ANNUAL REPORT 2018

FRAUNHOFER CHALMERS
RESEARCH CENTRE FOR INDUSTRIAL MATHEMATICS

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Cover
Areas of Advance and industrial applications

Annual Report 2018
Fraunhofer-Chalmers Research Centre for Industrial Mathematics, FCC
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CONTENTS

FCC is offering contract research, services, algorithms and tailored software based on advanced mathematics within Modeling, Simulation and Optimization (MSO). MSO provides a significant leading edge in industrial innovation of products and production systems and in 2018, we have successfully proved this together with clients from the automotive and vehicle, metrology, pharmaceutical, wood and paper, and electronics industries. Examples include simulation and optimization of robotized adhesive, spray painting and additive manufacturing processes, simulation of assembly ergonomics, modeling and simulation of drug compound distribution and effect, offline programming of robot carried inspection sensors, and simulation of paper forming.

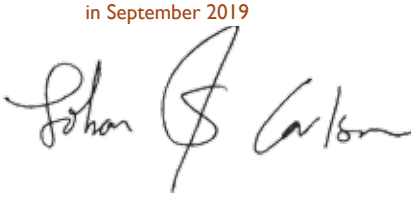
During 2018, we have performed over 50 projects for our industrial clients and 26 public projects financed by public research agencies such as SSF, VINNOVA and the EU. The revenue shows a growth of 8 percent since last year, an industrial income of 38 percent and a positive net result. Our work and technologies have helped clients mainly in Sweden and Germany, but also in US, France, Denmark, Japan, Israel, South Korea, Great Britain, and China.

However, the full potential of using advanced mathematics in industry is far from reached and new technologies together with increased efforts in marketing and sales will hopefully continue our growth in 2019 and beyond.

To be attractive for our clients and employees in the long run, the scientific activities of FCC are indeed important. In 2018, we have published 31 scientific papers, including 13 in journals, and can congratulate one of our coworkers who earned his Licentiate degree in November 2018. Also, 15 students from Chalmers worked half a day a week as contracted students and 11 students from Chalmers did their master thesis work at FCC.

PREFACE AND PROFILE

Gothenburg
in September 2019



Johan S. Carlson
Director

Photo: Anna-Lena Lundqvist

The department Geometry and Motion Planning works in close cooperation with the Chalmers Wingquist Laboratory and Production Area of Advance. In 2018 the department continued and extended several projects, e.g. on automatic path-planning and line-balancing, sealing, virtual paint, flexible materials, metrology, massive point clouds and intelligently moving manikins. The software platform IPS for rigid body path planning, robot station optimization and flexible cable simulation is recognized through licensing by industrial clients in Europe, United States, China, and Japan. The department has substantial joint development with the ITWM department Mathematical Methods in Dynamics and Durability. In 2018 there has also been extensive cooperation with our two spin-off companies; Industrial Path Solutions Sweden AB and fleXstructures GmbH.

A great advantage for FCC is the possibility of long term collaborations with Fraunhofer and Chalmers. The cooperation and exchange of projects with Fraunhofer during 2018 has involved a variety of subjects such as dynamics, biomechanics, the simulation of flexibles, virtual paint, product configuration optimization, robotics, multi-criteria optimization, and machine learning and big data analytics. Besides the MAVO and WISA project with Fraunhofer ITWM, Fraunhofer IPK, Fraunhofer IGD, and Fraunhofer IPA, we are looking for joint projects with other Fraunhofer units such as Fraunhofer IFAM and Fraunhofer IWU.

The well-established collaboration with Chalmers centres and departments includes in 2018; projects, grant applications, guest lectures, FCC industrial PhD program, and master students with Wingquist Laboratory, Industrial and Materials Science, Biology and Biological Engineering, Mechanics and Maritime Sciences, Computer Science and Engineering, Electrical Engineering, and Mathematical Sciences. FCC is also very active in the Chalmers VINNOVA excellence centre "Competence Centre on Additive Manufacturing – Metal (CAM2)", and the Areas of Advance Production, Building Futures, and Life Science Engineering.

I am proud of and impressed by the excellent work done by our coworkers at FCC and I appreciate the fruitful collaboration with our colleagues at Chalmers and Fraunhofer. Highlights include the FCC jubilee conference within the framework of the innovation platform German Swedish Tech Forum, the establishment of the FCC Advisory Board, and winning the first price in Robotics at the Hannover Fair for the IPS software for automatic path planning and optimization. FCC was awarded best paper for a joint publication with ITWM on the ECCOMAS Thematic Conference on Multibody Dynamics. FCC has also established a strong position in AI and machine learning with a good portfolio of projects and by the strategic involvement in the Chalmers foundation AI initiative (CHAIR) and in the Fraunhofer Center for Machine Learning.

Strengthened by the industrial focus on digitalization and the increased support and interaction with our founders, we will continue the challenging but rewarding work with FCC – A Swedish centre in industrial mathematics following the Fraunhofer model with a high level of contracted research boosted by pre-competitive research funded by Fraunhofer and Chalmers.

Enjoy your reading!

The department Computational Engineering and Design has continued to expand its work on novel numerical methods, fast algorithms and engineering tools to support virtual product and process development. The simulation tools are applied in projects together with Swedish and international industry and public partners, for applications in fluid dynamics, structural dynamics and electromagnetics. The department collaborates with the ITWM departments Optimization, Flow and Material Simulation, and Mathematical Methods in Dynamics and Durability, and runs several multi-physics projects involving fluid-structure, fluid-heat transfer and fluid-electromagnetics interaction including simulation of paint and surface treatment processes, cooling of electronics and the project on innovative simulation of paper with Swedish paper and packaging industry. The industrial impact of the core competences and technologies has increased through the founding of the spin-off company IPS IBOFlow AB.

The department Systems and Data Analysis offers competence in dynamical systems, prediction and control, mathematical statistics, big data analytics, and data science in both technical and biological/biomedical applications. In 2018, the department has continued its activities in model based data analysis in drug development and the development of robust and efficient computational tools for mixed effects modeling. Another key activity has been the successfully completed project Remote Data Collection and Visualization with Volvo Cars, with the aim to develop technology for data processing of remotely collected automotive data to be used for decision support for product development of new and existing functions in the car. We have also worked in close collaboration with ITWM department System Analysis, Prognosis and Control on machine learning methods such as incremental clustering and classification and subspace clustering.

Business Fields

FCC offers Contract Research, Software and Services for a broad range of industrial applications. The cornerstones in all activities are Modeling, Simulation, Optimization (MSO) and Visualization of products and processes. For marketing the MSO activities they are divided into the business fields Manufacturing Industry, Life Science, Paper and Packaging, Electronics and Information, and Communication Technologies. To continue the growth, a number of new fields will be investigated during the next few years including Additive Manufacturing, Built Environment, Big Data, Robot and Human Collaboration, Scanning/3D point clouds, and Mechanical Fatigue. The activities within each business field is based on the centre's core competences. The core competences are developed by the departments and the aim is to keep-up and ahead of the state-of-the-art, and have an interaction with the scientific society, in these areas. The business fields are not linked to a specific department, and several projects in for example Manufacturing Industry involve researchers from two departments.

Manufacturing Industry

In the largest business field, Manufacturing, FCC strives to be a leading developer of advanced mathematical tools and algorithms supporting virtual product and process development for complex assembled products in the sub fields of assembly and industrial robotics, geometry assurance and metrology, and surface treatment. For Swedish economy and export, the manufacturing industry is an important sector, representing half of the export value and 30% of all R&D investments in Sweden. In Industrial Robotics, we have been able to develop and implement an automatic solution for robot motion programming and optimization, supporting applications such as welding, assembly, inspection, sealing and gluing. In Geometry Assurance and Metrology, FCC has, in tight collaboration with Wingquist Laboratory, been developing and implementing methods and algorithms supporting the technical vision to create a closed loop from breaking down requirement to inspection features, via automatic programming and optimization of the motions of the coordinate measurement machines or robots, to advanced analysis of the inspection data. In Surface Treatment, FCC's position is very strong with the only software on the market that can accurately simulate the spray painting of a car in a few hours on a desktop computer. The same software can also be used to simulate the laydown of sealing and glue material.

