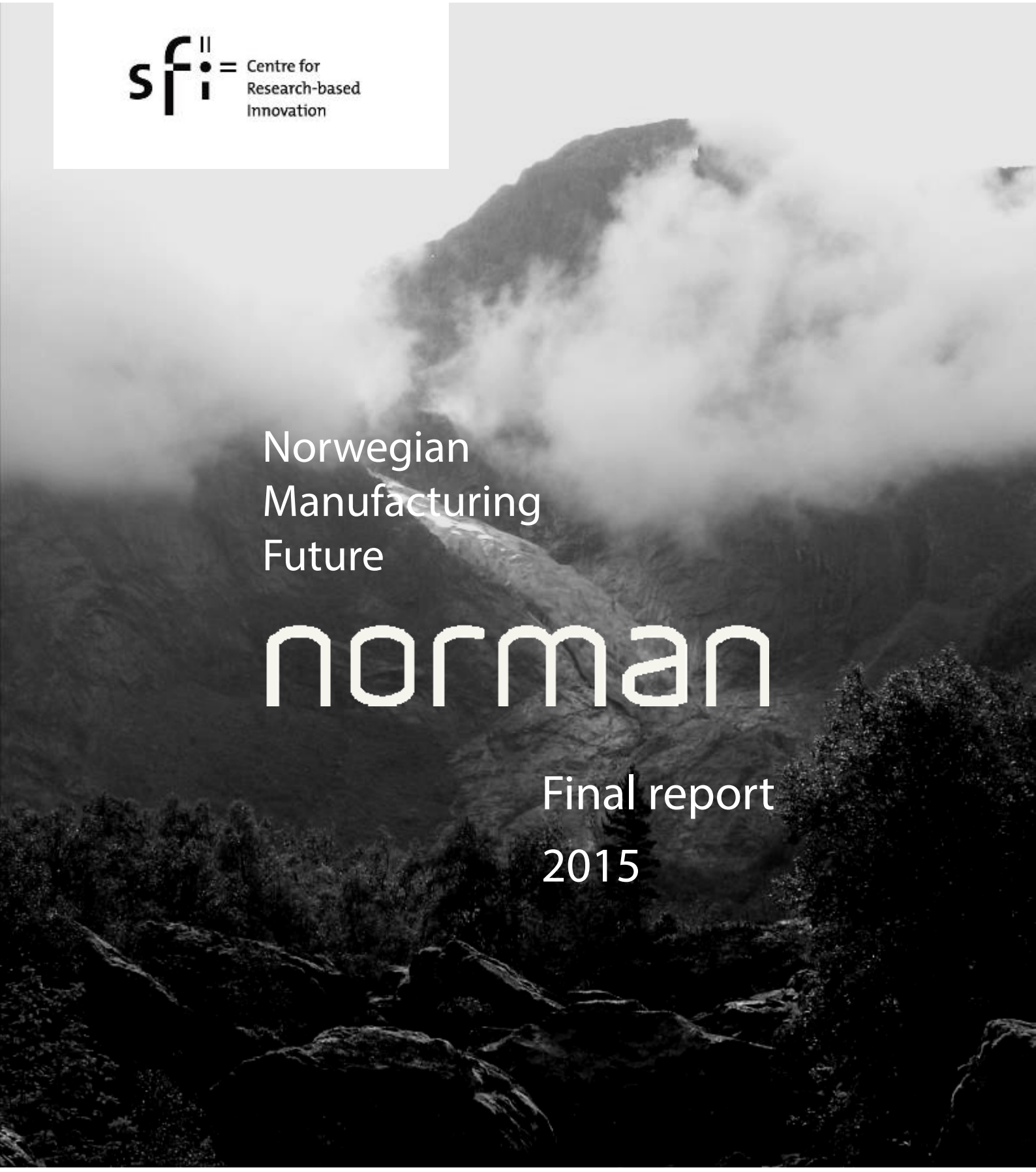
sfi = Centre for Research-based Innovation



Norwegian Manufacturing Future

norman

Final report 2015

SINTEF NTNU The Research Council of Norway

SFI NORMAN— Norwegian Manufacturing Future

A Centre for Research-based Innovation,

established by the Research Council of Norway in 2007

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SINTEF

Foreword

This document is the report from the centre for research based innovation in Norwegian Manufacturing, SFI NORMAN. The report describes the research activities, the achievements and effects of the centre.

We have carefully measured and counted publications, demonstrators, theses and people as well as all our achievements for the more than eight years of activity. You will also find stories from companies, organizations and people in the report.

It has been our aim to carefully report and at the same time create a document that is interesting both for all partners involved, for the funders and for industry and society in general.

Approximately two hundred individuals have been involved and contributed within SFI NORMAN, or given it support in some way. For many of those SFI NORMAN has been a life time opportunity for them to pursue an academic career, like those receiving funding for taking a PhD. Others have participated and supported even without any funding and support for their effort. Common for all of these is that they have done the work with passion and pride to contribute to knowledge development and research to the benefit of increased competiveness in Norwegian industry. For this all deserve sincere thanks.

The report has been produced with effort from a lot of people, and we do appreciate this. In the important final stages Jorunn Auth, Børge Sjøbakk and Anita Romsdal has been the key contributors and we are very grateful for their effort.

I am happy and proud to have been a part of NORMAN for more than a decade, since the initial discussions started until the reporting now is ending. I am extremely grateful for been given the opportunity to contribute to and lead the centre in its final period. A number of people made it possible and have supported me in my work, and I am very grateful for that. My special thanks goes to Tonje Hamar for her professional and friendly support, and unlimited trust in all these years.

But most important: enjoy the reading!

Jan Ola Strandhagen

Centre Director

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Summary

Background and Objectives

In 2007, The Norwegian Manufacturing Future (NORMAN) centre was established - based on the assumption that Norwegian manufacturing has a promising future, especially in the making of high-value and technology-intensive goods. The availability of skilled labor, competence-intensive products, high levels of productivity and the capacity to innovate, combined with very strong infrastructure, will continue to give Norwegian companies an advantage. The national academic level within manufacturing is high, and there is a long and close relationship between academy and industry.

The overall objectives for SFI NORMAN was to develop new and multi-disciplinary research on next-generation manufacturing, and create theories, methods, models, and management tools that enable Norwegian manufactures to thrive in global competition.

Goal Achievement

SFI NORMAN covered the entire innovation process – from basic research to the implementation of new knowledge in companies' everyday operations. Our research demonstrated that innovation processes are cyclic rather than linear. Development, learning and reaping of results happen both in the short and long term. The centre showed how collaboration and joint competence development between complementary industry partners, universities and research institutes are critical success factors. It was an example of the Norwegian knowledge development model in practice.

SFI NORMAN was a complex, yet exciting arena. It was future-oriented and delivered results that satisfy the demands of tomorrow, such as zero defects, increased product customization, frequent changeovers, new environmental requirements and green growth – based on innovative thinking.

At the closure, the following had been achieved:

- Nine PhDs awarded, two complete postdoc periods
- Over 200 scholarly articles published
- Over 400 dissemination measures for users
- Seven cross-disciplinary demonstrators in industrial companies created
- Six international academic conferences hosted
- Twelve workshops organized between industry and research partners
- One major industrial conference organized; Norwegian Manufacturing Future

Research Highlights

The main highlights of the research is presented from the three main research areas

Advanced Manufacturing Technology: The most important impact is the large number of spin-off projects, both nationally and internationally funded. The majority of these projects have focused on higher technology readiness levels (TRLs) than the SFI. These projects have built on the more fundamental results, in the form of proof of concepts or similar generated in the SFI, and matured them into prototypes or even actual systems demonstrated in relevant industrial environments. Another highlight is the fundamental contribution the activities within this research area has had for the development of a new technical standard for Additive Manufacturing technology, which now has been approved by both ISO and ASTM International. Finally, the amount and quality of academic publications from this research area is highly significant.

Operations Management in Norwegian Manufacturing: The aim has been to create knowledge and develop strategies and models for planning and control, management and work organization for operations of future manufacturing. The research has enriched industry practices with concepts, models and tools which exploit technology, automation and expert knowledge into advanced decision support and real time planning and control, all based on the Norwegian tradition of sophisticated and coordinated autonomy in manufacturing. Besidesthis, the research area has resulted in a number of journal and conference publications, innovation research projects, PhDs, university courses and international activities.

Product and Process Development: The main objective has been to gain insight into new product development (NPD) and develop practical methods for improving capabilities and practices in industrial companies. The developed NPD framework has been used in industrial companies to capture research data and to help the companies improve their product development and product introduction practices. Overall, the research has resulted in a number of publications, improved industry practices, innovation research projects, PhDs as well as improved education through new courses, MSc theses, etc. The activities have also generated a significant international research network and researcher mobility.

Partners

SFI NORMAN was established as a strong cross-disciplinary centre for research on intelligent manufacturing, eco-friendly manufacturing and knowledge based innovations. SINTEF was the host and NTNU a key research partner.

A large number of industrial companies were closely involved in defining and carrying out research activities during the eight year period:

Full eight years participants:

- Benteler Aluminium Systems Norway AS
- Ekornes ASA
- GKN Aerospace Norway AS
- Hansen Protection AS
- Hexagon Ragasco AS
- Kongsberg Automotive AS
- Nammo Raufoss AS
- Pipelife Norge AS
- Plasto AS
- Raufoss Technology AS
- Sandvik Teeness AS

From 2011:

- Brødrene AA AS
- Rolls Royce Marine AS
- TINE SA

Shorter periods:

- Elko AS (2007-2011)
- Mills DA (2007-2009)
- Nortura SA (2007-2009)
- Steertec Raufoss AS (2007)

Sammendrag

Bakgrunn og mål

I 2007 ble SFI NORMAN (Norwegian Manufacturing Future) etablert. Bakgrunnen for senteret var at norsk vareproduserende industri har en lovende fremtid, spesielt innen fremstilling av høyteknologiske produkter med stor verdi. Tilgjengelighet på faglært arbeidskraft, kunnskapsintensive produkter, høy produktivitet og innovasjonsevne i kombinasjon med svært sterk infrastruktur vil fortsette å gi norske bedrifter et konkurransefortrinn. Det nasjonale faglige nivået innen produksjon er høyt, og det er et langt og nært forhold mellom akademia og industri.

De overordnede målene for SFI NORMAN var å utvikle ny og tverrfaglig forskning på neste generasjons produksjon, og utvikle teorier, modeller og verktøy som støtter norske produsenters konkurranseevne globalt.

Måloppnåelse

SFI NORMAN dekte hele innovasjonsprosessen - fra grunnforskning til implementering av ny kunnskap i bedrifters daglige drift. Forskningen har demonstrert at innovasjonsprosesser er sykliske heller enn lineære. Utvikling, læring og høsting av resultater skjer både på kort og lang sikt. Senteret viste hvordan samarbeid og felles kompetanseutvikling mellom industripartnere, universiteter og forskningsinstitutter er kritiske suksessfaktorer. Slik var det et eksempel på den norske innovasjonsmodellen i praksis.

SFI NORMAN var en kompleks, men likevel spennende arena. Senteret var fremtidsrettet og leverte resultater som tilfredsstiller morgendagens krav til nytenking innen produksjon – for eksempel null feil, økt produkttilpasning, hyppige omstillinger, nye miljøkrav og grønn vekst.

Ved avslutningen hadde man oppnådd følgende:

- Ni fullførte doktorgrader og to post.doc-perioder
- Over 200 vitenskapelige publikasjoner publisert
- Over 400 formidlingstiltak for brukere
- Syv tverrfaglige industrielle demonstratorer
- Seks internasjonale faglige konferanser arrangert
- Tolv workshops mellom industri- og forskningspartnere gjennomført
- Én stor industriell konferanse organisert; Framtida til norsk vareproduserende industri

Forskningshøydepunkt

Advanced Manufacturing Technology: Den viktigste effekten er det store antallet nasjonale og internasjonale spinoff-prosjekter som har blitt etablert. De fleste av disse prosjektene har hatt fokus på høyere teknologimodenhetsnivåer (Technology Readiness Levels, TRLs) enn hva som har vært fokus i SFI NORMAN. Prosjektene har bygget på mer grunnleggende, konseptuelle resultater fra senteret, og modnet dem i form av prototyper og systemer demonstrert i relevante industrimiljøer. Et annet høydepunkt er det grunnleggende bidraget aktiviteter innenfor dette forskningsområdet har hatt for utviklingen av en ny teknisk standard for Additive Manufacturing-teknologi, som nå er godkjent av både ISO og ASTM International. Mengden og kvaliteten på vitenskapelige publikasjoner fra dette forskningsområdet er også av stor betydning.

Operations Management in Norwegian Manufacturing: Målet har vært å utvikle kunnskap, strategier og modeller for planlegging og styring, ledelse og arbeidsorganisering av fremtidens produksjon. Forskningen har beriket bransjepraksis med begreper, modeller og verktøy som utnytter teknologi, automatisering og ekspertkunnskap om avansert beslutningsstøtte, sanntidsplanlegging og –styring. Dette har vært basert på den norske tradisjonen for sofistikert og koordinert autonomi i produksjon. Foruten dette har forskningsområdet resultert i en rekke journal- og konferanseartikler, innovasjonsprosjekter for næringslivet, doktorgrader, universitetsfag og internasjonale aktiviteter.

Product and Process Development: Hovedmålet har vært å få økt forståelse om produktutvikling og utvikle praktiske metoder for å forbedre kompetanse og praksis i industribedrifter. Et rammeverk for produktutvikling er utviklet og brukt til å fange opp forskningsdata og bistå industrielle bedrifter i å forbedre sin praksis med produktutvikling og innføring av nye produkter. Samlet sett har forskningen i forskningsområdet resultert i en rekke publikasjoner, forbedret bransjepraksis, innovasjonsprosjekter for næringslivet, doktorgrader samt forbedret utdanning gjennom nye kurs og fullførte mastergrader. Aktivitetene har også generert et betydelig internasjonalt forskernettverk med utveksling av forskere.

Partnere

SFI NORMAN har vært etablert som et sterkt, tverrfaglig senter for forskning på neste generasjons produksjon og kunnskapsbasert innovasjon. SINTEF var vert, og NTNU har vært en sentral forskningspartner.

Et stort antall industripartnere har vært tett involvert i å definere og gjennomføre forskningsaktiviteter gjennom prosjektperioden:

Samtlige åtte år:

- Benteler Aluminium Systems Norway AS
- Ekornes ASA
- GKN Aerospace Norway AS
- Hansen Protection AS
- Hexagon Ragasco AS
- Kongsberg Automotive AS
- Nammo Raufoss AS
- Pipelife Norge AS
- Plasto AS
- Raufoss Technology AS
- Sandvik Teeness AS

Fra 2011:

- Brødrene AA AS
- Rolls Royce Marine AS
- TINE SA

Kortere perioder:

- Elko AS (2007-2011)
- Mills DA (2007-2009)
- Nortura SA (2007-2009)
- Steertec Raufoss AS (2007)

SFI NORMAN has been hosted at SINTEF Technology and Society.

SINTEF Technology and Society is a multidisciplinary research institute that operates in the fields of science and technology, and the social sciences. Its strategy is to build social science into the national technology projects.

