.choir.utwente.nl), which is part of the UT's ambition to be the leading university for technology in health care. The area of application of production & logistics is embedded in the BETA research school in operations management, communications in the e-Quality expertise centre, and risk in the FELab, which coordinates research and applications in Financial Engineering.

The UT has also founded a campus-wide educational cooperation in the area of industrial engineering (IE@UT). STOR is part of the core of this new research initiative. This initiative is further strengthened by growing cooperation in the master's programmes of the participating research groups. This has already resulted in a growing flow of students into the STOR IEOR (Industrial Engineering and Operations Research) master's track. The master's programme forms an integral part of the research programme, since master's projects often form the starting point for both fundamental and applied research projects, and allow for close cooperation with industrial and societal partners. There is an increasing shift to such cooperation.

The mathematical programme of STOR covers Applied Probability, Statistics, and Discrete and Stochastic Operations Research. A substantial part of the research effort is fundamental in nature. Research topics covered by STOR are the following:

- Mathematical programming (discrete & continuous optimisation), and algorithmic discrete mathematics (approximation algorithms, exact algorithms, and online algorithms) provide techniques for best possible, local or global decisions in deterministic settings.
- (Algorithmic) Game Theory aims at analysing and embedding local decisions in larger, decentralised settings with more than one decision maker. The goal is to understand and ultimately design such systems for the better. The mathematical theory of games lays the necessary foundations for this.

- Queuing theory provides the mathematical framework for the sharing of limited resources and delay analysis in systems governed by randomness. The mathematical setting is Applied Probability.
- Large deviations and importance sampling provides a basis for analysis and numerical simulation of rare events in the setting of statistics and probability.
- Stochastic graphs, in particular analysis of the structural properties of huge graphs. The mathematical setting is tail probabilities for light and heavy-tailed distributions.
- Mathematical statistics provides sensitivity and robustness analyses, and studies the impact of dependencies on risks involved in the development, selection, testing and operation of complex systems.

These fields cover a broad arsenal of methods within Mathematics of Operations Research. The specific combination of topics present within STOR result in a focus on analysis, decision support and optimisation under both complete and partial information.

The emphasis is on the optimal design and operation of systems with scarce resources. Increasing complexity in automated systems, the competition on worldwide economic markets, and the development of new technologies that require new mathematical models – with the Internet being one of the most prominent examples – make this a challenging area of research. In particular, it enforces an aligned research effort from several disciplines.

The interplay of the three major research directions present within STOR provides a good strategic basis for such research efforts: in the practice of decision-making, three time-scales are usually distinguished: the strategic, tactical and operational levels. Basically, stochastic methods are required at the strategic level, where explicit knowledge of system parameters is not yet known, while optimisation methods are required rather at the tactical and operational level, where good estimates for data are known. Statistical methods are required at all levels, and answer ubiquitous questions on how to collect, how to process, and how to analyse data. Therefore, a combined effort by STOR researchers is the key to success in many projects.

3.b. Programme development

The previous review period brought many changes. The present review period has been used to strengthen the local, national and international research position of the programme, both in areas of application and in mathematics. The coming period will show a continuation of this development.

Present review period:
At local level, the research environment at the UT has changed considerably in favour of the STOR programme, see 3a.

The development of the STOR programme is supported by the appointment of two new full professors (Boucherie, Uetz). Active personnel management is undertaken. In particular, the procedure for the succession of Albers (Statistics & Probability) has already started. In addition, a number of vacancies have been filled and opened for assistant professors. This has strengthened (and will further strengthen) the STOR programme.

At the national level, cooperation with CWI, TU/e and EURANDOM has been intensified, which has resulted in various joint research programmes, and through Uetz a close link to Maastricht is developing. At the international level, cooperation has been, and will further

be, intensified with several leading research institutes, including INRIA (France), TU Berlin (Germany), and IBM (USA).

Outlook:
The chairs within STOR will increasingly operate as an aligned research team to further enhance the visibility of mathematics groups within the UT, and allow for greater participation of mathematics chairs in university, national and international research efforts. STOR is well positioned within the 3TU cooperation, in particular in the areas of telecommunications and logistics. STOR participates in e-Quality, a knowledge centre in the area of quality of service that aims for joint applications for research projects. In addition, within 3TU there is a growing awareness of the fundamental role of mathematics at technical universities. This development offers opportunities to further strengthen the role of fundamental mathematics in the STOR programme.

Research motivated and stimulated by applications is carried out in three main areas: health care logistics, industrial engineering and communications. Some research highlights in these areas are presented below.