Life Science

In Life Science, FCC strives to be a leading provider of advanced services and tools based on state-of-the-art mathematics and beyond in model based drug discovery and development, systems and synthetic biology, computational cardiology, and quantitative bioimage analysis. In these fields we have successfully acquired industrially and publicly funded projects on both the national and European level. A major part of FCC's life science activities falls within pharmacometrics, i.e., science concerned with mathematical models of biology, pharmacology, disease, and physiology used to describe and quantify interactions between drug compounds and patients. Here we have well-developed relations with AstraZeneca with a mix of projects and project types, ranging from multi-year contract research projects, long term service contracts, and jointly executed public projects.

Paper and Packaging

In Paper and Packaging, FCC supports the Swedish industry with multi-scale methods, algorithms and software for simulation of the papermaking process and paperboard package quality. The focus is in particular on detailed simulations of the build-up of the paper in the forming section of the paper machine, and how the paperboard's resilience to edge penetration and mechanical properties depend on pulp, chemical and forming fabric properties, and process conditions. The unique results have received significant attention and have contributed to new process knowledge.

Electronics

In Electronics, FCC develops simulation tools for drop-on-demand solder jet printing that take the complex rheology of the solder paste into account and the strong fluid-structure interaction in the printer head. In addition, a conjugate heat transfer solver based on IBOFlow® is developed for electronics cooling applications. A collaboration with a large software house was initiated after a benchmark study showed that IBOFlow was at least as good, or better, than available commercial tools. The product has been recently released on the market resulting in a dramatic increase in the number of IBOFlow users.

Information and Communication Technologies

In the Information and Communication Technologies business field, FCC has set out to be a high-end provider of tailor made methods and tools with a high mathematical content. This is a field where our customers can be found among both SMEs and large corporations. Our goal is to excel on mathematical tools and algorithms of importance for ICT applications where our engineering mathematics background and wide experience from a large number of applied projects can be exploited. Areas of particular interest are on-board and off-board data analysis of car signals and function utilization in the automotive industry and automation, control, and sensor solutions in the process industry.

Geometry and Motion Planning

At the Geometry and Motion Planning department, the following core competences are developed: (i) Distance and Collision algorithms that fast and accurately detects collisions and calculates distances between large geometrical objects; (ii) Automatic Path Planning algorithms that fast calculates collision free motions for moving objects in cluttered environment; (iii) Load Balancing, Sequencing and Coordination algorithms that optimise cycle time and equipment utilization in multi robot stations and lines.

Computational Engineering and Design

At the Computational Engineering and Design department, the following core competences are developed: (i) Immersed boundary methods that greatly simplify preprocessing by avoiding the need of a body-conforming mesh, and handle fluid-structure interaction efficiently; (ii) Discrete Element Modeling and Simulation of granular material; (iii) Computational Structure Mechanics for simulation of deformation of flexible structures, welding and additive Manufacturing.

Systems and Data Analysis

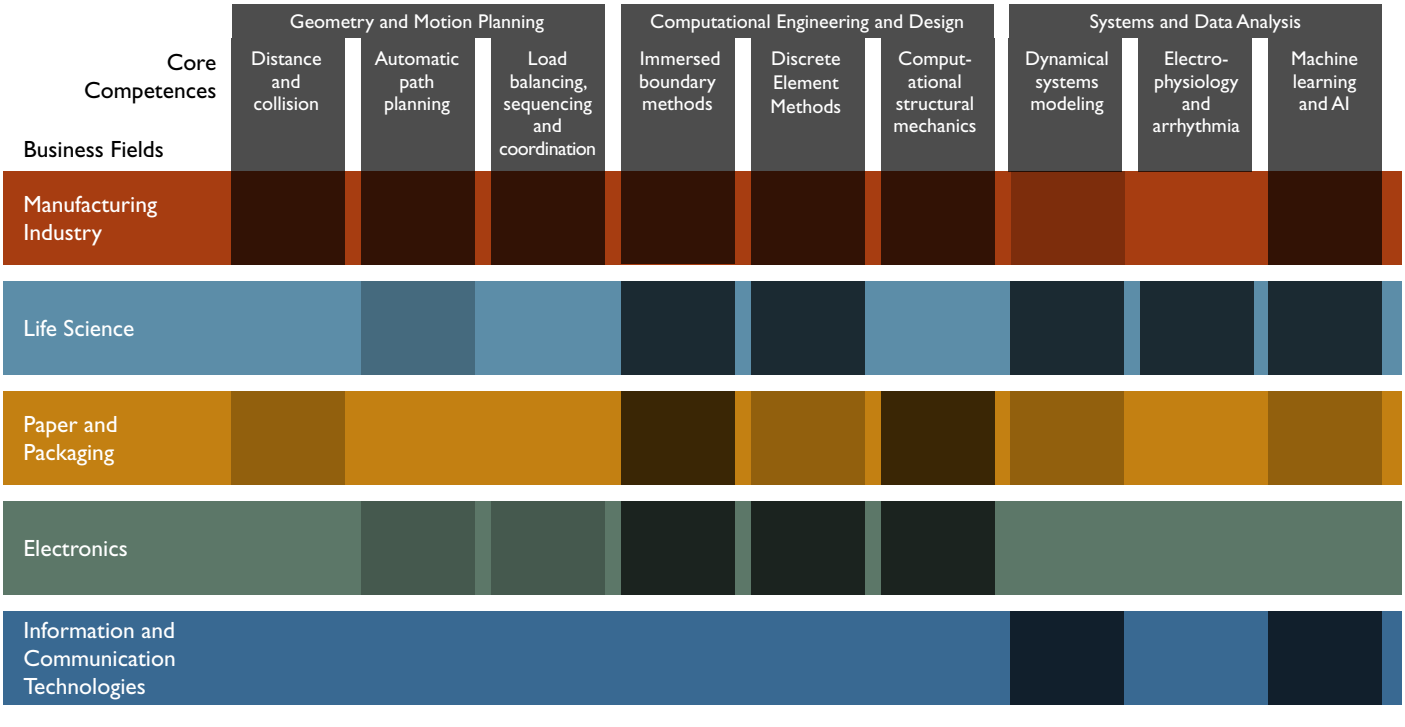
At the Systems and Data Analysis department the following core competences are developed: (i) Dynamical Systems Modeling for characterizing, understanding, predicting, and controlling the time evolution of physical and living systems; (ii) Electrophysiology and Arrhythmia for addressing cardiac disease and cardiac drug safety which are essential for clinical diagnosis and interventions, as well as for the development of new drugs.

Data Science and Machine Learning to gain knowledge and insights from data using techniques such as clustering, classification, anomaly detection, and reinforcement learning.

Core Competences

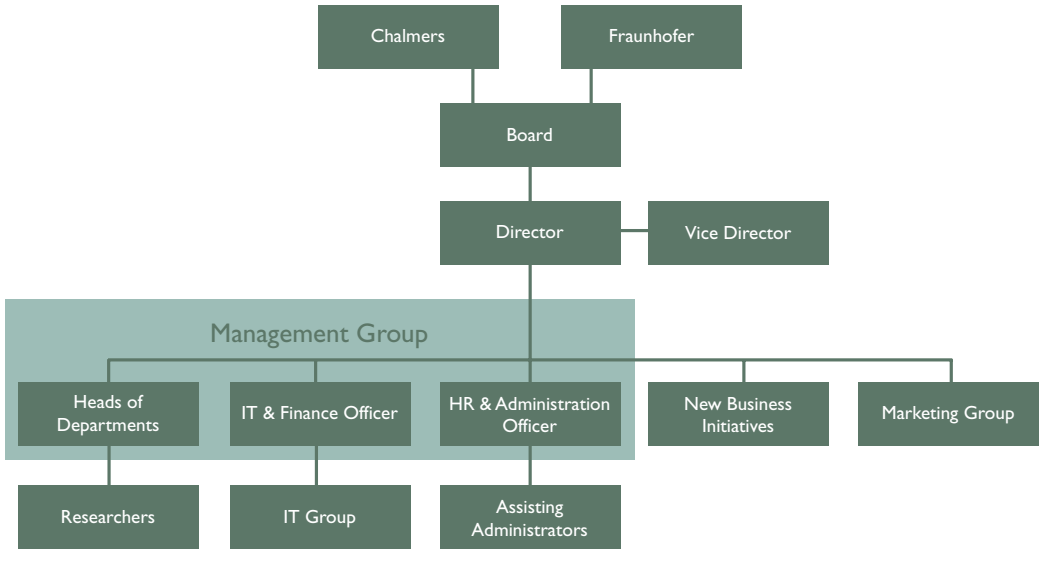
BUSINESS FIELDS AND CORE COMPETENCES

The existing (dark grey) and potential (light grey) links between Core Competences and Business Fields.