Visiting address: S.P. Andersens veg 5, 7465 Trondheim

Contact e-mail: ts@sintef.no

Foreword by Host Institution

After eight years and 160 million Norwegian kroner, SFI NORMAN is now concluded. The aim of the centre has been to strengthen the competitiveness of the Norwegian manufacturing industry through long-term research, innovation and application of new knowledge. As such, SFI NORMAN covers the entire innovation process – from basic research to the implementation of new knowledge in companies' everyday operations.

SFI NORMAN has demonstrated that innovation processes are cyclic rather than linear. Development, learning and reaping of results happen both in the short and long term. The centre has shown how collaboration and joint competence development between complementary industry partners, universities and research institutes are critical success factors. It is truly an example of the Norwegian knowledge development model in practice.

The vision of SFI NORMAN was to create new and multi-disciplinary knowledge for the manufacturing systems of the future, and to create theories, methods, models, and management models that enable Norwegian manufacturers to thrive in global competition.

SFI NORMAN has been a complex, yet exciting arena. It has been future-oriented and delivered results that satisfy the demands of tomorrow, such as zero defects, increased product customization, frequent changeovers, new environmental requirements and green growth – based on innovative thinking. These types of development processes are taking place worldwide.

SFI NORMAN's results have been demonstrated in our active participation in EU projects, industry collaboration, researcher exchanges, scientific publications, and completed doctorates. Our legacy is a solid foundation for the future of Norwegian manufacturing.

Tonje Hamar

Director, SINTEF Technology and Society

Research Organization and Achievements

Organization of the Centre

SFI NORMAN was operated for more than eight years, with a large number of industrial and research partners involved. The organization and structure were proposed in the application, a somewhat different model was applied for the first part up to the Mid-way evaluation in 2010. Based on advice from the evaluation a third model was applied for the last four years.

The structure of a five member board, a Centre manager and an industrial coordinator maintained during the whole period. An advisory board was somewhat changed after the midway evaluation advice. The structure of research areas, work packages and industrial workshops was changed and improved after the midway evaluation.

The first section briefly describes the organization during the period of 2007-2010, while more focus and space is given to the operation in the final four years.

A project period of eight years is long – and precisely what researchers dream of; the opportunity to immerse ourselves in research topics over an extended time. The centre went through several stages and saw the need for implementation of changes on the way. Our choices were examined in the midway evaluation, with support for our main operations model and some recommendations for the final project period. A clearer publication strategy was implemented, international collaboration was strengthened, and the research focus was slightly amended through a reorganization of the research tasks and permanent involvement of scientific advisors. In addition, the establishment of more active arenas for communication, interaction and dissemination between researchers, PhD candidates and companies became a key factor in the success of the centre model.

Over the eight-year period, over 200 people were involved in centre activities as researchers, board/ advisory board members and students.

SFI NORMAN Part I: 2007-10

Until the Midway Evaluation in 2010, SFI NORMAN was organized into five main projects:

Customized Reconfigurable Adaptive Manufacturing (CREAM): Agent-based control system with integrated self-balancing functionality for assembly lines, routines and concepts for flexible feeder optimization, automated procedure for fast 2D and 3D calibration of industrial robots. **Project leader:** Roald Karlsen (SINTEF).

Robust and Adaptive Manufacturing Processes (RAMP): Development of an Open Real-time Robot Controller Framework with motion controller framework, Real-Time Sensor Servoing using Line-of-Sight Path Generation and Tool Orientation Control, an Accurate 3D Machine Vision with Automatic 3D Calibration for Reconfigurable Assembly Systems. **Project leader:** Kristian Martinsen (RTIM).

Demand Driven and transparent Manufacturing Value Chains (DRIVE): Development of a tool for measuring supply chain strategic issues, a quantitative approach for placing the customer order decoupling point, the Manufacturing Planning and Control (MPC) guide which assist in the redesign of the manufacturing planning and control (MPC) system, a conceptual framework for customer driven and transparent manufacturing control. **Project leader:** Jan Ola Strandhagen (SINTEF).

The Norwegian Manufacturing Model (NORM): Developed a methodological tool for analyzing shop-floor organization in manufacturing companies and a framework for change based on the analyzes. Mapping based on the methodology has been performed for 12 Norwegian, 1 Japanese and 1 Canadian. Reconfigured the Norwegian model with particular focus on the changing role of trade unions and new models for leadership. Developed a demo on innovation culture and the innovative company in society. **Project leader:** Morten Hatling (SINTEF).

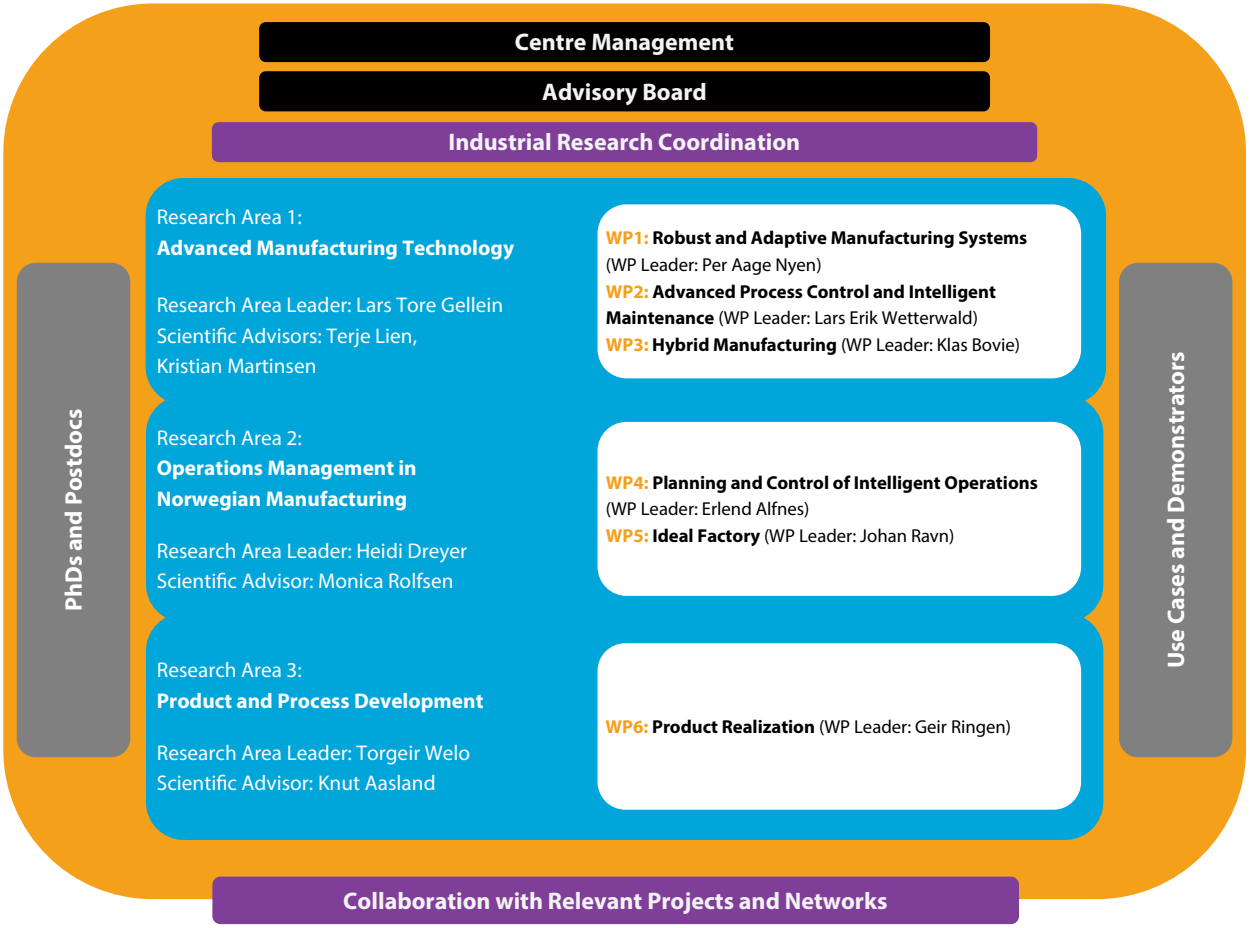
Design Factory (DEFA): Integration of engineering design and management science on company design function development, establishment of framework for assessment of product development efficiency in companies, finding a model for lean product development in Norwegian companies, development of method to change company culture to achieve higher innovativeness. **Project leader:** Knut Aasland (NTNU).

The Midway Evaluation

SFI NORMAN passed the Midway evaluation without any need for major changes. The evaluation identified some key challenges for the centre and these were incorporated in the plans for the final period. Key changes included strengthening of publishing and internationalization, targeting and prioritizing the research areas, and revising the strategy for dissemination and utilization of the research results. Closer collaboration between the technical and the social science research areas was established. In addition, the centre management and administration was restructured, as well as the organization of the research activities.

SFI NORMAN Part II: 2011-14

After the Midway evaluation in 2010, it was decided to restructure the research activities, resulting in establishment of three research areas (RA), consisting of six work packages (WP), see figure below. In addition, workshops were established as a central meeting place between industry representatives and researchers. In total, 12 one-day workshops were conducted at the premises of industrial partners. The feedback from participants shows that these workshops were a key factor in the success of SFI NORMAN.



Organization of the research following the Midway Evaluation in 2010

Research Organization and Achievements

Industrial Research Coordination

By Ottar Henriksen (ottar.henriksen@sintef.no)
Industrial Research Coordinator

In the first years of SFI NORMAN (2007-2010) the main priority for the "Industrial Research Coordination" (IRC) was to engage industry in the creation of "demonstrators" on the basis of industry's strategic needs and topics in the different research projects. This phase of NORMAN was important to get strategic dialogue between industry and research institutions.

Based on the feedback from the mid-term evaluation in 2010, the Board decided to increase networking and learning between the consortium partners. Key topics to focus:

- How can NORMAN improve the learning between the industrial partners on different strategies to increase the speed and magnitude of innovation?
- How can NORMAN get an increased insight into the different industrial partner's utilization of research elements in their innovation processes?
- How can NORMAN improve the dialogue and learning between the industrial partners and the research teams?
- How can NORMAN improve the understanding among the industrial partners of the value of long-term research projects in combination with shorter term innovation projects?
- How can NORMAN improve the visualization to the industrial partners of the value of PhD education as a key element to increase competence in the industry?

To address these topics, the management decided to develop a new workshop structure. The workshops evolved during 2011 as "the meeting place" between the industry representatives and the researchers. Based on the positive experience in 2011, we arranged all together 12 one day workshops in 2011-2014 with the following design:

- All consortium partners were invited to full day workshops. Most of the attendees got together the evening before the workshop. These evening events turned out to be an integrated part of the workshops since people started to discuss research, industrial challenges and research-based innovations during the evening hours.
- Each workshop was organized at the premises of one of the industrial partners.
- One of the three research areas coordinated the research topics to be presented and discussed in each workshop
- The timeline of the workshop was a mix of presentations from case company and research teams, walk/observe in a manufacturing plant and topics to be discussed/solved in multidisciplinary teams.

Based on the feed-back from the participants it seems as these workshops in the second half were important for the success of SFI NORMAN.

Overview of Workshops

When	Host	Topic	Participants
03/11	Kongsberg Automotive, Raufoss	Planning of action items after the mid-term evaluation	27
06/11	Volvo Aero Norge AS, Kongsberg	Manufacturing Management, Ideal Factory, cross-disciplinary research coming years	20
09/11	Teeness, Trondheim	Product development-"Go to Gemba" and discussion of research topics 2012	44
12/11	Ekornes, Sykkylven	Advanced Production Technology	46
03/12	Benteler Aluminium Systems, Raufoss	Operations Management in Norwegian Manufacturing	49
05/12	Plasto, Åndalsnes	Product development	39
09/12	Pipelife, Surnadal	Advanced Production Technology	42
01/13	Hansen Protection, Moss	Business Model Development	47
05/13	Nammo Raufoss Industry Park	Can Lean Product Development facilitate Innovation?	60
10/13	TINE, Trondheim	RFID, Lean Six Sigma, Production Control and –Systems	49
01/14	Rolls-Royce, Ålesund	Manufacturing Engineering & Design for Manufuture and Assembly	47
06/14	SFI NORMAN, RAGASCO, Raufoss	Summing up and discussion on future research	63

Workshop Stories

"The workshop gave Benteler the opportunity to get valuable feedback—not only positive aspects, but also ideas on improvement potential from centre participants"

Anders Artelius
Benteler Aluminium Systems Norway AS

One specific area that was treated in the workshop at Benteler Aluminium Systems was ideas and proposals on how to better handle variants with frequent change-overs and setups. This was also highlighted in the presentation session after the plant tour, where the status of the spare parts project Autopart was presented.

In addition, Benteler's efforts in having a cross-functional approach to R&D focusing on material, process and products were confirmed positive by both industrial and academia partners as a necessity to remain competitive and to develop competence and technologies further.

From Benteler's perspective the workshop gave a joint forum among industrialists and scientists to explore and do research on drivers to maintain a competitive Norwegian position within product development as well as within the manufacturing and logistical concepts of our activities. Norwegian boundary conditions in a global competitive perspective , and the impact of these in systems for product development-, manufacturing- and supply and methodology are important elements in the future progress of our activities.

"For our company, Ragasco, this is value adding. Perspectives on how philosophies and strategies will evolve are presented and this stimulates reflection on how we run our company."

Skjalg Sylte Stavheim
Ragasco AS

From the workshop at Hansen Protection, two very good and well prepared presentations by NORMAN researchers Anita Romsdal and Torbjørn Netland, stood out (studies on Tine and Volvo). These presented research methods for explaining goods flow at goods producing companies which where communicated in an insightful matter. Future trends and future work methods and ways of thinking were presented.

Participation in shop floor analyses gives insight by understanding how other companies work, while at the same time offers the opportunity for the hosting company to get good feedback.

Research Area 1:
Advanced Manufacturing Technology

The overall objective in Research Area (RA) 1, Advanced Manufacturing Technology, has been to obtain automated, high value adding manufacturing through development and application of innovative strategies, technologies and tools supporting adaptivity in manufacturing systems. The main driver is that the future market will increasingly demand a highly flexible manufacturing capability that accommodates new customized, high-value, low-volume products. This implies processes with short cycle times and the ability to rapidly and efficiently reconfigure the production system. Maintaining productivity and reliability, whilst allowing flexibility and adaptability, has been the major technological challenge addressed. The research activities mainly involved activities executed by research groups at SINTEF Raufoss Manufacturing, Production and Quality Engineering (NTNU) and partly Industrial Economics and Technology Management (NTNU).

RA1 has been structured in three work packages: (WP1) Robust and Adaptive Manufacturing Systems, (WP2) Advanced Process Control and Predictive Maintenance and (WP3) Hybrid Manufacturing. Highlights from research achievement are described in the following sections.