Research in the health care area of application is envisaged to grow through close contacts with hospital research groups, with groups within the UT, and with the new fields of technical medicine and biomedical engineering. In particular, the design of logistical processes for the hospital of the future is a recently started project, in which the strategic, tactical and operational design of hospitals to optimise patient flow from both the perspective of the patient (e.g. short waiting list) and the perspective of the hospital (e.g. high degree of utilisation of resources such as specialists) is being investigated. This project calls for a queuing theoretic approach at the (long-term) strategic level, scheduling at the (medium-term) tactical level, and on-line algorithms at the (short-term) operational level. Furthermore, there is close interaction between these levels, calling for an integrated approach to scheduling in a queuing model. Within health care, other projects are dedicated to particular optimisation problems, such as the design of optimal schedules for operating theatres (queuing theory and scheduling), or the modelling of brain activity and the analysis of PET scans (stochastic processes and statistics). Theoretical developments in asymptotic statistics, modelling and estimation errors, large deviations, and tail probabilities, with their applications in, for example, Statistical Quality Control, will be developed into applications, such as for control charts in health care monitoring.

Research in the area of Industrial Engineering (IE) is envisaged to grow through strong embedding in IE@UT, Beta and the 3TU initiative SCIMM. Cooperation is currently on an individual basis, but groups participating in IE@UT have all expressed their keen interest in enhancing the level of cooperation. Typical projects are optimal revenue sharing in supply chains, where game theory, queuing theory and economic theory are combined; resource allocation and planning in the process industry, based on more realistic models (e.g. spatial resources), where scheduling methods for the tactical level and on-line algorithms for the operational level are needed. Furthermore, in a recently started IOP project in cooperation with Mechanical Engineering, the development of synthesis-based design tools is being investigated, using non-linear optimisation techniques.

Research in the area of communications (e.g. wireless, Internet) and decentralised systems (traffic, economics, logistics) are envisaged to grow by focusing research efforts on Computer Science (embedded systems, formal methods) and Mathematics (mechanism design theory, game theory). The increasing complexity and sheer importance of decentralised systems – again think of the Internet – simply calls for this development. Present projects are a project with Maastricht on Graphs, Mechanisms and

Scheduling (NWO project), and projects in Twente. In the PageRank (NWO MEERVOUD) project of Litvak, the behaviour of a web surfer is modelled as a huge Markov chain whose equilibrium distribution is an important ingredient for Page Rank, as used to list the web pages displayed in a query. Besides stochastic processes, graph theory and numerical analysis also play an important role in this research. Within the Micro Combined Heat and Power (μCHP) Wise SRO, the efficient usage of scarce resources and energy efficiency in embedded systems are being investigated. The rapid growth of the functionality of mobile devices in ad hoc networks or the heterogeneous architecture of new processors require new mapping, routing and scheduling methods, in a highly decentralised environment. Apart from such projects with a clear focus on applications, we plan to analyse the theoretical foundations of the design of decentralised systems, too. For example, in an upcoming PhD project (funded by CTIT) the computational complexity of optimal mechanism design will be analysed, both in general and in concrete settings, such as scheduling and routing.

4. Processes in research, internal and external collaboration

Almost all research results are obtained in the form of cooperation involving two or more researchers. Such cooperation occurs within research projects or through national or international research contacts. In the research projects the PhD students work together with at least one academic staff member of STOR. Whenever possible, the cooperation of PhD students with other researchers is stimulated. To achieve an active exchange of research results between the academic staff and the PhD students, STOR organises regular seminars on several levels (from weekly research seminars to open problem sessions).

National and international research cooperation is mainly based on individual contacts. These contacts are stimulated by the chairs and increase the visibility of the research group and also lead to visits by recognised international researchers to STOR, providing academic staff as well as students the opportunity to develop academically. STOR itself is an international group, with staff members from China, Germany, Russia and the Netherlands.

The past few years have shown a rapid growth in the number of PhD projects within STOR. These projects show a mix of funding through CTIT SROs, and by NWO, STW, and Senter/Novem, which all roughly contribute 25% of the PhD students. Close cooperation within the Netherlands is strengthened through increasing participation in research programmes and institutes. There is a close relationship with Eurandom and CWI, and also strong participation in the Beta and EIDMA research schools and particularly in the PhD and MSc educational programme of LNMB. Currently, STOR is playing a crucial part in the national MSc teaching programme. STOR also participates in MRI.