FCC personnel

ORGANIZATION



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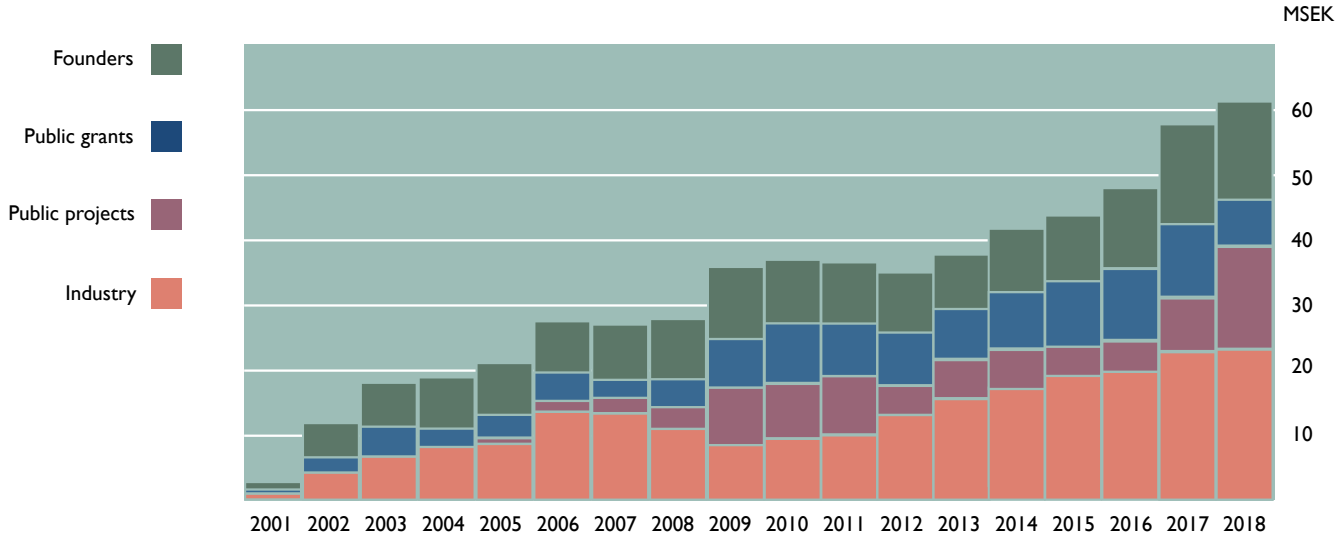


Total income

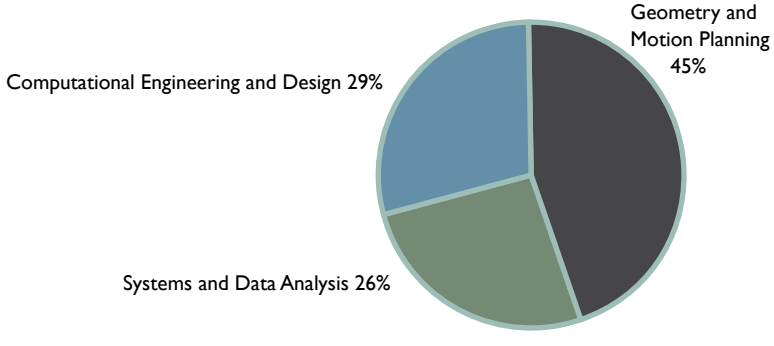
In 2018, the total income increased to 61.5 million Swedish crowns or over 6 million euros which was once again an all-time-high. The result was a positive net, as has been the case every year since our start in 2001.

The profile of the Centre is controlled by its income structure. In 2018, 38% came from industrial projects, 12% from public grants, 26% from public projects under industrial command and 24% base funding from the founders. Compared to previous year we had an increase of industrial projects and public projects under industrial command, but a decrease of public grants.

FACTS AND FIGURES

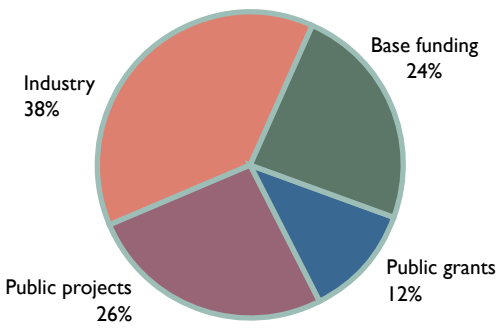
Departments by income

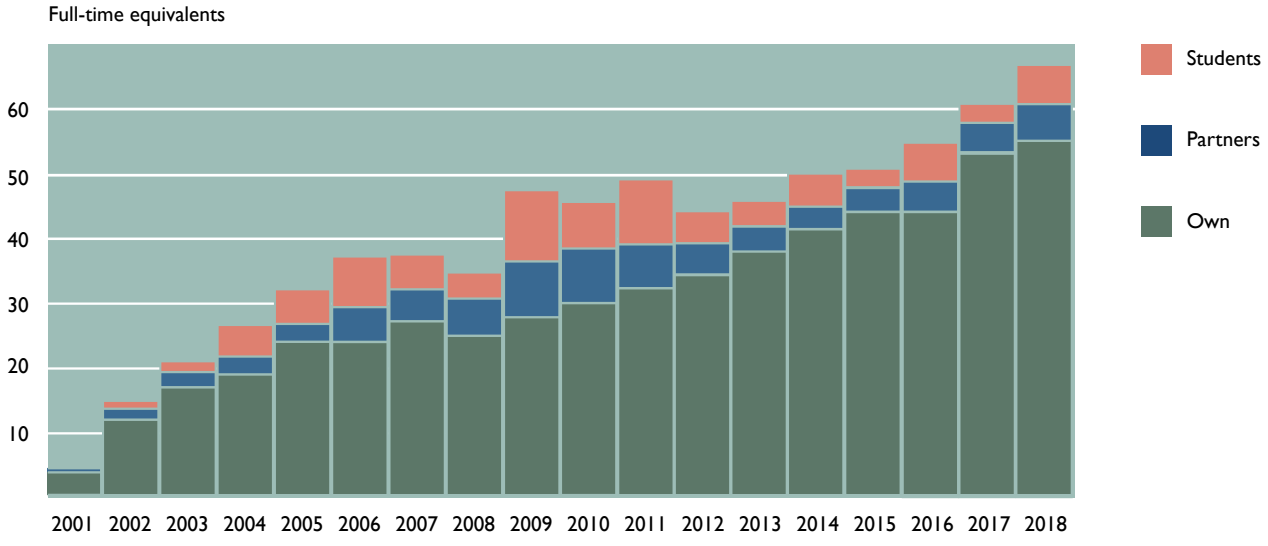
The Centre has three departments. Their relative income was 45%, 29%, and 26% of the grand total including 2% transfer projects between departments.



Project mix by income

The profile of the Centre is controlled by its income structure. We distinguish between four categories: industrial projects, public grants, public projects under industrial command, and base funding. In 2018 there was a good balance, showing a clear industrial profile.





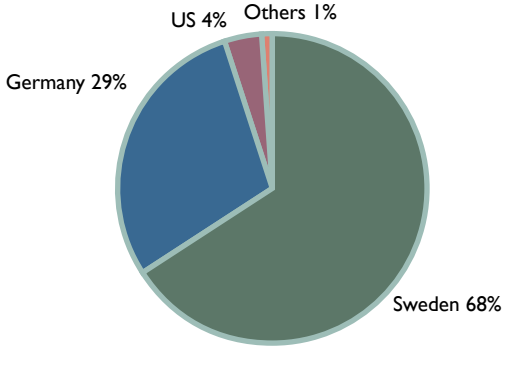
Staff – full-time equivalents

The number of staff 2018 was 67 full-time equivalents (FTE) including own staff (55 FTE), students (6 FTE), and partners (6 FTE). We were happy to recruit 13 new co-workers, six of which were previously contracted students. The number of students was 26 (6 FTE) including eight female students; 11 (5 FTE) doing their Master's thesis projects, and 15 (1 FTE) students in Master's programs contracted on 10-20% for project work.