By Lars Tore Gellein (lars.tore.gellein@sintef.no)
Research Director SINTEF Raufoss Manufacturing

Robust and Adaptive Manufacturing Systems (WP1)

Quite early in the SFI NORMAN project, WP1 caught interest in the concept of Holonic Manufacturing Systems (HMS) described by Van Brussel et al (1). The referred publication is a descriptive architecture for cooperating holons in a production system. The basic holon types represent products, resources and orders, respectively. Initially, it was easy to accept and understand the advantages of autonomous resource units (machines) as the doctrine of Just-In-Time production over the last three decades has been basically resource oriented. Although 'holonification' of orders and products is interesting academically, its advantages in a practical sense were harder to grasp. In order to investigate the projected potentials of holonified orders and products, it was essential to define a proper case study. In collaboration with the innovation project IHAP (Innovativ Helautomatisert Adaptiv Produksjon av turbinledeskovler) for GKN Aerospace Norway an ideal case and development process for a complete holonification of a new control system was established.

The HMS has been demonstrated both in a simulated environment as well as in a prototype installation at GKN's plant in Kongsberg. First, the mechanisms were demonstrated in a simulated environment in order to convince the industry about the operational advantages of HMS concerning key performance indicators such as throughput time, work-in-process, resilience to disturbances, etc. In stage two, a small number of connected manufacturing operations in the factory were interfaced to basic holon implementations of products, resources and orders. These holons were not implemented to replace the existing control mecha-

1 Van Brussel H, Wyns J, Valckenaers P, Bongaerts I, Peeters P. Reference architecture for holonic manufacturing systems: PROSA. Computers in Industry. 1998

nisms, but rather to conduct a shadow play in which non-effective decision making was recorded over time. These recordings were then compared to the actual decisions made with the existing control system in order to analyze general effects of HMS control. This work is one of very few which attempts to implement an industrialized HMS architecture as described by Van Brussel et al.

In addition, a toolbox called "Integrated Development Environment for Reconfigurable Control Systems" (IDE for RCS) has been developed in WP1. The tool box consists of a range of methods for analysis, development and integration system components, and also includes Visual Components as a tool for verification and validation of HMSs. The industrial case for GKN, described above, was also used to demonstrate the applicability of the IDE for RCS toolbox. The case was ideal since it encompasses a broad range of issues, such as total redesign of an existing shop floor control system, redesign of an existing production line, integration of new production equipment, mixed part production in the redesigned line, introduction of automated part handling, introduction of an automated transport system, and finally, conversion from batch production and flow to one-piece production and one-piece flow.

The research conducted in WP1 has resulted in some spin-off projects, such as the mentioned innovation project IHAP (Innovativ Helautomatisert Adaptiv Produksjon av turbinledeskovler) and NAP (Nullfeilproduksjon i autonome produksjonssystemer).

Advanced Process Control and Predictive Maintenance (WP2)

The main research priorities under WP2 have been i) techniques and tools for self-adjustment, self-calibration and control, aiming at a significant impact of changeover time/cost, tooling and programming of reconfigurable systems, and ii) intelligent maintenance systems based on condition prediction mechanisms, and analysis of machines' behavior, aiming at increased reliability and availability for critical production equipment.

Related to the first main priority different approaches to give robots better accuracy in manufacturing operations like assembly and object measurement have been developed and tested. The latest approach in SFI NORMAN has been to integrate optical and tactile measurement systems in the robot environment, both stationary and on the robot end effector. By utilizing calibration methods in combination with measurement strategies, in-line robotic coordinate measurement has been demonstrated to match CMM on large and complex products.

Further, the robot measurement capabilities have been utilized as a programming tool for the development of new programming methods for industrial robots. The work has been done in collaboration with several innovation projects (ex. Autoflex) and the companies Benteler and Rolls-Royce. The combination of offline programming of robot operations, vision alignment, touch probe measurement alignment and real time force con-

Makino grinding cell – a central target for resource holonification at GKN Aerospace Norway

trol has been further developed to find the best method for aligning offline programs with the real world objects. In addition the same tools have been utilized to develop new "shop floor" programming methods aimed for one-piece automation of manual manufacturing operations. Case studies have been performed on industrial cases together with Benteler and Rolls-Royce. The vision based programming system has been tested on three case studies. Assembly of high tolerance and heavy parts in Rolls-Royce thruster production, disassembly and assembly of heavy and high tolerance components in changeover of press tools at Benteler, and finally programming of sewing paths in Ekornes robotic sewing of recliner covers. The method shows promising results on both the speed of programming a robot task, and the intuitivism of the programming method by visualizing the programs graphically in the pictures taken by robot mounted cameras. All three case studies have been tested by industrial partners for feedback.

Sensor for edge detection developed in SFI NORMAN

Finally, software has been developed for integration of external real-time control of robots, PyMoCo (3) and ROS (4). In addition, a new speed sensor (mechanics and electronics) has been developed. The sensor is used for measurements required for further development of the control system for the automated sewing cell.

The second main research priority was mainly covered through Quan Yu and Zhenyou Zhang's PhD work. They have, together with their supervisor Prof. Kesheng Wang, developed a framework for fault diagnosis and prognosis systems for condition based maintenance. The framework consists of the six steps data acquisition, signal pre-processing, feature extraction, fault diagnosis, fault prognosis and maintenance decision. The system integrates a structured light based 3D vision system used for data acquisition. Several data mining methods have been applied, such as ANN, Decision Tree and Association Rules, in fault diagnosis and prognosis. The framework is established and demonstrated in KDL (Knowledge Development Laboratory) of IPK, NTNU. In addition, the possibility of applying RFID techniques in condition monitoring has been researched, and a demo of RFID application in a production system has been established.

The research conducted in WP2 has also resulted in several spin-off projects, such as the innovation projects KUPP (Kundetilpassede produkter med samarbeidende autonome produksjonsceller), Robust Industrial Sewing, Autoflex (Flexible automated manufacturing of large and complex products) and Multimat (Multimaterial systemer med integrert og automatisert sprøytestøping, sammenføyning og montasje).

Hybrid Manufacturing (WP3)

The main research focus within WP3 has been the successful application and integration of additive manufacturing (AM) technology in industrial manufacturing systems. Besides several successful case studies for the NORMAN partner companies, a principal research topic has been the integration of additive manufacturing with conventional manufacturing technology. The main research achievement on this topic is the development and successful demonstration of a hybrid manufacturing cell prototype, where a conventional 5-axes CNC milling machine and a state-of-the-art additive powder-bed fusion machine has been integrated into an efficient hybrid manufacturing solution. In order to maintain the integrity and the most important advantages of these two fundamentally different manufacturing principles, the integration has been aimed at,

3 A software for building flexible, real-time trajectory generation components developed at NTNU IPK and ITK, SINTEF Raufoss Manufacturing AS.

4 A framework that provides functionality for communication between different nodes using services, used as a middleware solution.

eliminating intermediary and manual operations, streamlining the workflow and connect it all by the development of an agent based common control system for the different machine units.

A common, high precision, pallet system in both machines combined with a measurement probe in the CNC milling machine ensures consistent precision and minimize the need for offset material. A new tool steel for base part and powder material has been applied for hybrid manufacturing, which in combination with a new method for preparing the milled surface for additive manufacturing, eliminates the need for cutting fluids and intermediary heat treatments. This enables CNC milling and AM building to be performed in a single sequence directly after each other with minimal manual operations. The integrated control system track the start and end of the CNC program, transfer the position coordinates and measurements required for starting the AM building as well as monitoring this process. The hybrid manufacturing cell is a semi-automatic system which enables the integration of additive manufacturing technology as a part of the modern industrial production system.

In order to have the highest benefit of the use of each operation in the hybrid manufacturing cell, a system for Optimized Manufacturing Operation Sequence (OMOS) has been developed in collaboration with exchange student and PhD candidate David Homar from Slovenia. OMOS analyses the design of the insert and determines which part should be made by which process. The parts are separated into different solid models and exported to suitable formats for further processing into a CNC code and an AM build file.

Case studies have demonstrated significant benefits of applied hybrid manufacturing to WP3 industrial partners. For example, this has enabled both improved cooling and a new technique for venting gas from critical spaces in injection molding tools. Applied in production, this demonstrator brought reduced cycle times, improved product quality and increased the life time of the critical tool insert by more than ten times as compared to the original tool.

AM enables cost efficient manufacturing of highly complex geometries. This is bound to have a revolutionary impact on product design in the years to come. Cross disciplinary collaboration with the team working on Research area 3, "Product and Process Development", has been carried to develop new guidelines for product design on the topic "Design for performance" which combines state-of-the-art design principles for conventional manufacturing with the new possibilities enabled by AM. Master's student Marius Einang (Dept. Engineering Design and Materials) concluded a student project and his master thesis on this topic, under the joint supervision of Dr. Knut E. Aasland (Dept. Engineering Design and Materials, NTNU) and Dr. Klas Boivie (SINTEF Raufoss Manufacturing AS).

The research, networking and dissemination done within WP3 has strengthened the AM focus and knowledge not only within the participating research group, but also within the participating industrial partners. AM is now a hot topic for many of the industrial partners within SFI NORMAN, and the R&D collaboration on this topic between industry and academia in Norway is recognized internally within the global industrial companies. Activities within WP3 have also given a fundamental contribution for the development of a new technical standard for AM technology, which now has been approved by both ISO and ASTM International. This standard will be the first joint standard developed in a unique collaboration between ISO and ASTM, and it will be a source of reference for national as well as international industry and academia.

The research conducted within WP3 has also resulted in several additional spin-off projects. The 7th FP EU project IC2 and the nationally funded innovation project Hypro are two examples. More recently the EU-project SASAM and the national innovation project NextForm (Neste generasjon formverktøy), which investigated the application of hybrid and additive manufacturing for advanced tools for metal forming and injection molding, and AddForm (Additiv tilvirkning av forminnsatser), that exploits AM technology for rapid development of injection moulding tools for small series manufacturing have further strengthened the project portfolio. Finally, a researcher-driven spin-off project application MKRAM has also recently been submitted for evaluation by NRC. Several of the industrial partners from SFI NORMAN have or are still participating in these projects.

Research Area 2:
Operations Management in Norwegian Manufacturing

The main objective of Research Area (RA) 2, Operations Management in Norwegian Manufacturing, has been to develop strategies and models for planning and control, management and work organization for the next generation manufacturing operations. The market increasingly demands customized products and services delivered with short delivery time. Speeding up and making manufacturing more efficient, adjustable and high performing is a crucial task on the research agenda. For manufacturing operations management this is the task of developing and applying a combination of advanced planning and control models that allow highly automated and intelligent production systems, and to exploit the knowledge and skills of a highly competent workforce. Competitiveness in the manufacturing industry will have to be chased by efficient, adaptive and flexible processes, manufactured and delivered in a responsive supply chain. Therefore how to enable intelligent and automated operations of manufacturing and supply chain by applying new planning and control models and work organization models is one of the critical challenges on the research agenda.

By Heidi Dreyer (heidi.c.dreyer@ntnu.no)
Professor NTNU Department of Production and Quality Engineering

Planning and Control of Intelligent Operations (WP4)

The manufacturing environment is characterized by cost pressure, shorter product life cycles, complex product and customization, and demand variability; all of which necessitates flexible, responsive and demand -driven manufacturing supply chains. WP4 addressed how the planning and control processes can support the need for taking decision and planning in real time, and planning and control models for the next generation demand-driven intelligent manufacturing operations. Together with Pipelife Norge AS, WP4 has developed methods and frameworks for how to integrate real time planning and control of material flows, resource status, and shop floor performance by incorporating information about events at the shop floor and supply chain to the planning and control practices.

Daryl Powell's PhD and Post Doctoral work "Investigating ERP support for Lean production" has identified the typical challenges experienced by manufacturers that attempt to use Lean principles together with contemporary ERP systems. The most exciting breakthrough in his project was the development and testing of an ERP-based lean implementation process. The research project "Autopart" developed the operations strategy for how to achieve competitive manufacturing of automotive spare parts. A new manufacturing business unit was established in 2013 at Benteler to fully exploit the potential of the spare parts market. In recent years, Benteler remarkably increased its on-time delivery performance for spare parts through improved logistics, planning, and control. Anita Romsdal's PhD work "Differentiated production planning and control in food supply chains" developed a framework for how planning approaches can be applied in supply chains to meet the challenges of volatile demand and short lived products. This allowed the case company Tine to reduce the stock level and to increase the delivery reliability.

Ideal Factory (WP5)

"We deem it realistic to see our operators in the future become caretakers, carrying out the main supervision of machines which will be running more or less unmanned". This quote by production manager Ole B. Hoen of GKN points to the quintessence of WP5. Operators in Norwegian industry earn more – or far more – than those with similar jobs in the rest of the world. Because of this, capital investment in automation to enable production with reduced manning is strategically important. This, however, puts new demands on competence, communication and coordination. In order to exploit flexible and reconfigurable production technology, it is essential that the organization share the same characteristics. WP5 addressed this challenge and developed knowledge and tools for organization design and control in modern industrial manufacturing. Norway has a tradition for sophisticated and coordinated autonomy in manufacturing and therefore well positioned to address this task. Jonas A. Ingvaldsen's PhD work (Democratic Lean?) gave companies input on how to organize work by combining lean production with the Norwegian tradition for participation and teamwork. The research project Ideell Fabrikk developed a concept for high-tech manufacturing (IdealFactory@xPS), seeking excellence through high-level interplay between skill, technology and management. 8 principles and accompanying roadmaps for the high-tech factory were developed. Torbjørn Netland's PhD work on XPS: Company specific production systems, developed the understanding of how production improvement in global firms can be achieved through all-encompassing production systems or regimes.

Highlights

- In the Ideal Factory project, a concept for planning, executing and controlling production with reduced manning was developed (PBM) and implemented at Volvo. This was presented at one of the NORMAN company workshops, and from there taken up by Pipelife. It serves as an example of how manufacturing companies from different industries can exploit each other's ideas and shows the important role of the NORMAN company workshops.

- Within the total body of academic publications, some academic achievements stand out. Daryl Powell earned the "best young scientist" award for his paper "Integrating Lean and ERP in Engineer/Make-to-Order Subsea Companies" at the International Conference on Production Research (ICPR22) in Iguassu Falls, Brazil (Hicks, Powell, 2013). With his co-writer Kasra Ferdows, Torbjørn Netland succeeded in presenting his research on XPS through an article in the highly esteemed Sloan Management Review (Netland & Ferdows 2014). And Jonas Ingvaldsen and Monica Rolfsen published their research on lean and teams in the Human relations Journal. (Ingvaldsen & Rolfsen 2012).

- We were successful in our application to The European Operations Management Association (EurOMA) for being the host and organizer of the 23rd International Annual EurOMA Conference in June 2016. More than 500 participants are expected to visit Trondheim in order to present and discuss innovations in operations management.

- The research project Autopart is one out of several spinoff projects from NORMAN. Spare parts production continues for years and even decades after end-of-production of the car. The high mix variability in spare part demand requires a flexibility and responsiveness that is not easily obtained in high volume part production for new cars. The collaborative work of researchers and industrialists resulted in the establishment of a new flexible manufacturing business unit in order to fully exploit the potential of the aftermarket.

- In 2013, Researcher and PhD candidate Torbjørn Netland reached the national final in the competition "Forsker Grand Prix". Of the ten participants in the semifinal in Trondheim, Netland secured his place in the final with his entertaining and enlightening presentation of his research on company-specific production systems.