5. Academic reputation

- *W. Albers*
  - Editorial Board Annals of the Institute of Statistical Mathematics.
  - Chairman Jury International Statistical Institute 'Jan Tinbergen Awards' (biennial).
  - Invited talk 34th Annual Meeting of the Statistical Society of Canada, London, Ontario, 28-31 May 2006.
  - Invited talk Joint Statistical Meeting, session on Nonparametric Statistical Process Control Methods, Seattle, 5-10 August 2006.

- *R.J. Boucherie*
  - Scientific advisor Eurandom.
  - Member board Beta.
  - Member board LNMB.

- *H.J. Broersma*
  - Received EPSRC grant 2008.
  - Editorial Boards: Discussiones Mathematicae, Graphs and Combinatorics, Networks, AKCE International Journal of Graphs and Combinatorics, International Journal of Combinatorics.
  - Visiting Professor Nankai University, China, 2005-2008.
  - Organiser & Programme Chair International Workshop on Graph-Theoretic Concepts in Computer Science 2008.

- *E. A. van Doorn*
  - Editorial Board Stochastic Models.
  - Editorial Board Telecommunication Systems.
  - Editorial Board Journal of Communications and Networks.
  - MASCOS Fellowship, Department of Mathematics, University of Queensland, March-May 2003.
  - Invited lecturer Summer School on Orthogonal Polynomials and Special Functions, Coimbra, Portugal, 13-20 June 2003.
  - Grey Fellowship, Department of Mathematics, University of Durham, UK, April-June 2005.
  - Invited talk at the International Conference on Difference Equations, Special Functions and Orthogonal Polynomials, Munich, 25-30 July 2005.

- *T.S.H. Driessen*
  - NWO-NSC (joint Dutch-Taiwanese) scholarship 2005.
  - Organisation of Twente Workshops on Cooperative Game Theory 2004, 2005.

- *J.L. Hurink*
  - Associate Editor Operations Research Letters.
  - Advisory Board OR Spectrum.
  - Editor special issues of Discrete Optimization.
  - Organising Committee CTW 2003, CTW 2007, SWI 2008, BETA Conference 2008.

- *W.C.M. Kallenberg*
  - Coordinating Editor Journal of Statistical Planning and Inference.
  - Associate Editor International Journal of Statistics and Management Systems.
  - Invited paper 'Shewhart control charts in new perspective' in special issue "Eighty Years of Control Charts" of Sequential Analysis (2007).

- *N. Litvak*
  - NWO Meervoud Grant.
  - Organising Committee Biennial BETA Conference 2006.

- *M.R.H. Mandjes*
  - Editorial Board Stochastic Models.

- *G. Still*
  - EUROPT Fellow 2007.
  - Editor of special issues of EJOR, CEJOR.
  - Organisation of 'Workshop on Advances in Continuous Optimization' 2006.

- *M. Uetz*
  - Associate Editor: Journal of Scheduling, Operations Research Letters.
  - Jury for NWO Open Competition 2008.
  - Invited Lectures: Operations Research 2008, Biennial BETA Conference 2008, Dagstuhl Scheduling Conference 2005.
  - Tiburtius Dissertation Prize 2003.
  - Conference Chair MAPSP 2009.

- *G.J. Woeginger*
  - Editorial Boards: Networks, Journal of Scheduling, OR Letters, Journal of Discrete Algorithms, INFORMS Journal on Computing, Acta Cybernetica.
  - NWO VICI grant 2004 'Exact and Parametric Computation'.
  - Programme chair of ICALP 2003, Track A (Algorithms and Complexity).
  - Programme Chair of MAPSP 2005.
  - Plenary speaker MISTA 2003 (1st Multidisciplinary International Conference on Scheduling).

- *W.H.M. Zijm*
  - Associate Editor Operations Research Spectrum.
  - Associate Editor Manufacturing and Services Operations Management.

6. External validation

6.a. Societal relevance

As stated in our mission, we aim to apply our mathematical approaches to areas of the utmost societal importance, such as telecommunications, production & logistics and health care. The first two of these areas are characterised by rapidly changing technologies, increasing task complexity and growing competition on worldwide markets. For the last area, delivering health care at high quality and affordable costs is a challenging issue. The mathematical approach to decision-making, with the emphasis on the optimal design and operation of systems with scarce resources, is often essential for the successful operation of companies, institutions and governments.

For the coming period, STOR aims at a further regional embedding through close contacts with industrial partners in the Twente region. This will be strengthened through the Industrial Engineering@UT initiative.