One (1 FTE) own staff-member was in the Chalmers two-year licentiate program Advanced Engineering Mathematics (AEM), and has earned his Licentiate degree during the year. Ten (8 FTE) own staff-members are in FCC industrial PhD programs, in parallel with project work.

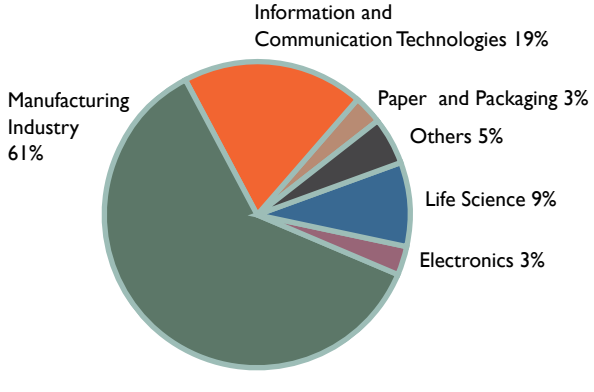
Countries by Income

During the year FCC have had customers in many different countries. The total project volume was divided between:



Business fields by income

During 2018, we have performed 52 projects for our industrial clients, and 26 public projects financed by public research agencies such as SSF, VINNOVA and the EU. Our largest business area is manufacturing industry.



GEOMETRY AND MOTION

The department strives to be a leading developer of mathematical tools, algorithms and software for geometry and motion planning, supporting the digital product realization of complex assembled products. In particular, the department endeavors to provide the most efficient and powerful motion planning technology for the widest range of applications in the automotive and manufacturing industry.

By modelling, simulation, optimization and visualization of geometries and motions in manual and robotized assembly processes, joining processes, and inspection processes the department covers some of the important challenges and opportunities related to digitalization and industry 4.0. Emerging applications are, e.g., self-programming assembly lines, additive manufacturing, human robot cooperation, 3D scanning and point clouds. Over all, the area of geometry and motion planning has proved to contribute with its algorithms and software to cut costs, improve quality and save time in product and production development as well as in running production.

Acknowledgement

In 2018, the Geometry and Motion Planning department has received substantial funding from the FFI, SIO Production and Vinnex program within Vinnova and from the Smart Systems 2015 program within SSF.

N PLANNING

Cooperation

The department works in close cooperation with Wingquist Laboratory with Geometry and Motion Planning as one of its four research groups. The department has a substantial joint development with the ITWM department Mathematical Methods in Dynamics and Durability and the related two spin-off companies: Industrial Path Solutions Sweden AB and fleXstructures GmbH. The cooperation also includes the Industrial Research and Development Corporation and the Virtual Ergonomics Centre. The department is an active member in Chalmers' areas of advance Production and Built Environment.

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During 2018, the department of Geometry and Motion Planning successfully developed methods, algorithms and tools supporting these activities within the main core competences:

- Automatic Path Planning
- Fast Collision Detection and Proximity Queries
- Load balancing, Sequencing and coordination of Robot lines
- Geometry Assurance and Metrology
- Discrete Mechanics and Optimal Control
- Computer Graphics

In particular, the FCC software tool Industrial Path Solutions (IPS) for digital product realization has been successfully used by our industrial partners to solve geometrically complex manufacturing problems in mere minutes instead of hours or even days. The strength of the mathematical algorithms in combination with the easy user interface has allowed the technology to be spread outside the expert teams of simulation engineers and is today used by almost 100 international companies in Sweden, Germany, US, Japan, South Korea, and China. The software is also used for educational

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purposes, e.g. master courses at Chalmers. The main application areas of IPS are:

- Assembly feasibility and ergonomic analysis
- Validation and design of flexibles, such as cables, hoses, bellows, and wiring harnesses
- Automatic off-line programming and optimization of robot lines and inspection machines
- Paint thickness and sealing lay down simulation
- Rendering and geometric analysis in huge scanned point clouds

New customer demands, materials, manufacturing technologies and business models will for sure continue to challenge the industry and push for the extensive use of simulation methods within the area of geometry and motion planning.

Core competences

- Automatic Path Planning
- Fast Collision Detection and Proximity Queries
- Load balancing, Sequencing and coordination of Robot lines
- Geometry Assurance and Metrology
- Discrete Mechanics and Optimal Control
- Computer Graphics

COMPUTATIONAL ENGINEERING AND DESIGN

The rapid increase in computational power has made simulations an integrated part of the development of products and processes. Virtual prototyping stimulates industrial innovation and simulations offer an alternative to measurements, when these are too expensive or even impossible to perform. Furthermore, the risk for unforeseen costs and quality problems is reduced by offering the possibility to perform analyses and optimization in the early phases of product and process development. The department of computational engineering and design supports these activities by developing novel numerical methods, fast algorithms and engineering tools, in particular for application in the areas:

- Fluid Dynamics
- Structural Dynamics
- Electromagnetics
- Optimization

Core competences

- Immersed Boundary Methods
- Multiphase Flow
- Computational Structural Mechanics
- Discrete Element Methods
- Computational Electromagnetics
- Complex Rheology
- Multiphysics Simulation
- High Performance Computing
- Simulation-based Optimization

The department shall be an internationally recognized developer of innovative methods, algorithms and software for virtual product and process development that offers unique possibilities for simulation and optimization of industrial Multiphysics applications.

The research in fluid dynamics is focused on immersed boundary techniques and the development of methods and algorithms for multiphase flows, complex rheology and fluid-structure interaction. The department strives to provide an innovative software that integrates state-of-the-art research on meshless techniques.

The IBOFlow® (Immersed Boundary Octree Flow Solver) software is tailored for applications involving moving objects interacting with the flow and sets a new standard for CFD software by avoiding the cumbersome generation of body-fitted 3D volume meshes. In an ongoing collaboration with a large software house, the focus on electronics cooling applications has resulted in a novel conjugated heat transfer solver that has been released to a large number of customers. In another electronics project together with Mycronic AB, solder jetting on a printed circuit board is simulated including

Acknowledgement

In 2018 the department received substantial funding from VINNOVA through the FFI Sustainable Production Technology, InfraSweden2030, SIP STRIM and Produktion2030 programs, and from the Building Futures and Production Areas of Advance at Chalmers.

multi-phase flow, complex rheology and strong fluid-structure interaction. The capabilities of IBOFlow have been boosted in many ways during the last year. A Lagrangian-Eulerian viscoelastic rheology model with temperature dependency was developed. To enable simulation of liquid metals during additive manufacturing the conjugated heat transfer model is extended to three phases, with phase transition models and temperature dependent surface tension. A Cut-Face IB method has been developed to smoothly capture objects on coarse grids.

The efforts on simulation of paint and surface treatment processes in automotive paint shops have continued and our software solutions receive an increased commercial interest. In the Fraunhofer WISA project SelfPaint, that we run together with Fraunhofer IPA and Fraunhofer ITWM, the aim is to develop a self-programming paint booth, where robot paths and process parameters are automatically selected based on process simulation and inline quality control. The unique Fraunhofer ansatz combines state-of-the-art simulation technology from FCC with inline terahertz measurement technology from ITWM and surface treatment technology from IPA.

In structural dynamics the research platform is our finite element based software LaStFEM (Large Strain Finite Element Method) that includes a wide variety of material models and allows analysis of beams, shells and volumes subject to large deformations. In 2018, the shell solver was integrated into the IPS platform and commercially released to a wide customer base with focus on accurate and rapid simulation of bellows, grommets and flat electrical cables. In an ongoing project with BMW and Fraunhofer ITWM, the aim is to predict deformation of shell structures, whereas welding simulations are performed to support geometry assurance activities at Chalmers IMS. The seamless coupling to IBOFlow enables complex fluid-structure interaction applications to be efficiently simulated such as e.g. table-top and roller hemming where the glue interacts with the folded structure.

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A high-end solver based on the Discrete Element Method (DEM) has been developed that utilize modern graphics cards to reach unparalleled performance and simulate up to 50M particles. During 2018 the software was successfully applied to optimize container filling of pellets together with Borealis, and combined with IBOFlow for simulation of fluidized beds in a project with AstraZeneca.