Torbjørn Netland at "Forsker Grand Prix"

Research Area 3:
Product and Process Development

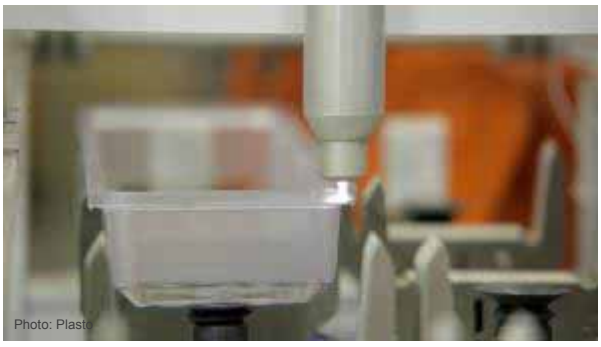
The overall objective of Research Area (RA) 3 has been to develop a practical framework for more effective and efficient New Product Development (NPD). The main driver was the need to sustain a more competitive product manufacturing sector in Norway through the focus on value-added products and innovation capabilities. The research activities mainly involved activities executed by research groups at Engineering Design and Materials (NTNU), Sintef Raufoss Manufacturing and Industrial Economics and Technology Management (NTNU).

By Torgeir Welo (torgeir.welo@ntnu.no)
Professor NTNU Department of Engineering Design and Materials

Product Realization (WP6)

The project has contributed to significant cooperative activities in and between research groups at Sintef and NTNU. One of the more significant results of RA3 in NORMAN has been serving as a seed for a number of new cooperative research projects between multiple organizations and industrial companies, including a number of IPN (e.g. KBD and Systemflomvern 2020), KPN (e.g. TrollLabs and Lean Operations), EU (e.g. Suplight and LinkedDesign), regional RCN (e.g. Ask4Cluster) projects, and even a 3rd generation SFI (SMART). The achievements in RA3 along with dissemination actions and practical application through these and many more project initiatives have brought NPD research in Norway to a significantly higher level than before NORMAN (2007).

In terms of research, RA3 has developed a framework for effective and efficient new product development (LeanPD), aimed at the (organizational) context typically present in Norwegian-based product manufacturing companies. The framework has been developed based on several literature reviews, studies of world industry-best practices and current practices in Norwegian companies, as well as hypothetical reasoning and new thinking. Along with this framework, a complementary LeanPD assessment tool has been developed and used successfully to identify NPD performance gaps and improvement potential within a number of manufacturing companies. In order to document NPD practices in Norwegian companies and test the capability framework, a large net-based survey was conducted. The entire framework and the results from the survey have been published in a number of international journals and at recognized conferences (overview given elsewhere). RA3 has been among the top contributors to publication credits within the SFI center, which is already known for quite excessive publication activities—especially after the mid-term review. The publication activities have also created a large academic network, international cooperation as well as several recruitments to temporary and permanent scientific positions.



SFI NORMAN partner Plasto is a demonstrator for open innovation in the fuzzy front end stages of product development

Active research cooperation with the industry has been the basis for RA3 throughout the period of the SFI center. Several companies have served as test pilots and industrial laboratories for studying NPD practices and testing new methods.

The LeanPD assessment framework has been an enabling tool for improving NPD practices within the SFI companies. A number of workshops have been arranged with individual companies, the SFI consortium as a whole as well as conferences and workshops open to the general public; e.g. NORMAN RA3 together with Norsk Industri and NCE Systems Engineering was the original inspiration to the annual KBD Forum. As mentioned, research within RA3 has also been the inspiration to several more company-specific research projects. One example is the very successful IP project Knowledge-Based Development which, among others, resulted in the 2014 quality award in one of the major international companies participating in the project.

In conclusion, RA3 has made a major contribution to NPD research in Norway during the past 7-8 years. The impact includes improved education, research insight, industry practices as well as research momentum and resources.

Highlights

- Development of explanatory models for new product development capabilities and practices based on industry-led research needs. LeanPD assessments done to improve NPD practices at a number of industrial companies;
- Workshops with industrial companies to gain insight into innovation and product development processes as well as to facilitate discussions and best practice sharing between SFI companies. The topic has been presented in several SFI Newsletters (e.g. Q3, 2013);
- Documentation of best-NPD practices in Norwegian manufacturing companies and the common denominators, showing which components that have influence on NPD performance (published in several papers);
- An emerging framework for increasing the success rate of new product introductions by improving early concept development based on workshops/semi-structured interviews with 10 automotive OEMs;
- Best paper awards at Concurrent Engineering 2010 conference, ICED 2013, as well as outstanding paper award Emerald publisher (Journal of Engineering, Design and Technology (2013);
- Successful completion of three PhDs and 2 post docs and serving as inspiration for more than 50 MSc topics;
- Development of several courses at different levels (MSc, PhD) offered to students in academia and industry;
- Initiation and realization of a number of different IP, KPN and EU projects as well as 3rd generation SFI;
- A significant number of conference and journal publications; typically, 15-20 credits p.a. according to the Norwegian DBH system (see details in separate report). Several of the publications are done together with international research groups.

Workshop on Lean Product Development (LPD) at SFI NORMAN partner TINE

Education

Research based education is a key strategy for NTNU and this strategy was adopted by SFI NORMAN. The strategy was implemented through following means:

- Strong focus on PhD education, involving all PhD candidates into cases, demonstrator development and workshops
- Recruiting and involving master students in cases, demonstrators and PhD projects
- Continuously update master course with results achieved in SFI NORMAN
- Developing new continued education courses, for example Lean Production

The results from this strategy and means are demonstrated below. The initial idea of creating a NORMAN PhD school was not pursued due to the spread in time and scientific focus of the selected PhD candidates.

Participants in the EVU (Etter– og videreutdanning) course Lean Production presenting their value stream maps.

SFI NORMAN PhD Candidates and Post Docs

- Hanne O. Finnestrand, PhD awarded in 2011: The Role of the Shop Steward in Organizations using High Involvement Workplace Practices
- Daryl Powell, PhD awarded in 2012: Investigating ERP Support for Lean Production
- Silje Helene Aschehoug, PhD awarded in 2012: Identifying, compiling, and collecting sustainability information relevant to Norwegian manufacturing firms
- Johannes Schrimpf, PhD awarded in 2013: Sensor-based Real-time Control of Industrial Robots
- Jonas A. Ingvaldsen, PhD awarded in 2013: Democratic Lean? Work Systems in Norwegian Industry
- Zhenyou Zhang, PhD awarded in 2014: Data Mining Approaches for Intelligent Condition-based Maintenance - A Framework of Intelligent Fault Diagnosis and Prognosis System (IFDPS)
- Eirin Anita Lodgaard, PhD awarded in 2014: Continuous Improvement in the Context of Product Development: Application of the PDCA Cycle in the Norwegian Automotive Supplier Industry
- Christer Westum Elverum, PhD awarded in 2014: Leveraging Prototypes in the Quest for Viable Concept Development: A Study of the Automotive Industry
- Quan Yu, PhD awarded in 2015: New Approaches for Automated Intelligent Quality Inspection System
- Emrah Arica, PhD candidate: Effective responsiveness to unscheduled events in production planning and control (PPC)
- Tarvaatsadat Nehzati, PhD candidate: Production planning for production network
- Tomasz Kosicki, PhD candidate: Teleoperation of Industrial Robots
- Odd Myklebust Post Doc
- Kjersti Øverbø Schulte Post Doc

Employment of PhD-candidates

By centre company	By other companies	By public organisations	By university	By research institute	Outside Norway	Total
	2		4	3		9

PhD Stories

- There has always been uncertainty in academia and in practice as to whether Lean and Information Technologies (such as ERP systems) are contradictory or complimentary in nature—this was the motivation for the choice of my PhD topic, says **Daryl Powell**. He finished his PhD in 2012. As part of his project, he carried out an exploratory case study of Kongsberg Automotive in order to investigate some of the typical challenges experienced by manufacturers that attempt to use Lean principles together with contemporary ERP systems.

- The most exciting breakthrough in my project was the development of an ERP-based lean implementation process together with the case company in Trondheim, says Powell. This process can be used by manufacturing companies to deploy Lean practices at the same time as they implement a new ERP system. The SFI NORMAN companies can now apply the new ideas and theory that Powell has developed in order to effectively integrate Lean principles with existing and/or new IT systems. Powell is able to put his insights into action in his current position as Lean Manager in Kongsberg Maritime Subsea.

Photo: Private

Daryl Powell, PhD

- An important motivation for taking on this research was to help firms in their efforts to improve the sustainability performance of their products, says **Silje Helene Aschehoug**, who finished her PhD in 2012. According to Aschehoug, sustainability may be one way of adding value to products beyond traditional aspects like functionality, quality and cost, and thus increase the competitiveness of firms.

- The most exciting findings in my project were the many influencing factors that determine the importance of sustainability information in product development—such as business context, customer type and supply chain position. The revealing of these factors may help firms to organize their sustainability efforts accordingly


Photo: Private

Silje Helene Aschehoug, PhD

After finalizing her thesis Aschehoug has worked with research within product development and innovation in relation to the SFI NORMAN project, using skills and knowledge gained through the PhD project. She has also participated with R&D in the EU project Sustainable and efficient Production of Light weight Solutions (SuPLight), developing a platform for social and ethical evaluation of design alternatives in product development. Further, she has worked as project manager for a BIA project funded by the Norwegian Research Council dealing with integrated production systems, and also managing a project funded by Regional Research Funds. These projects concern knowledge-based development of sustainable and intelligent energy power pylons and involve innovation and product development.

PhD Stories

Before starting his PhD project, **Johannes Schrimpf** worked at SINTEF in different projects focusing on real-time control of industrial robots. *—The chosen PhD topic gave me a possibility to continue work I did in a project working on sewing automation, called "Automated 3D Sewing". During the project, there was close contact between this project and my PhD work*. The main focus in the PhD project was on sensor-based control of industrial robots in real time. *—It was interesting to work on a case where non-rigid materials were handled during a sewing process, a task that requires a very flexible system. The most exciting part was to build a demonstrator setup in the laboratory and to experiment with different control methods*. Schrimpf worked in close cooperation with Ekornes, with meetings discussing the requirements and the results of the experimental work and the demonstrator setup.

Johannes Schrimpf, PhD

Besides the work directly aiming at the cases described in the PhD project, the main benefit for the companies is the possibility to gain insight in the current research status in automation using sensor-based real-time controlled robots. Many of the general methods utilized during the PhD work can be used in flexible manufacturing systems.

Today Schrimpf works as a postdoctoral researcher at the Department of Engineering Cybernetics at NTNU. Here, he is involved in the "Robust Industrial Sewing Automation" project in cooperation with Ekornes and SINTEF Raufoss Manufacturing. The work can be seen as a continuation of the PhD project.

Associated PhDs

Several researchers have carried out their PhDs within related topics, with financial support from outside the centre (e.g. from spin-off projects):

- Marco Semini: Applicability of operations research in manufacturing
- Torbjørn Netland: Company-specific production systems: Managing production improvements in global firms
- Anita Romsdal: Differentiated production planning and control in food supply chains
- Vegard Brøtan: Additive manufacturing for high value metal production in an optimized hybrid manufacturing cell
- Søren Ulonska: A knowledge-based approach for integration of system design methodology and documentation in advanced multi-disciplinary NPD projects
- Martin Gudem: Lean Innovation: A framework for addressing emotional value in product engineering
- Bjørg Granly: Towards a Context-specific Roadmap for Sustainable Manufacturing: Evidences from practices in Norwegian SMEs
- Magne Brattland: Modal Analysis of Active Flexible Multibody Systems in a Finite Element Environment
- Fredrik Widerø: Material flow in screw extrusion of aluminium
- Philipp Spenhoff : Coordinated planning for lean part manufacturing

A PhD degree is the highest level of formalized education in Norway.

A doctoral degree from NTNU qualifies you to a range of positions both in the private and public sector. Though academia has traditionally been the main career path, an increasing number of doctors are going into leading positions in the private sector.

For more information, see https://www.ntnu.no/phd

Photo: Maxime Landrot / NTNU Comm.Div

International Collaboration

Research is by nature global and international networking and collaboration is a must. Most of the industrial partners work and operate globally. Research is a truly international activity, but needs to be stimulated to succeed in this direction. This thinking was important in the planning and operation of SFI NORMAN, and was given particular attention after the midway evaluation. The means applied in SFI NORMAN have been

- Hosting and attending scientific conferences
- Support initiative of international projects (EU-projects)
- Stimulating joint international publications
- Exchange of professors, researchers and students
- Appointed international renowned experts to the Advisory Board
- Stimulating membership in international scientific committees

In this section we present some of the achievements in this area.

International Conferences

MITIP: In June 2011, Norwegian University of Science and Technology (NTNU), Department of Production and Quality Engineering and SINTEF Industrial Management hosted the 13th *International Conference on Modern Information Technology in Innovation Process of Industrial Enterprises* (MITIP) on behalf of SFI NORMAN. The conference, which was chaired by Professor Heidi C. Dreyer from NTNU, was targeted to scholars and practitioners involved in research activities focusing on (but not limited to) the role of ICT in intelligent manufacturing and supply chain operations. Over 60 participants from 15 different countries participated at the conference.

IWAMA: *The International Workshop of Advanced Manufacturing and Automation* (IWAMA) has been a joint workshop between SFI NORMAN, SINTEF, NTNU and Shanghai University since 2010. IWAMA aims at providing a common platform for academics, researchers, practicing professionals and experts from industries to interact and discuss trends and advances in some areas of manufacturing and automation while sharing ideas and perspectives. In October 2014 the 4th IWAMA was hosted by Shanghai University in China, and over 120 participants presented 92 papers.

Rector Torbjørn Digernes, NTNU, at MITIP 2011

The participants of IWAMA 2014, Shanghai

IWOT: In September 2012, the Norwegian University of Science and Technology (NTNU), Department of Industrial Economics and Technology Management hosted the 16th *International Workshop on Team Working* (IWOT), chaired by associate prof. Monica Rolfsen from NTNU. These conferences focus on team working, socio-technical systems theory and organizational psychology, and consist of 40-50 participants from Northern Europe. The conference in Trondheim focused on autonomous teams, and had Professor Bjørn Gustavsen as a key note speaker. There was also a company visit to Teeness, one of the SFI NORMAN companies. After the conference, Rolfsen edited a special issue of Journal of Team Performance Management with papers from the conference.

CIRP LCE 2104: The 21st CIRP Conference on Life Cycle Engineering held at NTNU 18.-20. June 2014. This annual CIRP conference was chaired by Professor Terje K. Lien, NTNU. The conference theme this year was “Life Cycle Engineering to Save Energy”. 100 delegates from 21 countries presented 90 papers covering a wide range of research in the Life Cycle Engineering domain such as Sustainable design, Green manufacturing, Energy efficiency in production, Life cycle analysis, Remanufacturing, Disassembly, Recycling, and other themes related to environmental conscious engineering. The conference was concluded by a visit to Leirfossene kraftverk to give the delegates an impression of what a modern hydroelectric power station deep inside a mountain looks like.