Within health care, the recently started LogiDOC project aims to design the hospital of the future. Within this project, there is close collaboration with staff members from a wide range of institutes in health care. This collaboration requires a joint effort by all groups within STOR.

6.b. Industrial contacts

Selection of industrial and non-profit contact per sector:

- Finance and insurance:
  ABP (Algemeen Burgerlijk Pensioenfonds), Achmea, DNB (De Nederlandsche Bank), ING, OHRA
- Consultancy:
  CQM (Centre for Quantitative Methods), ORTEC, INFORM Aachen
- Health care and environment:
  AMC (Academic Medical Centre), Erasmus MC, LUMC (Leiden University Medical Centre), MST (Medisch Spectrum Twente), Roessingh Rehabilitation Centre, Organon, RIVM
- Telecommunications:
  Ericsson, Thales, Vodafone, France Télécom, TNO ICT, Siemens VDO
- Production and logistics:
  Grolsch, Movares, KPN, NS Reizigers, Pro Rail, TPG, Unilever
- Energy:
  Essent, E-ON, Gasterra

7. Researchers and other personnel

Table 20. Researchers in the STOR programme

	Name	2003	2004	2005	2006	2007	2008
STOR							
Tenured staff							
professor (hgl)	Albers, Prof. W.	0.40	0.40	0.40	0.38	0.40	0.40
	Bisschop, Prof. J.J.	0.07					
	Boucherie, Prof. R.J.		0.26	0.40	0.40	0.40	0.40
	Uetz, Prof. M.J.					0.03	0.38
	Woeginger, Prof. G.J.	0.40					
	Zijm, Prof. W.H.M.						
associate professor (uhd)	Boucherie, Prof. R.J.	0.40	0.13				
	Broersma, Prof. H.J.	0.40	0.26				
	Doorn, Dr. E.A. van	0.40	0.40	0.40	0.38	0.40	0.40
	Hurink, Dr. J.L.			0.30	0.40	0.40	0.40
	Kallenberg, Dr. W.C.M.	0.40	0.40	0.40	0.40	0.40	0.40
	Kern, Dr. W.	0.38	0.40	0.40	0.30	0.40	0.40
	Nawijn, Dr. W.M.	0.08	0.06				
assistant professor (ud)	Driessen, Dr. T.S.H.	0.40	0.40	0.40	0.40	0.40	0.40
	Hurink, Dr. J.L.	0.40	0.40	0.10			
	Litvak, Dr. N.	0.40	0.40	0.40	0.40	0.24	0.40
	Mandal, Dr. P.K.	0.40	0.40	0.40	0.40	0.40	0.40
	Ommeren, Dr. J.C.W. van	0.40	0.40	0.40	0.40	0.40	0.40
	Paulusma, Dr. D.	0.40	0.30				
	Post, Dr. G.F.	0.14	0.15	0.18	0.22	0.22	0.22
	Scheinhardt, Dr. W.R.W.	0.40	0.40	0.40	0.40	0.40	0.40
	Schreuder, Dr. J.A.M.	0.00	0.00	0.00	0.00	0.00	0.00
	Spierdijk, Dr. L.		0.34	0.40	0.17		
	Still, Dr. G.J.	0.40	0.40	0.40	0.40	0.25	0.20

	Name	2003	2004	2005	2006	2007	2008
	Timmer, Dr. J.B.	0.40	0.40	0.40	0.40	0.40	0.40
Total tenured staff		**6.68**	**6.30**	**5.78**	**5.46**	**5.14**	**5.61**
Non-tenured staff							
professor (hgl)	Bisschop, Prof. J.J.	0.12		0.11	0.11	0.11	
	Broersma, Prof. H.J.		0.02	0.05	0.05	0.05	0.05
	Hoede, Prof. C.	0.11					
	Kallenberg, Prof. L.C.M.					0.00	0.00
	Mandjes, Prof. M.R.H.	0.20	0.08				
associate professor (uhd)	Berg, Prof. J.L. van den	0.10					
	Nawijn, Dr. W.M.		0.09				
postdoctoral fellows	Al Hanbali, A.M.					0.58	0.91
	Bumb, A.F. Dr.	0.65	1.00	0.66			
	Graaf, Dr. M. de				0.17	0.21	0.21
	Hoevenaars, Dr. L.K.		1.00				
other junior staff (moz, twaio)	Achir, M.					0.05	
	Bruns, P.B.						
	Goseling, J.						0.04
	Malhotra, R.	0.04					
	Wu, J.		0.06	0.06			
	Zhao, H.		0.08	0.20			
Total non-tenured staff		**1.22**	**2.33**	**1.08**	**0.33**	**1.00**	**1.21**
PhD Students							
junior staff (aio, oio, moz-p)	Baarsma, H.E.		0.07	0.80	0.80	0.80	0.53
	Bomhoff, M.J.					0.08	0.40
	Bonsma, P.S.	0.67	0.67	0.67	0.36		
	Bouza Allende, G.			0.11	0.28		
	Brueggemann, T.	0.80	0.80	0.80	0.60		