In 2018, the shell solver was integrated into the IPS platform and commercially released to a wide customer base

A large public project was also acquired during 2018 from VINNOVA's strategic innovation program InfraSweden2030. In the project DigiRoad, modeling and simulation of handling and compaction of unbound aggregates in road construction is performed together with our partners Chalmers Rock Processing, NCC, Dynapac, and Volvo Construction Equipment. Within the Competence Centre for Additive Manufacture – Metal (CAM2), hosted by Chalmers, we are responsible for development of process and geometry simulation tools to increase productivity. DEM simulation is e.g. used to predict the influence of particle shape and powder quality in powder bed additive manufacturing processes.

In electromagnetics, research is performed on models, numerical methods and algorithms for multi species negative corona discharge simulations. The in-house software has for example been used for simulation of externally charged paint applicators and electrostatic precipitators. In optimization, the research is focused on simulation-based optimal design and multiple criteria optimization. This includes novel optimization algorithms, coupling of simulation and optimization software and development of decision support systems that integrate multiple criteria optimization and simulation.

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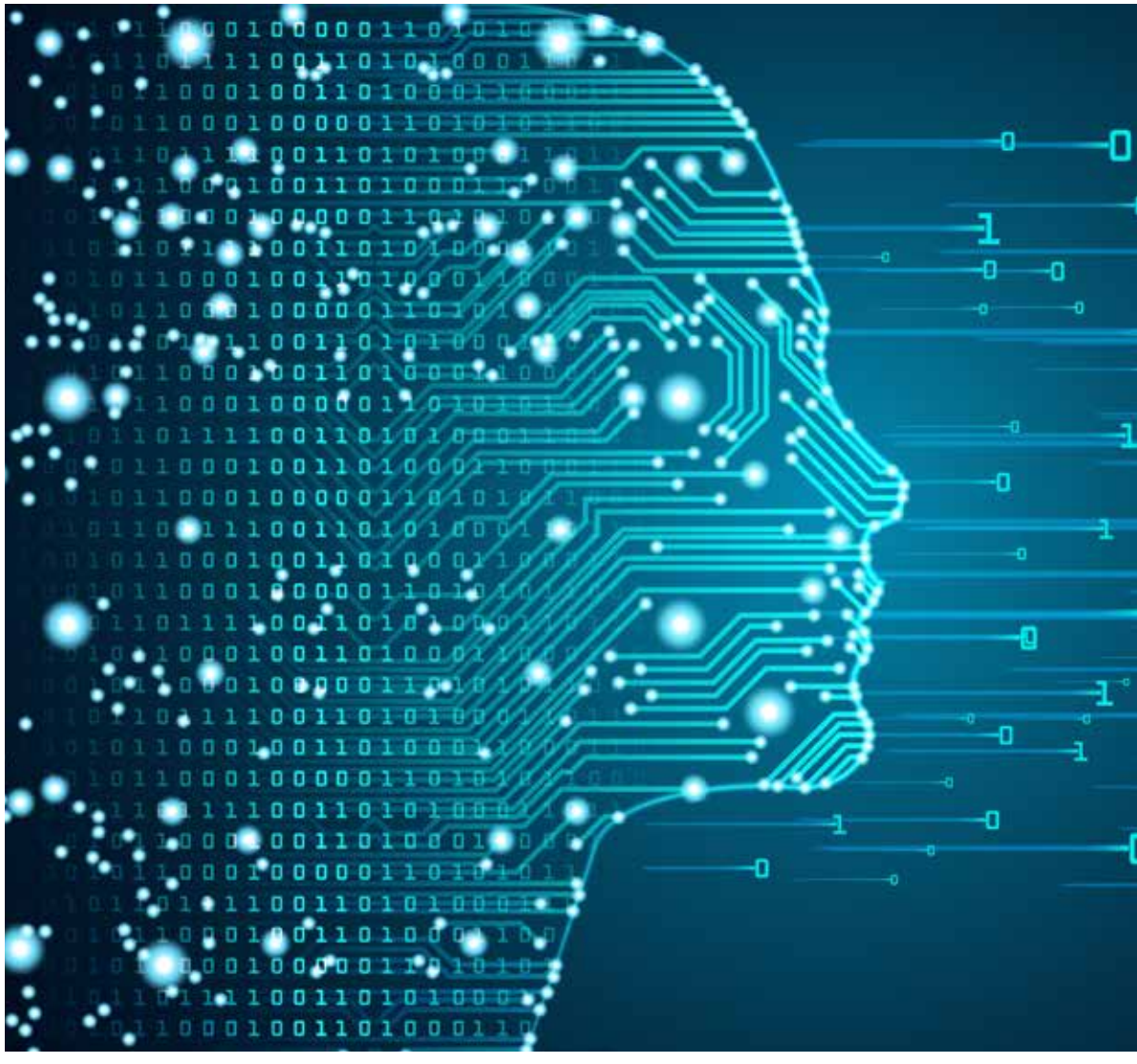
Cooperation

The department has a successful cooperation with the departments of Mathematical Methods in Dynamics and Durability and Optimization at Fraunhofer ITWM which has grown the past years by working on joint projects. Other strategic cooperations include Rise IVF, Fraunhofer IPA, Fraunhofer IFAM and Chalmers divisions of Fluid Dynamics, Product Development, Computational Mathematics and Materials and Manufacture. The department is an active member in Chalmers' areas of advance Production and Building Futures. The software tools are commercialized in cooperation with our spin-off company IPS IBOFlow AB.

SYSTEMS AND DATA ANALYSIS

Core competences

- Machine Learning, AI, and Big Data Analytics
- Dynamical Systems Modeling
- Estimation, Prediction, and Control
- Pharmacometrics and Systems Biology
- Systems and Synthetic Biology
- Electrophysiology and Arrhythmia



Computational tools and techniques for systems and data analysis are key to gaining better understanding of processes and products as well as to optimize their performance. The department has long-time experience in mathematics and algorithms for systems and data analysis as well as in tools, techniques, and mathematics that constitute the basic building blocks of machine learning and applied artificial intelligence.

The department conducts research, application and development of computational methods, software tools, data analysis, and dynamical systems modeling on different levels of abstraction utilizing time and spatially resolved measurement data. In particular, within the areas:

- Big Automotive Data Analytics
- Digitalization in Manufacturing
- Data Analysis in Life Science

Dynamical processes play a key role in many industrial applications such as in the automotive, aerospace, pharmaceutical, and chemical process industry. Knowledge about how to build, simulate, and analyze mathematical models of such processes is crucial to be able to optimize performance, design control systems, or make highly reliable predictions about process behavior.

In Big Automotive Data Analytics the department has pursued work on federated learning and vehicle usage modeling.

The department provides key competence throughout the whole chain of modeling, simulation, analysis, and control of dynamical processes covering a wide range of application areas.