Daryl Powell (NTNU) was awarded the Young Scientist Award for his paper "Integrating Lean and ERP in Engineer/Make-to-Order Subsea Companies" at the 22th International Conference on Production Research (ICPR22) in Iguassu Falls, Brazil, 2013. The paper was written in collaboration with Professor Chris Hicks at Newcastle University.

Christer Elverum, Sören Ulonska and Torgeir Welo at the 2013 CIRP Design product development conference , held in Bochum, Germany. The scope of the conference was Smart Product Engineering. Together with Geir Ringen they presented three papers that covered the main topics of research area 3 in SFI NORMAN.

The 2013 International Conference on Advances in Production Management Systems (APMS) was arranged at Penn State University, USA. From the left: Anita Friis Sommer (Aalborg University), Barbara Resta (University of Bergamo), Daryl Powell (NTNU), Harald Rødseth (NTNU) and Børge Sjøbakk (SINTEF).

International Collaboration

EU Projects

IFaCOM—Intelligent Fault Correction and self-Optimizing Manufacturing systems (agreement no. FP7-2011-NMP-ICT-FoF-285489, 2011-2015). The vision of IFaCOM is to achieve near zero defect level of manufacturing for all kinds of manufacturing, with emphasis on production of high value parts, large variety custom design manufacturing and high performance products. NTNU IPK is coordinator of the project. GKN participate as a Norwegian industrial partner.

IC2—Intelligent and Customized Tooling (agreement no. FP7-NMP-2009-SME-3-246172, 2010-2013). The project addressed the need for new technology and organizational models for the European tooling industry. Coordinator: SINTEF Raufoss Manufacturing. Norwegian partners: NTNU IPK, Plasto, Raufoss Offshore, Baldur Coatings.

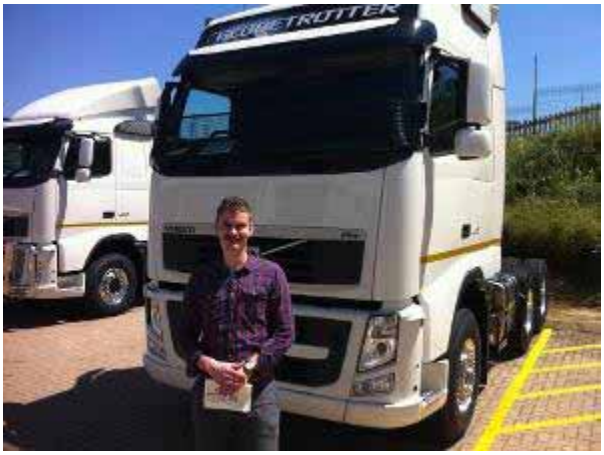
SASAM—Support Action for Standardization in Additive Manufacturing (agreement no. FP7-NMP-2012-CSA-6-319167, 2012-2104). It aimed to drive the growth of AM to efficient and sustainable industrial processes by integrating and coordinating standardization activities for Europe. Coordinator: TNO. Norwegian partner: SINTEF Raufoss Manufacturing.

Diginova—Innovation for Digital Fabrication (agreement no. FP7-NMP-2011-CSA-5-290559, 2012-2014). DIGINOVA established the current status across material domains and application domains in Europe in order to identify the most promising technology and business propositions for Digital Fabrication. Coordinator: OCE Technologies B.V. Norwegian partners: SINTEF Raufoss Manufacturing.

LinkedDesign: Linked Knowledge in Manufacturing, Engineering and Design for Next-Generation Production (agreement no. FP7-2011-NMP-ICT-FoF -284613, 2011-2015). The objective of the project is to provide an integrated, holistic view on data, persons and processes across the full product lifecycle. The project is a large-scale integrated project with collaboration between 14 industrial and academic partners. SAP in Germany is the project coordinator and there is broad participation from NTNU (IPK, IDI, IPM) and SINTEF (T&S).

Researcher Exchange

For the academic year 2011-2012, Torbjørn Netland received the prestigious Fulbright grant for a research visit to Georgetown University, McDonough School of Business, Washington D.C. His research objectives were to identify successful ways to implement production improvement programmes. Specifically, Netland studied how companies can increase productivity by developing and deploying company-specific production systems (XPSs)—such as the Volvo Production System (VPS), which has been his primary case company. The established cooperation with Georgetown University has led to several publications, including an article on 'managing corporate lean programs' published in the MIT Sloan Management Review, Summer 2014, and an article about 'the role of management control practices in the implementation of lean programs', just published in the Journal of Operations Management.



Torbjørn Netland visiting a Volvo plant in South Africa

In 2013/2014 Professor Torgeir Welo spent a 6 months sabbatical period at Georgia Institute of Technology, Atlanta, The G.W. Woodruff School of Mechanical Engineering with professor Chris Paredis, who is also the director of the Model-Based Systems Engineering Center. The main purpose of the stay was to learn more about systems engineering from one of the world -leading groups within the field, with the intention to possibly combine lean product development strategies with value-based SE in future cooperative research projects. Also, staying in Atlanta made it possible to be

actively involved in the research conducted by NORMAN PhD student Christer Elverum, who spent more than a year at Stanford University in California. The main goal here was to soak up some of the multidisciplinary and creative way of working that Stanford is known for, as well as conduct case studies within the automotive industry in the Silicon Valley area.

Professor Torgeir Welo (to the right) in Atlanta

As a result of this exchange, one Professor was recruited from Stanford to work on a permanent basis at NTNU to build up a PhD school type capabilities in Trondheim (now, TrollLabs). The cooperation with Stanford resulted in NTNU (MSc and PhD) student teams participating in ME 310 course at Stanford four straight years in a row (2012-2015).

In 2013/2014 Professor Heidi C. Dreyer spent a year at Cardiff Business School, Section of Logistics and Operations Management (LOM) as a visiting researcher. This led to a collaboration (research project and project applications) on food production and the supply chain research with Prof. Mohammed Naim, Senior Lecturer Robert Mason, Lecturer Laura Purvis, Lecturer Vasco Sancheres, and Lecturer Irina Harris. Together they have analyzed the characteristics of food manufacturing in SME in Wales and Norway, developed analytical frameworks and models and proposed how the characteristics of the SME food supply chain should be embedded in the design, strategy in planning and control of the operations. As in Norway the food sector is vital for Wales and the growth ambition stated by the Welsh government is to increase the volume of food produces with 30%. The research enabled the researchers to contribute with input to the Welsh Government and the Food and Drink division action plan, and to establishing a strategic collaboration between the Business School and the Welsh Government. Additionally to the research on food supply chain NTNU and Cardiff Business School have established collaboration in the engineer to order in the advanced manufacturing industry area, and resulting in contributions to the SFI IMPACT application, the Retail Supply Chain 2020 project, and ASTUTE 2020.

Professor Heidi Dreyer in Cardiff, UK

Advisory Board

From the start of SFI NORMAN, the role of the Advisory Board was to oversee that the centre's scientific focus and results were of an international standard, and to facilitate international collaboration. At that stage, the Advisory Board consisted of five representatives from industry, five representatives from NTNU/SINTEF and two international experts. A recommendation from the Midway evaluation was to further increase NORMAN's visibility on the international academic arena through the establishment of more committing international collaboration. To this end, the Advisory Board was reorganized, where new international academics and international industrial representatives were brought in. The new Advisory Board also visited the centre annually to review and discuss the SFI NORMAN research with management, senior researchers and PhD candidates. At the closing, the Advisory Board consisted of four representatives from industry, four representatives for NTNU/SINTEF and three international experts

Results and Effects

We are proud to present the main results and effects of SFI NORMAN. What could be argued is that the most important and valuable result is the increased awareness, focus and attention given to research and innovation for the benefit of manufacturing competiveness in Norway. Of the more tangible results we have already presented the PhDs, the master students and the numerous publications created by NORMAN. In this section, we focus on the results directed to the industry and the society as whole:

- The demonstrator showing industrial application of research results
- The numerous spin-off research projects created based on SFI NORMAN
- The Industrial workshops within the NORMAN community
- Dissemination and effects to society, including the NORMAN Closing seminar

Effects for the Host Institution

SFI NORMAN has been a virtual centre where industry partners, university and research partners have been able to transfer their individual goals into a joint research project. This model of collaboration have been under development throughout the project period, and requires skilled management and trusting collaboration. The project has gone through several phases – a demanding establishing phase, agreeing on organization and work form, joining ambitions, describing state of the art and identifying industrial challenges for the future, and on this foundation define and prioritize our shared research topics. Our choices were investigated by the Research Council of Norway (RCN) in a midway evaluation. We were able to continue without too large adjustment, and were given some good advice on the way. As a consequence we established a clearer strategy for publication, and prioritized partners for international collaboration.

The centre has been structured over several dimensions: clearly defined work packages delivering specialized knowledge, and multi-disciplinary activities ensuring collaboration across the work packages and contribution to a unified project. Industry and academia have shared the challenge of having to excel internationally, both individually and joint – a demanding arena where knowledge is infinite and competition everlasting.

A project period of eight years is long, and precisely what we in the world of research wish for: a place to delve deep into the matter on a longer scale. Implementation of new techniques and new technology has an impact on organization and management, and can influence the surrounding society. SFI NORMAN was to attend to this in its entirety, being a multidisciplinary centre, not just a set of separate activities. In other words, the project has aimed to reflect the real world and the society of which we are part. The effects for the host institution are many:

- We have been able to develop and apply new and original knowledge.
- We have made knowledge accessible and exposed to testing to industry and research environments within and outside of the centre.
- We have contributed to the future with highly qualified co-workers, e.g. through new PhD's and international exchange.
- We have strengthened the competitive ability of Norwegian industry, and created a platform for the future which provides an opportunity for continued knowledge development and international collaboration.
- SFI NORMAN has been a scientific starting point, generating new projects and arenas for collaboration, both nationally and internationally.

Impact for Research Partners

SFI NORMAN provided an ideal opportunity for the research partners to gain access to empirical data through the industrial partners. The industrial partners also created opportunities for PhD and master theses for students and resulted in a large number of scientific publications. The spin-off projects from SFI NORMAN created opportunities for continued collaboration with the industrial companies and other research partners from SFI NORMAN.

The centre stimulated active cooperation between different departments within NTNU and SINTEF, as well as with industry and international universities. This collaboration materialized in the generation of a significant portfolio of research projects and was an important catalyst for growing and strengthening the involved research groups. PhD education was increased and improved with SFI NORMAN, and we are proud of the high number of SFI NORMAN candidates who have defended their thesis. Our research was continuously brought into teaching and education in a much broader and deeper way by including methods, cases, industrial visits, internships, guest lecturers and seminars in courses. This led to an increase in the number of master project and student assignments, teaching quality was improved, and we contributed with a high number of candidates recruited to industrial positions. In the future, the involved researchers will continue to share experiences and knowledge from SFI NORMAN with industry, students, as well as with the academic and public society on a regular basis.

SFI NORMAN was the fundament for establishing strong international research collaboration. This is visible throught the level of joint publications, level of mobility, number of international seminars and conferences, and joint project proposals and funded projects. SFI NORMAN also directly resulted in international recruitments, including to faculty positions.

Although the centre is now officially terminated, the spirit, cooperation, knowledge and network generated through SFI NORMAN will continue to have a positive impact towards a sustainable manufacturing industry in Norway in the years to come.

Results and Effects

Industrial Demonstrators

In order to safeguard and substantiate the industrial relevance and viability, the focus on industrial demonstrators and cases has been very strong within RA1. With a strong coordination with research activities conducted in adjacent projects several successful demonstrators have been developed. The most important ones are:

1. **Holonic Manufacturing System (HMS):** demonstrated both in a simulated environment as well as in a prototype installation in order to convince the industry about the operational advantages of HMS concerning certain key performance indicators.
2. **Integrated Development Environment for Reconfigurable Control Systems (IDE for RCS):** total redesign of an existing shop floor control system, redesign of an existing production line, integration of new production equipment and similar has been demonstrated to prove the applicability of the toolbox.
3. **New programming methods for industrial robots:** demonstration of new and efficient, vision based programming methods in the three cases i) Assembly of high tolerance and heavy parts, ii) Disassembly and assembly of high tolerance and heavy tool components, and finally iii) Programming of sewing paths.
4. **Different approaches to give robots better accuracy in manufacturing operations:** approaches such as integration of touch probes in the robot environment have been developed, and the measurement accuracy has been demonstrated to match in-line industrial CMM for complex and large products.
5. **Framework of fault diagnosis and prognosis systems for condition based maintenance:** demonstrated the six steps of data acquisition, signal pre-processing, feature extraction, fault diagnosis, fault prognosis and maintenance decision with an industrial case from Kongsberg Automotive, among other cases.
6. **RFID in production systems:** the possibility of applying RFID techniques in condition monitoring of an assembly line has been demonstrated.
7. **Hybrid manufacturing cell:** a prototype manufacturing cell integrating an additive machine and a 5-axis CNC machine has been demonstrated through successful production of several products, typically with a base part built in the CNC machine and a more knowledge-intensive and complex part built in the additive machine.

Spin-off Projects

The role of an SFI is to create knowledge and research results that can be applied by and adjusted by industry. It has therefore been a strategy to support and apply for innovation projects and other projects where researchers and individual companies can exploit the SFI NORMAN results, and create more company specific results to develop their competitiveness. In this section we briefly present some examples of projects initiated based on SFI NORMAN.

IHAP: A four-year (2011-2015) innovation project, run by GKN Aerospace Norway in cooperation with SINTEF Raufoss Manufacturing AS, Norwegian University of Science and Technology (NTNU), Jærtek, Kongsberg Terotech, and Tronrud Engineering. The main goal of the project has been to achieve increased competitiveness in both ongoing and future jet engine programs by developing a new production system which facilitates one-piece production and one-piece flow of vanes with reduced manpower. A basic condition for achieving the ambitions of the project is the base technology developed in NORMAN. This comprises methods and tools for developing robust and adaptive manufacturing systems, including holonic manufacturing systems, and techniques for advanced process control, including advanced robotics based on vision and sensor control.

AUTOPART: SFI NORMAN shaped awareness of the opportunities and challenges related to manufacturing spare parts for products with long lifetimes, such as cars, ships, and planes. Spare parts can be the most profitable part of the business, but this requires the development of solutions adapted to the characteristics of spare parts. This was the goal of the AUTOPART spin-off project, an innovation project for the industrial sector supported by the Research Council of Norway. It lasted from 2011 to 2014 and resulted, among other things, into a separate spare parts manufacturing business unit at Benteler Automotive in Raufoss. The project developed a complete spare parts operations strategy, covering competitive priorities, performance measurement, organization, layout, planning, product

lifecycle management, information sharing, market understanding and distribution strategy. AUTOPART was a collaboration between Benteler, Plastal, SINTEF, and NTNU.

The AUTOPART project is one of many spin-off projects from SFI NORMAN. Here, Trude Helen Øvstetun from Benteler shows some of the spare parts the company delivers.