	Name	2003	2004	2005	2006	2007	2008
	Cheung, S.K.	0.80	0.80	0.80	0.80	0.07	
	Coenen, T.J.M.	0.07	0.80	0.80	0.80	0.66	0.07
	Dieker, A.B.	0.80	0.80	0.80	0.20		
	Endrayanto, A.I.	0.80	0.80	0.80	0.18		
	Foreest, N.D. van	1.00	0.73				
	Grigoras, D.R.				0.80	0.33	
	Haan, R. de			0.60	0.80	0.80	0.80
	Heideveld, S.A.			0.37	0.80	0.53	
	Kortbeek, N.						0.27
	Lukocius, V.		0.27	0.80	0.80	0.80	0.53
	Miretskiy, D.			0.23	0.80	0.80	0.80
	Nieberg, T.	0.80	0.80	0.80	0.40		
	Paulus, J.J.			0.54	0.80	0.80	0.80
	Saha, S.			0.13	0.40	0.40	0.40
	Salman, M.	0.80	0.80	0.26			
	Sri Nurdiati, S.N.	0.80	0.80	0.07			
	Ta, A.T.K.	0.07					
	Volkovich, Y.			0.73	0.80	0.80	0.80
	Wang, X.		0.33	0.80	0.80	0.80	0.46
	Wu, J.				0.43		
	Xu, G.					0.04	0.33
	Zonderland, M. E.						0.13
Total PhD Students		**7.41**	**8.47**	**10.91**	**11.65**	**7.71**	**6.32**
Total Research Staff STOR		**15.31**	**17.09**	**17.77**	**17.44**	**13.85**	**13.14**

8. Resources, funding and facilities

8.a. Laboratory infrastructure

Not applicable

8.b. FTE funding PhDs/PostDocs

Table 21. Source of funding for PhD and Post Doctoral researchers in the STOR programme

Funding	2003	2004	2005	2006	2007	2008	Average
Direct funding	23%	23%	30%	29%	24%	17%	25%
Research funds	46%	46%	28%	22%	22%	32%	33%
Contracts	31%	31%	41%	49%	53%	51%	43%
Other	0%	0%	0%	0%	0%	0%	0%
Total	100%	100%	100%	100%	100%	100%	100%

8.c. List of external funds

Table 22. Overview of projects in the STOR programme

Project	Start date	Enddate	Sponsor	Staff
NL-RF: Axiomatic approach	Feb 2000	Jan 2003	NWO	--
Control of control charts	Feb 2001	Feb 2005	STW	1 PhD
Stochastic network analysis for the design of self optimising cellular mobile communications systems	June 2001	Dec 2004	STW	1 PhD 1 yr PD
EYES: Energy-efficient sensor networks	Mar 2002	Mar 2005	European Commission	1 PhD
EQUIP: Enabling quality of service in IP-based communication networks	Apr 2002	Apr 2006	NWO	1 PhD
Freeband/AWGN: Adaptive wireless networking	Sept 2002	Apr 2007	STW	1 PhD
Local search with exponential neighbourhoods	Oct 2002	Oct 2006	NWO	1 PhD
Beyond 3G: Building expertise yielding outperforming networks derived from 3G	Jul 2003	Dec 2005	Senter Novem	1 PhD
PN@H: Quality of service for personal networks at home	Sept 2003	Mar 2008	Senter Novem/IOP Gencom	1 PhD
BRICKS/IS3: Decision support systems for logistic networks and supply chain optimisation	Jan 2004	Jan 2010	Senter Novem/BSIK	1 PhD