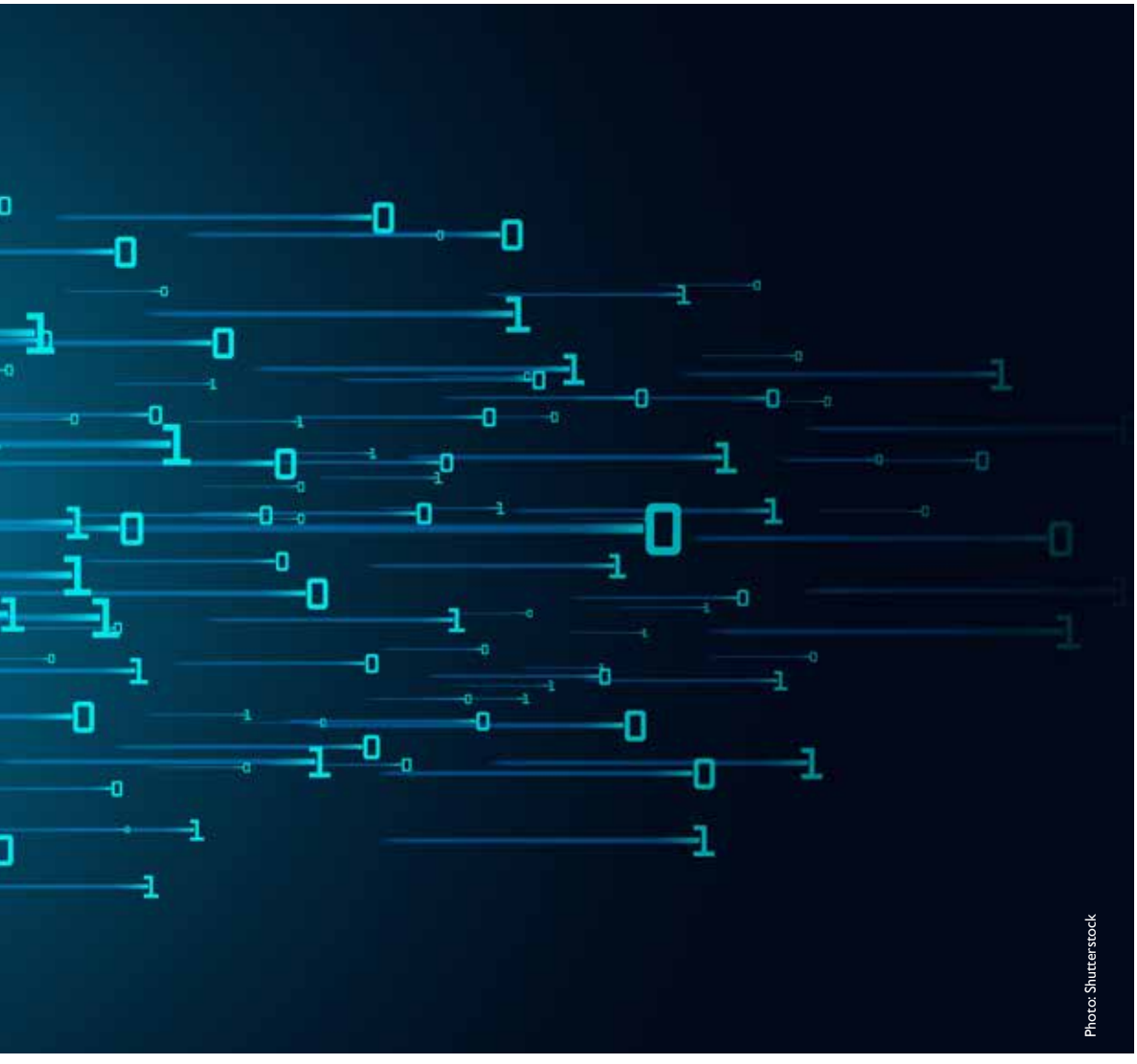


Photo: Shutterstock

Acknowledgement

In 2018, the Systems and Data Analysis department has received funding from VINNOVA in the following projects:

The Strategic Vehicle Research and Innovation program's initiative Big Automotive Data Analytics BADA (FUMA – Fleet telematics big data analytics for vehicle Usage Modeling and Analysis, OODIDA – On-board Off-board Distributed Data Analytics).

The Strategic Vehicle Research and Innovation program's Machine Learning initiative (MALEKC – Machine Learning for Engineering Knowledge Capture).

The Smart Digital Factory initiative (RCA-ML – Root Cause Analysis of Quality Deviations in Manufacturing Using Machine Learning).

The Strategic Innovation Program Production 2030 testbeds (SUMMIT – SUstainability, sMart Maintenance and factory design Testbed).

The Strategic Innovation Program Process Industrial IT and Automation, PiiA (Preventor).

The department has also received funding from the Swedish Foundation for Strategic Research (Hierarchical Mixed Effects Models and Smart Assembly 4.0).

Example applications include machine learning using acoustic transmission spectra for fluid property estimation with Acosense and Stora Enso, machine learning for root-cause analysis of quality deviations combining machine sensor data and quality data with SKF, time-series analysis for optimization of heat control in apartment buildings with Örebrobostäder, and pharmacokinetic and pharmacodynamic modeling in projects with AstraZeneca, Merck, and Grünenthal.

In Big Automotive Data Analytics the department has pursued work on federated learning and vehicle usage modeling. Federated learning, i.e., distributed data processing combined with remote execution of machine learning algorithms, are particularly suited for networks of computational resources such as a vehicle fleet or a population of mobile devices. The algorithms are implemented in a demonstrator platform named OODIDA (On-board Off-board DIstributed Data Analytics), which facilitates data driven function development utilizing a fleet of reference vehicles as testing ground. This work is pursued in collaboration with Chalmers, Volvo Cars, AB Volvo, and Alkit Communications. Another large project at the department in this area, jointly executed with Scania, is FUMA (Fleet telematics big data analytics for vehicle usage modeling and analysis), where very large amounts of time resolved geo-position data from the Scania vehicle fleet is used to derive and categorize vehicles in so called usage modes to improve the knowledge of how vehicles actually are used in operation to the benefit of both customers and future product&service development.

The department shall be an acknowledged developer of computational methods, algorithms, and software tools for system and data analysis utilizing time and spatially resolved measurement data.

Cooperation

The department successfully cooperates with the department of System Analysis, Prognosis and Control and Competence Center High Performance Computing, both at Fraunhofer ITWM. Other strategic cooperation includes joint work with Food and Nutrition Science, Systems Engineering Design, Structural Engineering, Systems and Control, and Mathematical Sciences at Chalmers University of Technology. Furthermore, we participate together with Fraunhofer ITWM, SCAI, IOSB, and IAIS in the Fraunhofer Machine Learning Center, which is one of three centers that constitute a Fraunhofer Cluster of Excellence entitled Cognitive Internet Technologies.

In Digitalization in Manufacturing we take part in the project Smart Assembly 4.0, with the objective to realize the idea of the autonomous, self-optimizing robotized assembly factory, which maximizes quality and throughput, maintaining flexibility and reducing cost, by a sensing, thinking and acting strategy. Here the emphasis for the department is to develop methods based on reinforcement learning to adaptively improve performance of production over time. We have also been active in projects for smart maintenance within the SUMMIT testbed hosted by Chalmers and developed methodology for data driven root cause analysis using machine learning together with SKF and FlexLink in a project within the VINNOVA Smart Industry initiative.

In the area of Data Analysis in Life Science we have continued our long-term collaboration with AstraZeneca providing modeling and simulation services in predictive model-based drug discovery and development as well as initiated an industrial PhD project within quantitative clinical pharmacology. We are also happy to report that Felix Held received his licentiate exam based on data and challenges provided by Grünenthal in our collaboration on dynamical modeling and quantification of drug effect in the case of oscillatory or time-varying base lines. Also, our long-term project with Merck on model-based quantification of synergy for combination therapy has continued according to plan with a prolongation to provide sponsorship for a second industrial PhD student to be recruited in 2019.

Joakim Almquist
PhD

Tim Cardilin
FCC PhD Graduate Program

Otto Frost
MSc

Emil Gustavsson
PhD

Jonas Hagmar
MSc

Felix Held, MSc,
AEM Graduate Program

Aurelién Hontabat
BSc

Anna Johnning
PhD

Emilio Jorge
MSc

Jakob Leander
Lic, PhD student

Anna Lokrantz
MSc

Adrian Nilsson
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Anders Sjöberg
MSc

Olof Skogby Steinholtz
MSc

Simon Smith
MSc

Gregor Ulm
MSc

Mikael Wallman
PhD

Magnus Önnheim
PhD

Jacob Söderström
MSc student

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Eliza Nordén
Contracted student

Ivana Pepic
Contracted student

Sebastian Persson
Contracted student

Yonca Yunatci
Contracted student

Styrelse och ledning 2018

ÅRSREDOVISNING

Styrelsen för Stiftelsen Fraunhofer-Chalmers centrum för industrimatematik, FCC, får härmed avge följande redovisning över verksamheten under tiden 1/1 – 31/12 2018, stiftelsens sjuttonde verksamhetsår.

Stiftelsen bildades av Chalmers och Fraunhofer i juni 2001 och registrerades av Länsstyrelsen i Västra Götalands län i oktober 2001 som en svensk näringsdrivande stiftelse. Stiftelsen har till ändamål att främja och genomföra vetenskaplig forskning, utveckling och utbildning inom området tillämpad matematik i nära samarbete med universitet och andra vetenskapliga och industriella organ samt verka för användning av matematiska modeller, metoder och resultat i industriell verksamhet. Stiftelsens verksamhet skall bedrivas utan vinstsyfte.

I maj arrangerades en jubileumskonferens i samarbete med Tysk-Svenska Handelskammaren, bland annat för att lyfta fram att FCC numera är en permanent del av Fraunhofer-Gesellschaft. På konferensen medverkade representanter för flera olika företag som samarbetar med FCC.