Knowledge-Based Development (KBD): A three-year (2011-2014) innovation project run by Kongsberg Devotek in collaboration with FMC, Kongsberg Automotive (KA), Kongsberg Gruppen (KOG), Buskerud and Vestfold University College (BVUC) and NTNU. The main idea of the project was to increase the effectiveness and quality of product development processes, by implementing Knowledge-based Development through combining state-of-the-art research and best practice from high-tech industry. The involved industry partners have been able to reduce their engineering lead times, number of errors and delivery times to customers. Knowledge from the project has been used to develop two new courses at BVUC: Lean Product Development and Knowledge Management. The project has drawn attention from world-leading practitioners and researchers.

Other examples of SFI NORMAN spin-off projects:

- **Autoflex (2012-2015) —***Flexible automated manufacturing of large and complex products:* Rolls-Royce Marine, Benteler Aluminium Systems and Intek Engineering together with SINTEF Raufoss Manufacturing.
- **Lean Operations (2011-2015) —***Interconnection between lean and the Norwegian model:* Benteler, NAMMO and Kongsberg Automotive together with NTNU Department of Industrial Economics and Technology Management and SINTEF Raufoss Manufacturing.
- **Ideal Factory—Ideell fabrikk (2008-2011) —** *Concept for Norwegian high-tech manufacturing:* Volvo Aero, Kongsberg Defence Systems and SINTEF.
- **HPWS.no (2013-2017) —***High Performance Work Systems in Project-Based Industry:* Grande Entreprenør, Kværner Verdal and Vitec together with SINTEF.

In the project HPWS.no the Norwegian contractor Grande Entreprenør has teamed up with Kværner Verdal, Vitec and SINTEF.

- **MIX (2013-2016) —***Sustainable multi-variant manufacturing in semi-process industry:* Pipelife Norge AS, Raufoss Technology, SINTEF, NTNU and SINTEF Raufoss Technology.
- **RIS (2011-2015) —***Flexible, adaptive and reconfigurable automated sewing as a robust industrial process:* Ekornes in cooperation with SINTEF Raufoss Manufacturing, NTNU and Amatec.
- **KUPP (2009-2012) —***New methods and concepts for automated, flexible assembly of low-volume products:* Kongsberg Automotive (KA) in cooperation with Sandvik Teeness, SINTEF Raufoss Manufacturing and NTNU.
- **Nextform (2014-2017) —***Next generation extrusion and casting processes for manufacturing of aluminium and plastic products:* Farsund Aluminium Casting (FAC), Benteler Aluminium Systems Norway (BASN) and Kongsberg Automotive (KA), as well as the technology and R&D partners SINTEF Raufoss Manufacturing and Tronrud Engineering.

Industry Stories

A consequence of the domestic and international competition in the plastic pipe industry is that Pipelife Norge at any given time has to be "best in class" in logistics and production.


Photo: Pipelife

Elling Halseide

Plant Manager,
Pipelife Norge AS

The company is continuously looking for solutions which can further enhance the present logistics and production processes.

– Through our collaboration with SFI NORMAN, we are aiming at developing these processes in a joint effort with suppliers and customers, says Plant Manager Elling Halseide.

– Important network

– The collaboration with SFI NORMAN provides a unique opportunity for support from particularly competent people within the fields of research, in a scale that otherwise would not have been possible. This, additionally, is conducive to the formation of a network with other companies which can be sources of inspiration as well as partners for dialogue when facing challenges in the future.

Production plants with different profiles

Halseide tells us that the scientific assistance from the research center is centered on IT tools for logistics, as well as automation of the production.

– This is work that carries most relevance for our plant in Surnadal, since the products manufactured on that site are standardized. At Stathelle we produce more customized goods and project deliveries.

In Surnadal the company produces plastic pipes for water supply and waste water, as well as pipes for cable protection and electric installation. At Stathelle the company produces polyethylene pipes, both short and long, and has specialized in subsea pipelines of great length and diameter.

Mostly overhead costs

The plant manager envisions a future where the need for competency in logistics and production will be at least as pronounced as it is today.

– We have, up until now, been keeping a strong focus on the use of personnel resources and efficiency per man-year. And this focus will not be decreased. After all, costs related to the human efforts are mainly what we can control. Raw material costs will always be somewhat similar for all manufacturers of plastic pipe systems, says Halseide.

Pipelife Norge AS is the largest manufacturer of plastic pipe systems in Norway, with production plants in Surnadal and Stathelle Its headquarters is located in Surnadal. The company is part of the international Pipelife Group.

While other furniture manufacturers move their production to low-cost countries, Ekornes rather goes for revolutionary robot sewing in Norway.


Photo: Ekornes

Leif-Jarle Aure

Project Manager,
Ekornes ASA

Why? – Maintaining the close proximity between product development and production is of paramount importance to us, says Project Manager Leif-Jarle Aure of the Ekornes Corporation.

Entering 2012 the company moves into the third phase of a project supported by the Research Council of Norway. The goal is to, over a period of three years, automate half of the upholstery sewing on the company's famous Stressless products. A pioneer project. As far as we know, nobody in the world has ever managed to robotize the production of non-rigid products like this before.

In the development work, the company joins forces with SFI NORMAN.

– The collaboration with the SFI has provided us with access to PhD candidates. They have been immensely useful. They are dedicated people who have been working intensively, and they have supplied important contributions to the development of the sensors in the automation solution we now are about to implement, says Aure.

Ekornes ASA is the largest furniture manufacturer in the Nordic region. Its headquarters is located in Sykkylven in Møre og Romsdal.

Results and Effects

- **EFFEKT (2013-2016)** —*Efficient manufacturing of advanced ship equipment:* Brunvoll and Oshaug Metall together with SINTEF, NTNU and Møreforsking Molde.
- **OPTILOG II (2007-2010)** —*Optimal production and logistics in integrated supply chains:* Pipelife, Ahlsell and NCC Construction together with SINTEF.
- **Retail Supply Chain 2020 (2014-2017)** — *Differentiated and efficient product and information flows in the retail supply chains where new demand and shopping patterns are emerging:* Tine, Nord Grønt, Fosen Transport, Coop, Norsk Lastbærer Pool, Hrafn, SINTEF and NTNU.

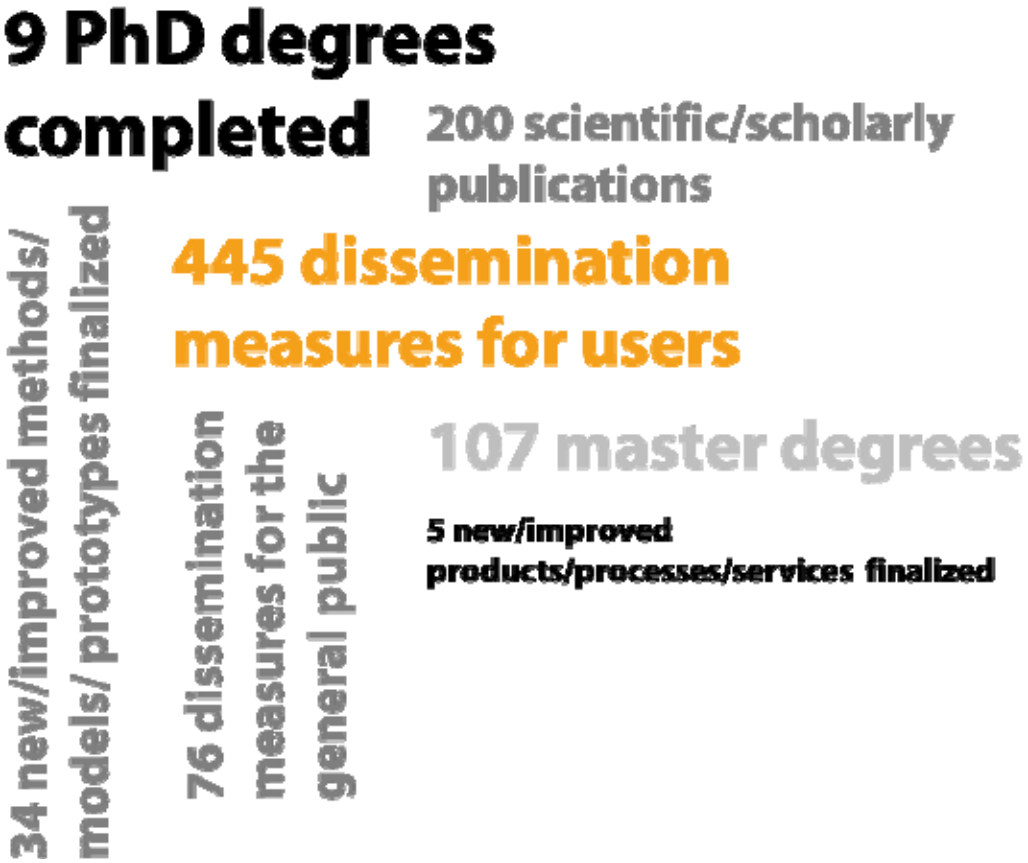
Impact for Society at Large

SFI NORMAN contributed to raising the general awareness in society of the importance of Norwegian manufacturing. The centre contributed to building a stronger foundation for the participating companies to strengthen their competitiveness and thus safeguard jobs within Norwegian manufacturing. NTNU will actively use the knowledge created in the centre to educate new students at both master and PhD level.

General Dissemination

Several media have been used to communicate this project to industry and other researchers (web pages, newspapers, social media etc.) The centre has aimed to reach manufacturing companies outside the consortium as well as relevant research groups in Norway and Europe. Ongoing research activities have been communicated to the industrial partners through newsletters, seminars, workshops and face-to-face communication between industry representatives and researchers. Annual reports have been distributed to partners and other relevant actors. The reports have also been made available on the SFI NORMAN webpage.

Newsletters: SFI NORMAN has sent short status reports that present recent NORMAN work and results to industrial stakeholders and the internal work force. By request from the industry the newsletters are written in Norwegian.



Media: SFI NORMAN has developed relations to journalists in relevant technical / industry magazines in Norway such as Moderne Produksjon, Teknisk Ukeblad, Automatisering and Industrien. There has been eight articles describing SFI NORMAN published since the beginning of the program, and we have a continuous dialog with journalists concerning new articles. SFI NORMAN also has a facebook page where PhD candidates and others involved in SFI NORMAN can communicate across disciplines and give feedback to the administration.

Home page: SFI NORMAN´s home page is organized with a front page presenting project news, the latest written documents and a welcome to SFI NORMAN-text. From this page it is easy to navigate to information about the projects, the PhD program, the annual reports, a calendar, and the members' area. Parts of the home page can also be explored in German. The news on the front page is intended to make the site more interesting to visit for both stakeholders and internal work force. Some NORMAN news have also been published at other web pages such as www.nce-raufoss.no and www.manufuture.no

Stakeholders: SFI NORMAN has invited industry partners and other stakeholders to workshops and seminars, like the International Work Shop in Trondheim and industrial seminars in Oslo, Gjøvik and Raufoss. We have also presented SFI NORMAN´s research activities and results to other stakeholders such as representatives of industry outside the consortium, professional and industrial programs and networks (Auto 21, Canada; Manufuture, EU and Norway; Automatiseringsforum; open seminars at the Norwegian Research Council etc.).

The home page and newspaper articles are examples of general dissemination of SFI NORMAN results

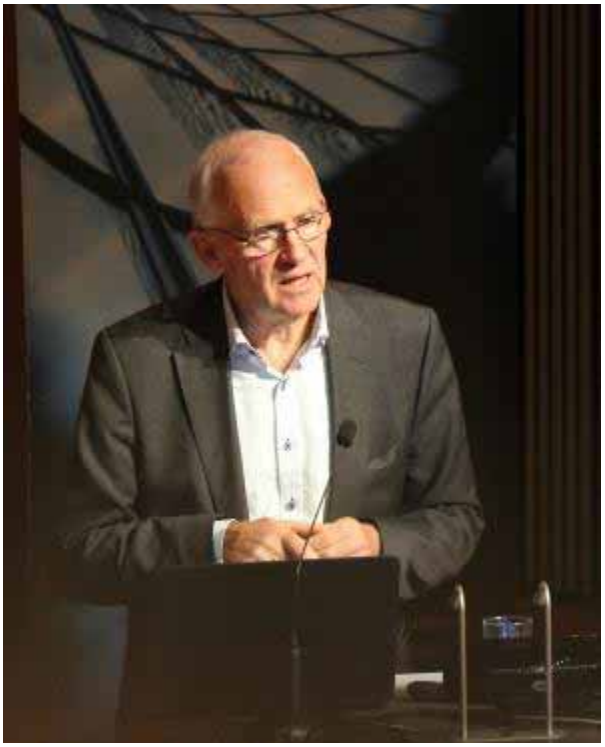
Results and Effects

Closing Seminar

The closing seminar for SFI NORMAN, “The Future for Norwegian Manufacturing Industry”, was held in the Research Council’s new offices at Lysaker on the 1st and 2nd of October 2014. Over 100 participants were given a broad and thorough insight into SFI NORMAN's work over the last eight years and they also got a good picture of the future opportunities and challenges for Norwegian Manufacturing Industry.

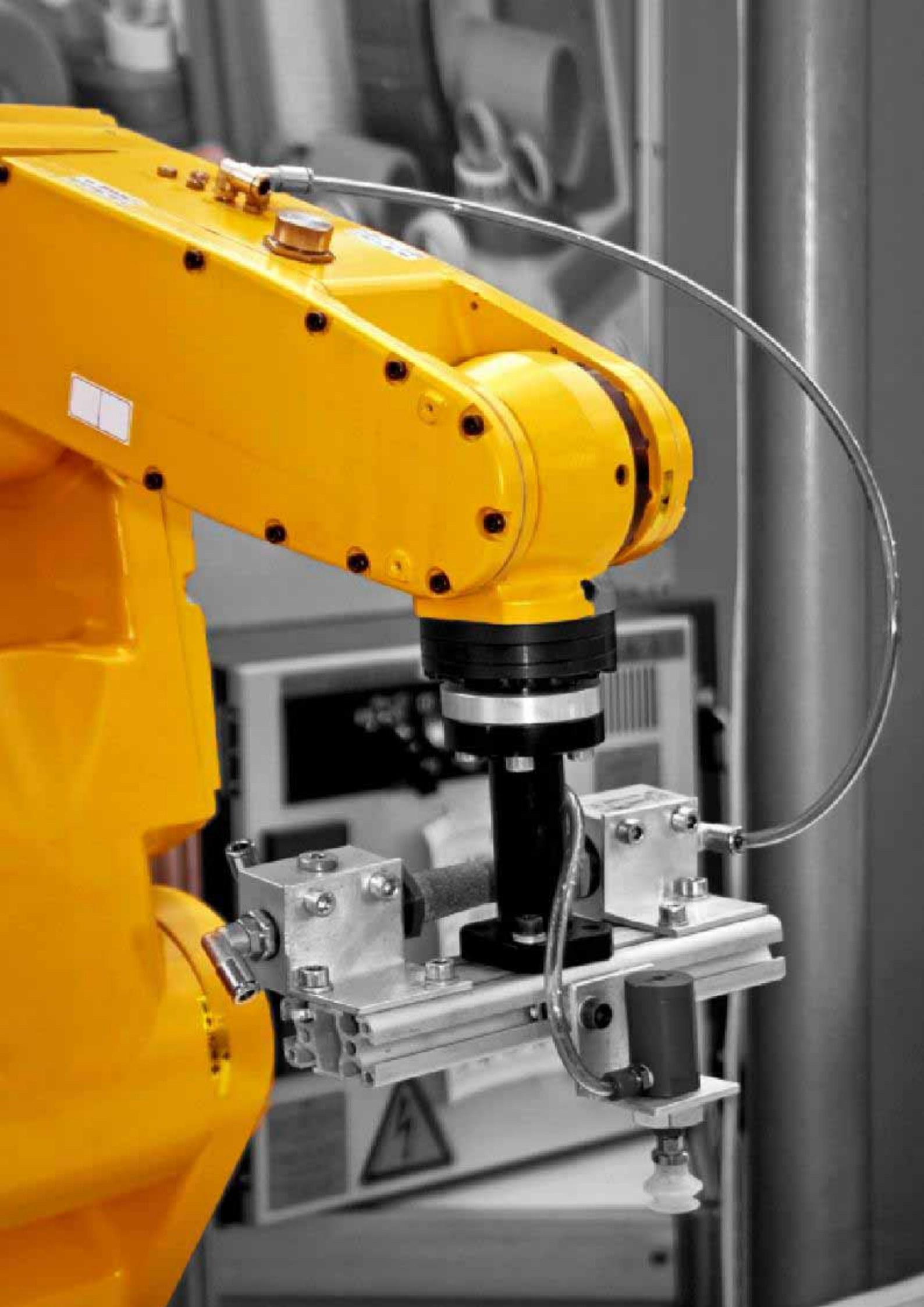
Centre Director Jan Ola Strandhagen giving his opening speech at the closing seminar

The program illustrated the importance of research and development in the eyes of a wide range of actors, such as SFI NORMAN’s industry partners, researchers and management from NTNU, SINTEF and SINTEF Raufoss Manufacturing, The Federation of Norwegian Industries and The Research Council of Norway. Presentation can be downloaded from SFI NORMAN’s webpage (www.sfinorman.no). The seminar also included a poster section, where SFI NORMAN PhD candidates were able to present their work.