Project	Start date	Enddate	Sponsor	Staff
BRICKS/PDC2: QoS Differentiation mechanisms – scheduling algorithms	Jan 2004	Jan 2010	Senter Novem/BSIK	1 PhD
Personal networks	Jan 2004	Dec 2007	Senter Novem/BSIK	1 PhD
Smart surroundings	Apr 2004	Nov 2008	Senter BSIK	1 PhD
CoBiS: Collaborative Business Items	Aug 2004	Feb 2007	European Commission	0.5 PhD
Exact algorithms	Aug 2004	Aug 2008	NWO	1 PhD
Easy wireless	Sept 2004	Nov 2007	Senter NOVEM	1 PhD
Statistical analysis of dependence effects on insurance portfolios	Sept 2004	Sept 2008	STW	1 PhD
NetRank: Ranking of nodes in complex stochastic networks,	Jan 2005	Jul 2009	NWO	2.1 yr PD
SST: Smart synthesis tools	June 2005	June 2009	SENTER NOVEM	1 PhD
Minimisation of energy consumption	Jan 2006	Jan 2010	NWO/ Casimir	0.8 yr PD
QNOISE: Queuing networks of interacting servers	Dec 2007	Feb 2009	NWO	1 yr PD
Logistical design for optimal care	Sept 2008	Sept 2012	STW	2 PhD
Scheduling a fleet of micro-CHP appliances	Jan 2008	Mar 2012	STW	1 PhD

9. Overview of the results

9.a. Description of scientific results

During the reporting period the research in Stochastics and Operations Research has shown a shift from theoretical research to more application-oriented research. A balance between theory and applications is found, in which general mathematical models are studied and methods are developed that allow for both application in the chosen areas of application and for mathematical publications. Typically, novel fundamental questions are extracted by studying applications, resulting in a strong cross-fertilisation between applications and theory. In particular, the rapid developments in the areas of logistics and communications have resulted in studying new model classes, such as queues in random environments, and extending results for, for example, fluid queues and the development of new optimisation results, including an increasing number of contributions in on-line and approximation methods. Such results have also been increasingly used in the chosen areas of application.

9.b. Key publications

Table 23. Key publications of the STOR programme

• W. Albers, W.C.M. Kallenberg (2005) Tail behavior of the empirical distribution function of convolutions. Mathematical methods of statistics, 14, 133-162.
• K. Avrachenkov, N. Litvak, D. Nemirovsky, and N. Osipova (2007) Monte Carlo methods in PageRank computation: When one iteration is sufficient. SIAM Journal on Numerical Analysis 45(2), 890—904.
• G. Bouza and G. Still (2007) Mathematical programs with complementarity constraints: Convergence properties of a smoothing method, Mathematics of Operations Research 32, 467-483.
• P. Coolen-Schrijner and E.A. van Doorn (2006) Quasi-stationary distributions for a class of discrete-time Markov chains. Methodology and Computing in Applied Probability 8, 449-465.
• D.P. Kroese, W.R.W. Scheinhardt and P.G. Taylor (2004) Spectral properties of the tandem Jackson network, seen as a quasi-birth-and-death process. *Annals of Applied Probability* 14(4), 2057-2089.
• N. Megow, M. Uetz, and T. Vredeveld (2006) Models and Algorithms for Stochastic Online Scheduling, Mathematics of Operations Research 31, 513-525.

9.c. Numerical overview of the results in a fixed format of categories

Table 24. Overview of the research output of the STOR programme

		2002	2003	2004	2005	2006	2007	2008	Total
1. Academic publications	a. PhD-theses	5	2	1	4	5	2	3	22
	b. in refereed journals	55	49	40	28	35	35	33	275
	c. international conference proceedings	23	26	29	21	13	11	19	142
	d. books	2	1						3
	e. book chapters	5	4	2	4	2	1	1	19
Total		90	82	72	57	55	49	56	461
2. International patents									

9.d. Full outcome list

2002

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10. SWOT analysis

- *Strengths*
- The embedding of STOR in UT.
- The strong coherence within STOR.
- A large number of externally funded PhD students stimulates new research.

- *Weaknesses*
- The structural embedding in regional, national and international networks has to be improved.
- The large number of PhD students funded through third money stream projects pulls attention more towards applications and may not leave enough room for basic mathematical research.

- *Opportunities*
- The areas of application STOR is involved in are important societal topics.
- The chair of Probability and Statistics will be filled already before the retirement of the full professor.

- *Threats*
- The number of mathematics students is rather low.
- Three senior staff members of the chair of Probability and Statistics will retire in the years 2008-2014.

- *Analysis*
- The STOR group has been rejuvenated, while continuity in all chairs is maintained, leading to novel research perspectives.
- STOR is actively involved in the key areas of research of the UT, and has growing involvement in Dutch and International networks, providing ample opportunities for research funding.