Stiftelsen bedriver sin verksamhet i Chalmers Teknikpark och har ett hyresavtal med Chalmersfastigheter AB till och med den 14 februari 2022 där totala ytan omfattar 1 609 kvm.

Chalmers och Fraunhofer har under året finansierat verksamheten med 14 496 kSEK.

Årets omsättning har varit 61,5 MSEK. Antalet anställda och studenter har motsvarat 61 heltidsekvivalenter (FTE) varav 8 kvinnor. Antalet studenter utgörs av 11 (5 FTE)

Resultaträkning
180101 – 181231, (kSEK)

Intäkter	
Nettoomsättning	61 514
Summa intäkter	61 514
Kostnader	
Externa kostnader	-13 758
Personalkostnader	-46 239
Avskrivningar av materiella anläggningstillgångar	-575
Summa kostnader	-60 572
Rörelseresultat	**942**
Resultat från finansiella investeringar	
Ränteintäkter och liknande resultatposter	326
Räntekostnader och liknande resultatposter	-35
Resultat efter finansiella poster	**1 233**
Bokslutsdispositioner	-438
Årets skatt	-265
Årets resultat	**530**

Balansräkning
181231, (kSEK)

Anläggningstillgångar	
Maskiner och inventarier	1 573
Summa anläggningstillgångar	1 573
Omsättningstillgångar	
Kundfordringar	10 633
Förutbetalda kostnader och upplupna intäkter	11 320
Övriga kortfristiga fordringar	42
Summa kortfristiga fodringar	21 995
Skattefordringar	0
Kassa och bank	21 944
Summa omsättningstillgångar	43 939
Summa tillgångar	**45 512**
Eget kapital	
Eget kapital vid årets ingång	6 817
Årets resultat	530
Summa eget kapital	7 347
Obeskattade reserver	2 274
Kortfristiga skulder	
Leverantörsskulder	5 812
Övriga kortfristiga skulder	2 544
Skatteskulder	0
Upplupna kostnader och förutbetalda intäkter	27 536
Summa kortfristiga skulder	35 892
Summa skulder och eget kapital	**45 513**

examensarbetare, 15 (1 FTE) studenter anställda på 10-20% för arbete i projekt, totalt 6 FTE. Härutöver har arbete motsvarande cirka 6 FTE lagts ut på partners.

Rörelsens intäkter har uppgått till 61 514 kSEK (56 857 kSEK föregående år). Av detta utgör 38% (40%) industriprojekt, 12% (20%) offentliga anslag, 26% (17%) offentliga projekt och 24% (22%) finansiering från stiftarna.

Årets resultat efter skatt är 530 kSEK (358 kSEK). Eget kapital uppgick den 31 december 2018 till 9 121 kSEK (8 249 kSEK) inkluderat kapitalandelen i obeskattade reserver.

Stiftelsens styrelse har under verksamhetsåret sammanträtt två gånger. Ersättning har utgått till ordföranden med 40 250 kronor och till övriga ledamöter med 20 125 kronor per person och år.

Stiftelsens ställning och resultatet av dess verksamhet framgår av ovanstående resultat- och balansräkningar, vilka utgör en integrerad del av årsredovisningen.

Göteborg den 7 april 2019

Rikard Söderberg, ordförande
Dieter Prätzel-Wolters, vice ordförande
Frank Treppe
Bernt Wennberg

Räkenskaperna har granskats av
Auktoriserad revisor Gunnar Andersson

APPENDIX PUBLICATIONS 2018

Journals

R. Andersson, M. Jirstrand, J. Almquist, J. Gabrielsson:
Challenging the dose-response-time data approach: Analysis of a complex system, European Journal of Pharmaceutical Sciences. 128:250-269. Online 17 November 2018.

T Andersson, D Nowak, T Johnson, A Mark, F Edelvik, K Küfer:
Multiobjective Optimization of a Heat-Sink Design Using the Sandwiching Algorithm and an Immersed Boundary Conjugate Heat Transfer Solver, ASME. J. Heat Transfer. 2018;140(10):102002-102002-10, 25 May 2018.

S Björkenstam, S Leyendecker, J Linn, J S Carlson, B Lennartson:
Inverse Dynamics for Discrete Geometric Mechanics of Multibody Systems with Application to Direct Optimal Control, ASME. J. Comput. Nonlinear Dynam. 2018;13(10):101001-101001-15, 30 July 2018.

T Cardilin, J Almquist, M Jirstrand, J Gabrielsson:
Evaluation and Translation of Combination Therapies in Oncology, European Journal of Pharmacology, Vol. 834, p 327-336, 5 September 2018.

Z Ned□lková, C Cromvik, P Lindroth, M Patriksson, A-B Strömberg:
A splitting algorithm for simulation-based optimization problems with categorical variables. Engineering Optimization, Volume 51, Issue 5, 2019, 815-831. Online 30 July 2018.

J Göhl, A Mark, S Sasic, F Edelvik:
An Immersed Boundary Based Dynamic Contact Angle Framework for Handling Complex Surfaces of Mixed Wettabilities, International Journal of Multiphase Flow, 2018, ISSN 0301-9322, Online 13 August 2018.

J Göhl, K Markstedt, A Mark, K Håkansson, P Gatenholm, F Edelvik:
Simulations of 3d Bioprinting: Predicting Bioprintability of Nanofibrillar Inks, Biofabrication, Vol. 10, No. 3, 18 June 2018.

G Kettil, A Målqvist, A Mark, F Edelvik, M Fredlund, K Wester:
A Multiscale Methodology for Simulation of Mechanical Properties of Paper, 6th European Conference on Computational Mechanics, Glasgow, UK, June 2018.

S Lorin, B S Lindau, L Lindkvist, R Söderberg:
Efficient Compliant Variation Simulation of Spot-Welded Assemblies, Journal of Computing and Information Science in Engineering, 19(1), 011007. 19 November 2018

A Forslund, S Lorin, L Lindkvist, K Wärmefjord, R Söderberg:
Minimizing Weld Variation Effects Using Permutation Genetic Algorithms and Virtual Locator Trimming, Journal of Computing and Information Science in Engineering 18 (4), 041010, 6 August 2018.

R Söderberg, K Wärmefjord, J Madrid, S Lorin, A Forslund, L Lindkvist:
An Information and Simulation Framework for Increased Quality in Welded Components, CIRP Annals, Online 24 May 2018.

H K Olafsdottir, J Leander, J Almquist, M Jirstrand:
Exact Gradients Improve Parameter Estimation in Nonlinear Mixed Effects Models with Stochastic Dynamics, AAPS J (2018) 20: 88. Online 1 August 2018.

F Svelander, G Kettil, T Johnson, A Mark, A Logg, F Edelvik:
Robust Intersection of Structured Hexahedral Meshes and Degenerate Triangle Meshes with Volume Fraction Applications, Numerical Algorithms, 77(4):1029–1068, April 2018.

T Cardilin, J Almquist, M Jirstrand, et al.:
Modeling of Radiation Therapy and Radiosensitizing Agents in Tumor Xenografts, PAGE 27 (2018) Abstr 8654. Montreux, Switzerland, May 2018.

M Carlsson, R Ask, N Sandgren, S Jakobsson, F Edelvik, L Hanson:
Simulation of High-Pressure Washing of Engine Blocks, In proceedings from 51st Conference on Manufacturing Systems - CIRP CMS 2018, Stockholm, May 2018, Procedia CIRP, 72:416-419, 2018.

F Edelvik, O Tiedje, J Jonuscheit, J S Carlson:
Analysis of Engineering Change Requests USelfpaint – A Self-Programming Paint Booth, In proceedings from 51st Conference on Manufacturing Systems - CIRP CMS 2018, Stockholm, Procedia CIRP, 72:474-479, May 2018.

Í Ö Arnarsson, E Gustavsson, J Malmqvist, M Jirstrand:
Analysis of Engineering Change Requests Using Markov Chains, DS 92: Proceedings of the DESIGN 2018 15th International Design Conference, p. 523-532. Dubrovnik, Croatia, 21-24 May 2018.

F Held, C Ekstrand, J Gabrielsson, M Jirstrand:
Investigation of Sparse Clinical Sampling in Light of Baseline Oscillations and Between-Individual Variability Using Pharmacokinetic/Pharmacodynamic Modelling, 14th International Congress of the European Association for Veterinary Pharmacology and Toxicology (EAVPT), Wroclaw, Poland, 24-27 June 2018.