Nils-Fredrik Drabløs, Ekornes, gave a presentation on the significance of research for the manufacturing industry

PhD candidate Taravatsadat Nehzati speaks to Prof. Dr. Günther Seliger, member of the Advisory Board, about her work within production planning in networks



Facts and Figures

Key Personnel

Centre Director
- Jan Ola Strandhagen, 2010-2014
- Odd Myklebust, 2007-2010

Industrial Research Coordinator
- Ottar Henriksen, 2010-2014
- Tor Giæver, 2007-2009

Assistant Manager
- Marte P. Buvik, 2010-2011

Research Manager
- Bjørn Andersen, NTNU, 2009
- Asgeir Tomasgard, NTNU, 2007-2008

Administrative Manager
- Heidi Kregnes, 2007-2008
- Janne Myran, 2011-2013
- Jorunn Auth, 2013-2014

Financial Officer
- Solfrid Sørensen, 2009-2014

Communication Advisor
- Line Silset Holien, 2010-2014
- Ina Roll Spinnangr, 2008-2009

Research Partners

A number of units and departments at NTNU and SINTEF have contributed to the research in NORMAN, with senior researchers in charge of different activities:

SINTEF Technology and Society (host institute):
- **Department of Industrial Management**
  - Senior Research Scientist Johan Ravn (WP5)

SINTEF Raufoss Manufacturing AS
- **Department of Production Technology**
  - Research Director Lars Tore Gellein (RA1)
  - Senior Research Scientist Per Aage Nyen (WP1)
  - Senior Advisor Lars Erik Wetterwald (WP2)
  - Senior Research Scientist Klas Boivie (WP3)
  - Chief Scientist Kristian Martinsen (Scientific Advisor RA1)
- **Department of Product and Production Development**
  - Chief Scientist Geir Ringen (WP6)

NTNU
- **Department of Production and Quality Engineering**
  - Professor/Senior Research Scientist Heidi Dreyer (RA2)
  - Associate Professor/Senior Research Scientist Erlend Alfnes (WP4)
  - Professor Terje K. Lien (Scientific Advisor RA1)
- **Department of Engineering Design and Materials**
  - Professor Torgeir Welo (RA3)
  - Associate Professor Knut Aasland (Scientific Advisor RA3)
- **Department of Industrial Economics and Technology Management**
  - Professor Monica Rolfsen (Scientific Advisor RA2)

Industrial Partners

A large number of industrial companies were closely involved in defining and carrying out research activities during the eight year period. The industrial partners range from large scale global companies to SMEs, from many industrial sectors and making products from a range of different materials. In common, they share the need to innovate products and processes in order to maintain and improve their competiveness.

Full eight years:

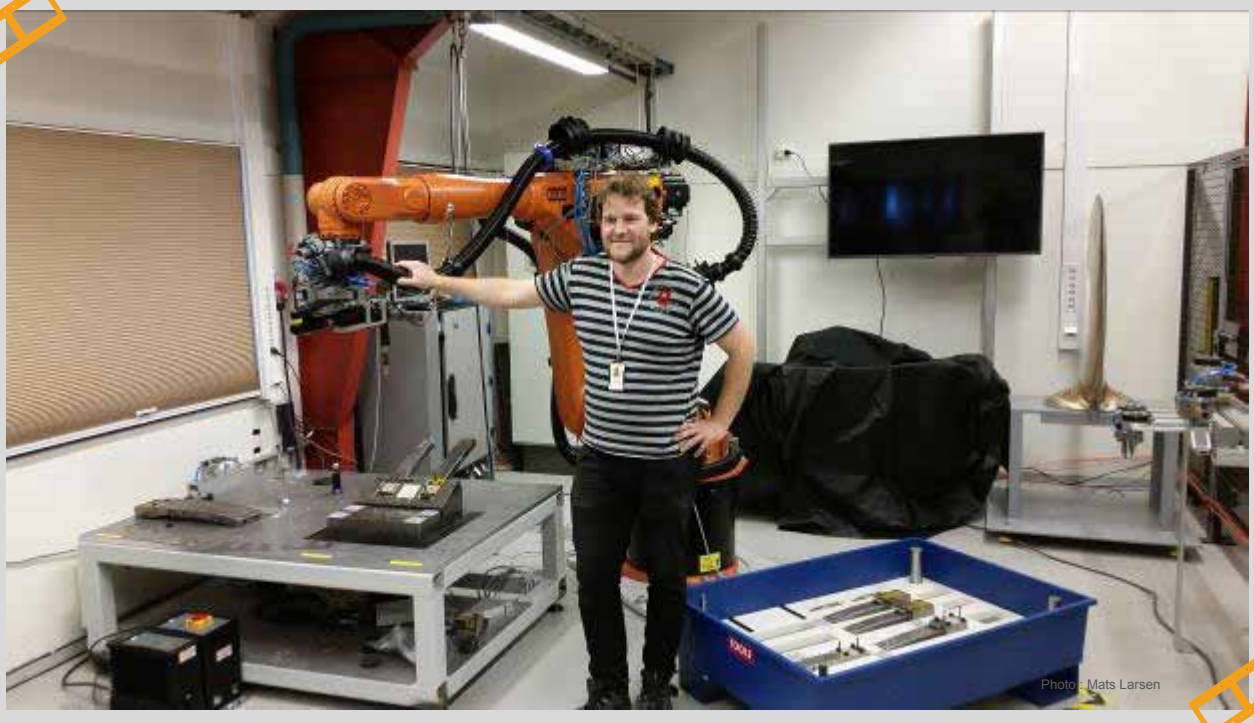
- Benteler Aluminium Systems Norway AS
- Ekornes ASA
- GKN Aerospace Norway AS
- Hansen Protection AS
- Hexagon Ragasco AS
- Kongsberg Automotive AS
- Nammo Raufoss AS
- Pipelife Norge AS
- Plasto AS
- Raufoss Technology AS
- Sandvik Teeness AS

From 2011:

- Brødrene AA AS
- Rolls Royce Marine AS
- TINE SA

Shorter periods:

- Elko AS (2007-2011)
- Mills DA (2007-2009)
- Nortura SA (2007-2009)
- Steertec Raufoss AS (2007)



Ådne S. Linnerud in the automation laboratory of SINTEF Raufoss Manufacturing at Raufoss, where research activities both in SFI Norman and the innovation project Autoflex have been performed

Facts and Figures

Advisory Board

Chairman

- Annik Magerholm Fet, Professor NTNU, 2013-2014
- Terje Kristoffer Lien, Professor NTNU, 2010-2013
- Sigurd Støren, Professor NTNU, 2007-2010

Members

- Mogens Myrup Andreassen, Professor Technical University of Denmark, 2008-2010
- Leif Jarle Aure, Project Manager Ekornes, 2007-2009
- Thomas Dahl, Research Director SINTEF, 2007-2008
- Annik Magerholm Fet, Professor NTNU, 2011-2013
- Jon Herberg, Director Hydro, 2009
- Hans Petter Hildre, Professor Høgskolen I Ålesund/ NTNU, 2007-2010
- Ole B. Hoen, Technical Manager, Volvo Aero Norge AS, 2011-2014
- Anders Kinnander, Professor Chalmers University of Technology, 2008-2014
- Kjell Larsen, Managing Director Pipelife Norge AS, 2009-2010
- Odd Terje Lium, Volvo Aero Norge AS, 2010
- Sverre Narvesen, Managing Director RTIM, 2007-2014
- Torodd Rande, Plant Manager Kongsberg Automotive, 2010
- Per Morten Schiefloe, Professor NTNU, 2007-2010
- Per Schjølberg, Professor NTNU, 2009-2014
- Günther Seliger, Professor TU Berlin, 2011-2014
- Ole Ivar Sivertsen, Professor NTNU, 2011-2014
- Skjalg S. Stavheim, Plant Manager Ragasco, 2011-2014
- Lars Stenerud, Managing Director Plasto, 2007-2008
- Jan Erik Torjusen, Technical Director Volvo Aero Norge AS, 2007-2009
- Kari Tyholt, Senior Researcher Mills, 2007--2009
- John Vigrestad, R&D Director Norsk Industri, 2007
- Johan C. Wortman, Professor University of Groningen, 2011-2014
- Per Kristian Østbye, Managing Director Kongsberg Automotive, 2007-2009

Board

Chair of the Board

- Ottar Henriksen , CEO Raufoss Technology, 2007-2009
- Morten Midjo, CEO Teeness, 2009-2010
- Lars Stenerud, Managing Director Plasto, 2011-2014

Members

- Torbjørn Digernes, Rector NTNU, 2007-2008
- Nils-Fredrik Drabløs, CEO Ekornes, 2010-2011
- Tonje Hamar, Executive Vice President SINTEF, 2007-2014
- Kjell Larsen, Managing Director Pipelife Norge AS, 2012-2014
- Morten Midjo, CEO Teeness, 2007-2009
- Axel Krogvig, CEO Nortura, 2007-2008
- Erland Paulsrud, President Nammo, 2009-2010
- Ragnhild Solheim, Director Nortura, 2008
- Lars Stenerud, Managing Director, Plasto, 2009-2010
- Svein Terje Strandlie, Vice president Benteler Aluminium Systems Norway AS, 2012-2014
- Ingvald Strømmen, Dean NTNU, 2009-2014

Observer from RCN:

- Senior Adviser Bjørn Braathen, 2007-2014

Key Results and Financing

	2007	2008	2009	2010	2011	2012	2013	2014	Total
Scientific/scholarly publications (peer reviewed)			3	14	26	41	64	52	**200**
Dissemination measures for users	22	33	36	62	53	83	60	96	**445**
Dissemination measures for the general public	4	4	6	6	5	18	14	19	**76**
Number of new/ improved methods/ models/prototypes finalized			2	5	10	10	7		**34**
Number of new/ improved processes finalized						5			**5**
PhD-degrees completed					1	2	2	3 (1)	**9**
Master degrees		9	8	17	16	27	18	12	**107**

Cost per partner category (MNOK)

Contributor	Cash	In-kind	Total
SINTEF	9	17	25
NTNU	5	12	17
Companies	21	17	38
RCN	80		80
Sum	**115**	**46**	**161**

Distribution of resources

Type of activity	MNOK
Research projects	139
Common centre activities	6
Administration	16
Total	**161**

Future Prospect

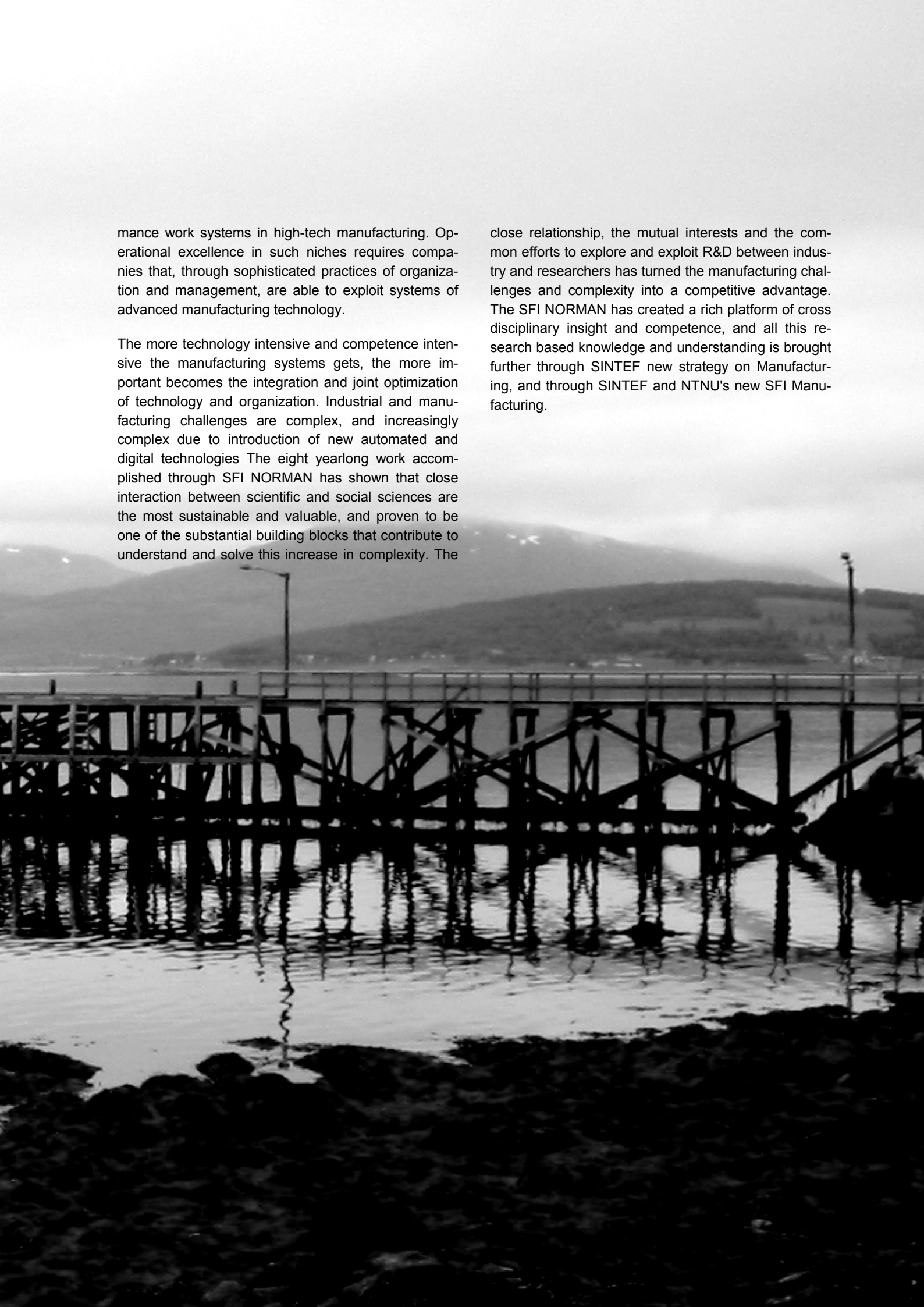
The foothold and dependency of the oil and gas industry is no longer as solid as it has been. Reduction in oil price, restructuring, lay-offs, and decrease in new investments within the sector is all serious, and redirect the focus to the necessity of building a strong land based industrial foothold. Production of sophisticated products is foreseen to build the competitiveness of the advanced economies' industrial sectors in the future. Increasingly, competitiveness in such industries depends on a complex interaction between social factors such as knowledge sharing, knowledge generation, learning and innovation, and technical factors such as robotization, automation and information systems. This is certainly also true for Norway, due to high cost of labor, high competence level and high level of technology use and technology acceptance. To a large degree, the modern technologies of manufacturing are available to all, given that one has the necessary resources to purchase. Thus, the competitive force of technology lies in how it is put to work in a production system: how the system is designed, organized and managed, and the performance of the workforce.

However, up to now, improvements and developments in these industries have tended to be biased towards the technology side. To balance this and to take into account the necessity of more effective human – machine interaction, and the need of knowledge sharing, learning and innovation, it proposes a mode for how to challenge highly automated, high-tech and knowledge based high-cost manufacturing, where: 1) State-of-the-art technology is necessary, but not sufficient; 2) state-of-the-art technology requires high level of competence and advanced organization, and 3) a joint organizational and technical perspective is needed in order to develop sustainable competitiveness through high perfor-

More than ever is there a need to ensure the future of Norwegian manufacturing competitiveness.

mance work systems in high-tech manufacturing. Operational excellence in such niches requires companies that, through sophisticated practices of organization and management, are able to exploit systems of advanced manufacturing technology.

The more technology intensive and competence intensive the manufacturing systems gets, the more important becomes the integration and joint optimization of technology and organization. Industrial and manufacturing challenges are complex, and increasingly complex due to introduction of new automated and digital technologies The eight yearlong work accomplished through SFI NORMAN has shown that close interaction between scientific and social sciences are the most sustainable and valuable, and proven to be one of the substantial building blocks that contribute to understand and solve this increase in complexity. The close relationship, the mutual interests and the common efforts to explore and exploit R&D between industry and researchers has turned the manufacturing challenges and complexity into a competitive advantage. The SFI NORMAN has created a rich platform of cross disciplinary insight and competence, and all this research based knowledge and understanding is brought further through SINTEF new strategy on Manufacturing, and through SINTEF and NTNU's new SFI Manufacturing.



Final Remarks

So it is time to sum up. The SFI NORMAN journey has reached its end. It is time to evaluate ourselves. Hopefully the reader has made up his view based on what can be found in this report.

But there is still a need to ask:

Did we reach our goals? Did we succeed? Were all the resources well spent? Did we make a difference?

Let me first say that SFI NORMAN was a huge opportunity and tough challenge for a number of people and organizations. People have different roles, views and interests. If all this is hidden it is impossible to cope. If it is open it is a tough challenge to handle for everyone involved. Sometimes we can reach a common understanding and move on. Sometimes the differences are too large, and we need to change project organization, shift focus and exchange personnel. This has also taken place in SFI NORMAN. Please note that all efforts and contributions for shorter and longer periods are all respected and acknowledged.

Regarding our achievements the numbers speak for themselves.

We should be proud of the number and quality of our PhDs educated. They are our finest results. They are now using their competence and skills in research and for the benefit of the industry.

Our publications and scientific conferences hosted were on an up-moving curve all the way, and ended at a very satisfactory level. Therefore, all of these are listed in the following pages. Well proven and documented. No question about it.

I am sure that some companies expected more tangible results from SFI NORMAN. Others were well satisfied. An important comment to this is that it is through the spin-off projects that research achievements have been transferred into innovations in the companies. These projects have of course lived their lives on their own. But they have been based on and rooted in SFI NORMAN.

Through a series of workshops, and several meetings, actions, demonstrators and cases we have developed “a joint research community” between industrialists, researchers, professors and students. We have learned to understand each other better, and trained to perform industrial targeted research together.

It is my belief that this joint mental platform on how to define, perform and lead industrial applied research is vital for Norwegian Manufacturing Future. I am grateful that it has given me the opportunity to still be on an up moving learning curve for the last eight years, and I sure hope this has been the case for many of you. If the answer to this is YES, SFI NORMAN has been a success.

It is up to all of you to decide and pursue the opportunities. I thank you all for the collaboration and wish you the best of success in future joint research.

Jan Ola Strandhagen

Centre Director

Appendices

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List of Master's Theses

Daniele Cortesi (2008): Designing a lean supply chain – case from the automotive industry (master)

Andreas Pöpper (2008): Lean Production for small and medium-sized enterprises - Difficulties and applicability of a new production system

Nina Ramstad Alme (2008): Logistikk- og lagerstyring hos kjøtt produsent

Predrag Popovic (2008): Supply Chain Information Parameters for Performance Measurement and Control

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Tarald Haugen Syvertsen (2008): Modeller for sanntidsstyrte verdikjeder – Et casestudie av RFID i norsk næringsmiddelindustri

Jonas Ingvaldsen (2008): Organizational dicipline within contemporary teambased manufacturing

Odvar Åsmul (2008): The Norwegian worklife model – strenghts and weaknesses

Per Fjellddalen (2008): Mellomledelse i kunnskapsbasert industry

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Johannes Schrimpf (2009): "Evaloation of Real-Time Sensor-Based Servoing Methods applied to a Testplatform"

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Thorben Gõldner (2009): Information Technologies and Lean manufacturing: exclusive or complementary?

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Jo Myroldhaug (2011): A Modular fixturing system for flexible machining of aluminium components and (sub)frames

Stian Amstrup (2011): 'A Modular Pallet Solution for Flexible and Robust Transportation of Cast Parts Using Hanging and/or Belt Conveyors'

Linda Sletten (2011): Performance Management using business intelligence

Yngve Mongstad (2011): Visual Logistic Analysis in the Aluminum Industry

Yong Zhou (2011): Logistics for a sustainable fresh food sector; environmental and resource efficiency in fresh food supply chains through modern collaboration models

Djuro Topalovic (2011): Logistics for a sustainable fresh food sector; environmental and resource efficiency in fresh food supply chains through improved planning and control.

Jens Kristian Klungseth (2011): Dynamic sales and operations planning of part production in the automotive industry

Alexey Lekanov (2011): Logistics Planning Module for Microsoft AX: Demand Planning

Anders Lerberg (2011): Logistics Planning Module for Microsoft AX: Supply Chain Planning

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Yoana Millazzot Teran (2011): Dynamic (Real-Time) scheduling on the shop- floor

Florian Labouysse (2012): Electro-mechanical design and assembly of a dual-arm robot cell

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Frederick Largilliere (2012): Design of a solution for the assembly of anti-vibration tools

Frank Saul (2012): 3D Vision

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David Homar (2012): OMOS – Optimized Manufacturing Operation Sequence

Chris Sanches (2012): Fuzzy front-end in new product development: Comparing basic models and best-practices

Hilde Sund (2012): Product Development in the Manufacturing Industry: Identification of Current Practice and Improvement Opportunities

Martin Martinsen (2012): Integrated Product Development: Development of a cost-effective and production-friendly choice chair base

Oksana Bondarenko (2012): Effective supply chains for offshore wind mills

Tara Kamran (2012): Effective supply chains for offshore wind mills Layli Dahir Yousef (2012): Integrating lean and MRP

Jesus Alejandro Escobar Avila (2012): Integrating lean and MRP Shuang Wu (2012): Integrating lean and MRP

Jia Zheng (2012): Integrating lean and MRP

Kazym Kaan Yener (2012): Integrating lean and MRP

Ilker Bas (2012): Integrating lean and MRP

Hua Bai (2012): Lean and ICT in Scandinavia

Erlend Johan Gjønnes (2012): Estimering av oppstartskostnad i

diskret produksjon

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Chaitanya Saraswat (2012): Solutions for effective service parts production

Gonzalo Chirinos (2012): Solutions for effective service parts production

Siavash Naghdalikhani (2012): Utvikling av kjøretøy til Eco-Marathon

Frida Haveråen (2012): Forecasting and Microsoft AX

Yngve Mongstad (2012): Use of RFID technology for efficient logistics in the supply chain of food specialities.

Yong Zhou (2012): Sustainability measurement in the fresh food sector.

Terje Bye (2013): Planning and control of fresh food production

Gran, Martine (2013): Operasjonalisering og styring av en differensiert løsning for produksjon og verdikjeder innen matindustri

Kvarme, Susanne Amalie (2013): Operasjonalisering og styring av en differensiert løsning for produksjon og verdikjeder innen matindustri

Yousef, L. D (2013): Investigating the application of lean principles in a small, one-of-a-kind production company

Zheng, Jia (2013): Integrating Lean and IT: A Concept for IT-enabled Lean for the Production of Customized Plastic Pipes.

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Yener, Kazym Kaan (2013): Investigating the application of lean principles in a small, engineer-to-order / make-to-order company

Fredheim, Vegard (2013): Manufacturing flexibility and competitiveness in the automotive spare parts industry

Bondarenko, Oksana (2013): Performance Management in Engineer-to-Order Companies: Considering a Performance Measurement System to Support Material Planning in Engineer-to-Order Companies.

Kamran, Tara (2013): Performance Management in Engineer-to-Order Companies: Considering a Performance Measurement System to Support Material Planning in Engineer-to-Order Companies.

Maestroni, Mattia (2013): Delivery strategy of spare parts in the OES automotive supplier industry

Gonzalo, Chirino (2013): Effective inventory and delivery strategies for spare parts

Pavlina Trubakova (2013): Material properties in AM-materials (powder-bed)

Oleksandr Semeniuta (2013): Flexible automation in Multi-material applications

Mats Larsen (2013): Robot control

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Bernardo Figueiredo (2013): Design and optimization of a light-wight aluminium gantry system

Jørgen Braaten (2014): Data mining for intelligent green monitoring of machine centers;

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I. Bas (2014): Metodikk for å støtte lokalisering av produksjon i globale markeder

G. Chirinos (2014): Decision-making framework for stock-control based on spare parts classification

Hønsi, M. og Sørbø, G.K (2014): Vertikal solution for ETO bedrifter basert på ERP systemet Microsoft Dynamics AX

Shuang, L (2014): Supply chain collaboration for waste reduction in fresh food supply chain

Shunan, Q (2014): Investigating the fit of lean planning methods for the process industry. Master's thesis

Morten Myhre (2014): Design og fabrikasjon av knutepunkter i 'jackets' plattformer

Hans Eikeland Engum (2014): FE simulering av strekkforming av aluminiusporfiler

Kristoffer Fjeld Langrind (2014): Standardisering av prosess for kundebasert produktutforming i tilbuds- og prosjektfasen

Wenche Aarøen (2014): Drivere for stabilisering innenfor Lean produktutvikling, Identifisering av organisatoriske og operasjonelle faktorer som påvirker prestasjoner.

Funding

Activity/Item	RCN	SINTEF	NTNU	Elko	Hansen Pro	Pipelife Norge	Raufoss Ind. Tools	Brødrene Aa	Teeness	Plasto	Ekornes	Nortura	Tine	Ragasco	Benteler	Kongsberg Automotive	Mills	Rolls Royce	Nammo	Raufoss Technology	GKN Aerospace Norway AS (Volvo)	Total
Research projects 2007 – 2010 *)	24334	7463	2229	723	2733	1150	781		1494	826	1187	987		1335	1506	1297	1407		1413	2185	1588	**54638**
Research area 1: Advanced Manufacturing Technology	11531	5113	1422	51	450	440		419	349	436	629		908	721	857	856		635	721	681	786	**27005**
Research area 2: Operations Management in Norwegian Manufacturing	7536	3288	910	26	262	259		245	202	257	372		530	422	500	512		394	428	395	465	**17003**
Research area 3: Product & Process development	3885	1678	476	26	190	182		173	146	178	256		376	300	353	346		240	291	284	320	**9700**
Phd / Postdoc	19659		11398																			**31057**
Management	7037	5966	533																			**13536**
Common centre activities	4170	2261	282																			**6713**
Equipment	1848																					**1848**
Sum	**80000**	**25769**	**17250**	**826**	**3635**	**2031**	**781**	**837**	**2191**	**1697**	**2444**	**987**	**1814**	**2778**	**3216**	**3011**	**1407**	**1269**	**2853**	**3545**	**3159**	**161500**

Cost

Activity/Item	SINTEF	NTNU	Elko	Hansen Pro	Pipelife Norge	Raufoss Ind. Tools	Brødrene Aa	Teeness	Plasto	Ekornes	Nortura	Tine	Ragasco	Benteler	Kongsberg Automotive	Mills	Rolls Royce	Nammo	Raufoss Technology	GKN Aerospace Norway AS (Volvo)	Total
Research projects 2007 – 2010 *)	37792	6864	313	2325	741	474		1085	262	210	253		357	596	253	677		435	1209	613	**54459**
Research area 1: Advanced Manufac-	19803	1809		252	242		221	152	237	152		431	241	380	387		282	246	204	311	**25350**
Research area 2: Operations Manage-ment in Norwegian	9570	4255		145	141		128	84	141	90		250	139	222	235		175	149	122	185	**16031**
Research area 3: Product & Process	4033	4440		108	100		92	65	96	60		181	103	159	151		107	95	82	124	**9996**
Phd / Postdoc		31057																			**31057**
Management	15474	493																			**15967**
Common centre activities	6100	692																			**6792**
Equipment	1335	513																			**1848**
Sum	**94107**	**50123**	**313**	**2830**	**1224**	**474**	**441**	**1386**	**736**	**512**	**253**	**862**	**840**	**1357**	**1026**	**677**	**564**	**925**	**1617**	**1233**	**161500**


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Science and Technology

norman

Host institution:

SINTEF

President – CEO: Unni M. Steinsmo

Centre Director:

Jan Ola Strandhagen, NTNU

Phone: +47 926 85 427

E-mail: ola.strandhagen@ntnu.no

Industrial Research Coordinator:

Ottar Henriksen, SINTEF

Phone: +47 901 44 405

E-mail: ottar.henriksen@sintef.no

Administrative Manager:

Jorunn Auth, SINTEF

Phone: +47 41 45 96 73

E-mail: jorunn.auth@sintef.no

SFI NORMAN

SINTEF Technology and Society

P.O. Box 4760 Sluppen

NO-7465 Trondheim

Norway

Contact Person, Research Council of Norway

Bjørn Braathen, Senior Adviser

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