S Ingelsten, J Göhl, A Mark, F Edelvik:
Simulating the Dispensing of Complex Rheological Fluids on Arbitrary Geometries Using the Immersed Boundary Method, Annual Transactions of the Nordic Rheology Society, Vol. 26, June 2018.

S Ingelsten, J Göhl, A Mark, F Edelvik:
A Virtual Framework for Simulation of Complex Viscoelastic Flows, In proceedings from 51st Conference on Manufacturing Systems - CIRP CMS 2018, Stockholm, Procedia CIRP, 72:392-397, May 2018.

C Cronrath, E Jorge, J Moberg, M Jirstrand, B Lennartson:
BAGGER: A Bayesian Algorithm for Safe and Query-Efficient Imitation Learning, IROS 2018 Workshop on Machine Learning in Robot Motion Planning, Madrid, Spain, 5 October 2018.

E Jorge, L Brynte, C Cronrath, et al.:
Reinforcement Learning in Real-Time Geometry Assurance, In proceedings of the 51st CIRP Conference on Manufacturing Systems, Stockholm, Sweden, 16-18 May 2018.

Y Li, N Delfs, P Mårdberg, R Bohlin, J S Carlson:
On Motion Planning for Narrow-Clearance Assemblies Using Virtual Manikins, In proceedings of the 51st CIRP Conference on Manufacturing Systems, Stockholm, Sweden, 16-18 May 2018.

A Lokrantz, E Gustavsson, M Jirstrand:
Root Cause Analysis of Failures and Quality Deviations in Manufacturing Using Machine Learning, In proceedings of the 51st CIRP Conference on Manufacturing Systems, Stockholm, Sweden, 16-18 May 2018.

S Lorin, B Lindau, R S Tabar, L Lindkvist, K Wärmefjord, R Söderberg:
Efficient Variation Simulation of Spot-Welded Assemblies, Proceedings of the ASME 2018 International Mechanical Engineering Congress and Exposition, IMECE2018, Pittsburgh, Pennsylvania, USA, 9-15 November 2018.

R Söderberg, K Wärmefjord, J Madrid, S Lorin, A Forslund, L Lindkvist:
An Information and Simulation Framework for Increased Quality in Welded Components, CIRP Annals, online 24 May 2018.

D Högberg, P Ruiz Castro, P Mårdberg, N Delfs, et al.:
DHM Based Test Procedure Concept for Proactive Ergonomics Assessments in the Vehicle Interior Design Process, Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018). Advances in Intelligent Systems and Computing, vol 822. 7 August 2018.

P Mårdberg, J Fredby, K Engström, et al.:
A Novel Tool for Optimization and Verification of Layout and Human Logistics in Digital Factories, In proceedings of the 51st CIRP Conference on Manufacturing Systems, Stockholm, Sweden, 16-18 May 2018.

A Nilsson, S Smith, G Ulm, E Gustavsson, M Jirstrand:
A Performance Evaluation of Federated Learning Algorithms, The 2nd Workshop on Distributed Infrastructures for Deep Learning (DIDL 2018). Rennes, France. 10 December 2018.

G Ulm, E Gustavsson, M Jirstrand:
Functional Federated Learning in Erlang (FFL-ERL), The 26th International Workshop on Functional and Logic Programming (WFLP 2018), Frankfurt am Main, Germany, 6 September 2018.

C Demazière, S González-Pintor, A Ålund:
JFNK Preconditioning for Coupled BWR Calculations, Proceedings of the PHYSOR 2018, Cancun, Mexico, Cancun, Mexico, 22-26 April 2018.

Conference Proceedings

Theses

H Berggren and F Melvås:
Real-Time Tracking of Human Motions and Adaptive Robot Path Planning for Assembly Cooperation, Master thesis, Chalmers University of Technology, June 2018. Supervisor: Y Li.

M Canavero:
Geometry Alignment for Collaborative Robots, Master thesis, Politecnico di Torino, Department of Control and Computer Engineering, July 2018. Supervisors: A Rizzo, R Bohlin.

E Fägerlind:
Walking Generation for Virtual Manikin, Master thesis, Chalmers University of Technology, June 2018. Supervisors: N Delfs, P Mårdberg.

F Held:
Modelling of Drug-Effect on Time-Varying Biomarkers, Licentiate thesis, Chalmers University of Technology, 23 November 2018. Supervisors: M Jirstrand, J Gabrielsson, M Cvijovic, E Hoppe.

C Larsen:
Including a Collaborative Robot in Digital Twin Manufacturing Systems, Master thesis, Chalmers University of Technology, June 2018. Supervisor: J S Carlson.

A Nilsson, S Smith:
Evaluating the Performance of Federated Learning: A Case Study of Distributed Machine Learning with Erlang, Master thesis, Chalmers University of Technology, May 2018. Supervisors: N Smallbone, G Ulm, E Gustavsson.

V Nilsson:
Modeling of Temperature Dependent Surface Tension Force, Master Thesis, Chalmers University of Technology, 12 December 2018. Supervisors: J Göhl, A Mark.

M Ottosson:
Coupling Algorithms for Fluid Structure Interaction at Low Density Ratios, Master thesis, Chalmers University of Technology, 12 June 2018. Supervisors: A Mark, C Cromvik.

O Skogby Steinholtz, J Söderström:
A Comparative Study of Black-Box Optimization Algorithms for Tuning of Hyper-Parameters in Deep Neural Networks, Master thesis, Chalmers University of Technology, May 2018. Supervisors: J Martinsson, A Lokrantz, A Sjöberg, E Jorge, O Frost.

J Thorén:
Accelerating Proximity Queries for Non-Convex Geometries in a Robot Cell Context, Master thesis, Chalmers University of Technology, June 2018. Supervisors: R Bohlin, E Sintorn.

M Vasudevan:
Numerical Modelling of Paint Curing in Convective Ovens, Master thesis, Chalmers University of Technology, 12 June 2018. Supervisors: A Mark, T Johnson, T Andersson.

Courses

R Bohlin:
Path Planning, Advanced Simulation and Optimization. Guest lecture, Robotics and Manufacturing Automation, course at Master level at the Department of Product and Production Development, Chalmers University of Technology, April 2018.

D Gleeson:
Teaching Assistant, Control Theory, Automation and Mechatronics Program, Chalmers University of Technology, September-October 2018.

Guest lecture - IPS presentation, Industrial Automation, Automation and Mechatronics Program, Chalmers University of Technology, December 2018.

E Gustavsson:
Lecturer and course responsible for Nonlinear Optimisation (TMA947) course at Chalmers University of Technology, September-November 2018.

S Lorin:
Supervisor, administrator and lecturer, Course in Engineering design, Chalmers University of Technology, November-December 2018.

A Mark:
Industrial CFD in an Immersed Boundary Framework, Guest Lecture in coarse "Turbulence modelling" at Applied Mechanics, Chalmers University of Technology, Göteborg, Mars 2018.

M Wallman:
"Physiological modeling – the heart", Lecture, part of the course Experimental systems biology, University of Gothenburg, Feb 2018.

Other Assignments

J.S. Carlsson:
Member of the Board Wingquist Laboratory at Chalmers.
Member of the Advisory Council SIO Production 2030.

F Edelvik:
FCC representative in the Swedish Surface Treatment Cluster.

M Jirstrand:
Member of Operational Team, Chalmers AI Research Center.

T Johnson:
Reviewer for Topological Methods in Nonlinear Analysis.
Reviewer for Plasma Sources Science and Technology.

A Mark:
FCC representative in the Swedish Surface Treatment Cluster.

The Fraunhofer-Chalmers Research Centre for Industrial Mathematics, FCC, has been founded by Chalmers and the Fraunhofer-Gesellschaft as a business making, non-profit Swedish foundation.

The purpose of FCC is to promote and undertake scientific research, development, and education in the field of applied mathematics, in close cooperation with universities and other scientific and industrial agencies, and promote the use of mathematical models, methods, and results in industrial activities.

The Centre, in close cooperation with Chalmers in Gothenburg and Fraunhofer ITWM in Kaiserslautern, shall be a leading partner for international industry and academia to mathematically model, analyse, simulate, optimize, and visualize phenomena and complex systems in industry and science, to make development of products and processes more efficient and secure their technological and financial quality.

Our vision is "Mathematics as Technology".

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